

# ME6404 – Fall 2016

## Lab 3 – Input Shaping

### Part I. Input Shaping on the Bridge Crane

#### 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 changes in system frequency on various input shapers.

#### Background:

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

In previous labs, you modified the trapezoidal velocity profile, and then held a move button so that the crane executes the desired trapezoidal velocity profile. Figure 1 shows what the controller is actually doing. Holding down a button will generate a step input. This is then convolved with the impulse sequences that you designed for “Pulse”. This results in a pulse in velocity command; however, due to the inertia of the crane and motor limitations, the actual velocity profile is similar to a trapezoid. Note that the negative impulse at  $t_f$  is used to bring the crane to a stop despite holding down the move button. Note that the impulses sum to zero, rather than one. Therefore, this is not a standard input shaper procedure. Rather, it is a modified version that always moves the crane the same distance. Varying  $t_f$  will change the length of the velocity profile, and therefore, the total move distance. Figure 2 shows the same process, but using a ZV input shaper. Note that the last two impulses are like the first two except they are negative in amplitude.

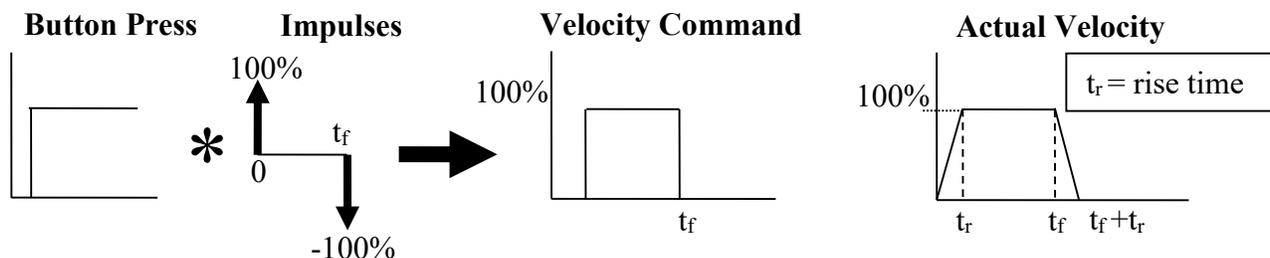
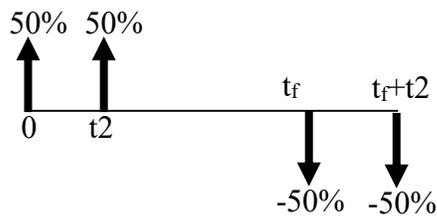
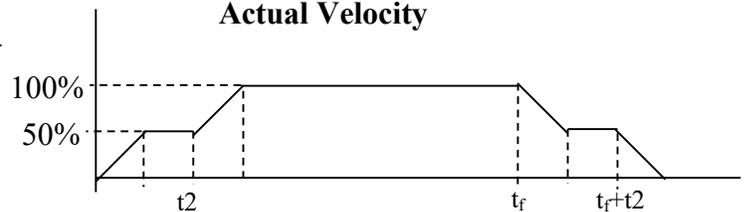


Figure 1: Convolution Using the “Pulse” Velocity Profile

### Impulse Sequence



### Actual Velocity



**Figure 2: Convolution Using “ZV Shaper Stop”**

### Lab Tasks:

#### Part A - Variation in move distance (use either the trolley or bridge axis):

1. Move the crane using the trapezoidal velocity profile with 100% speed. Use a 0.8 m cable length (measured from center of hoist drum to center of payload). Do this for  $t_f = 1100$  ms, 1600ms, and 2000ms. Measure the residual payload oscillations.
2. Repeat step 1 with the same three  $t_f$ 's, the same cable length, but use a ZV shaper of your own design that you think will best minimize the payload oscillations.

#### Part B - Variation in system frequency (use either the trolley or bridge axis)

1. Move the crane using a trapezoidal velocity profile with 100% speed and  $t_f = 1500$ ms. Do this for cable lengths of 0.6 m, 0.9 m, and 1.2 m. Measure the residual payload oscillations.
2. Repeat step 1 with the same  $t_f$ , the same three cable lengths, and using **only one** ZV shaper of your own design that you think will best minimize the oscillations for **all** cable lengths.
3. Repeat step 1 with the same  $t_f$ , the same three cable lengths, and using **only one** robust shaper (SI, EI, ZVD, ZVDD, etc) of your own design that you think will best minimize the oscillations for **all** cable lengths.

### Lab Procedure:

1. Sign up for sessions on the bridge crane Google calendar.
2. Figure 3 shows the shaper design interface of the GUI.
3. Use (A) and (B) to modify the impulse amplitudes and times. Always hit enter on the keyboard after you modify a text box. The first impulse should occur at time = 0. To bring the crane to a stop, the last  $n$  impulses should mirror the first  $n$  impulses, but with negative amplitudes.
4. Return to the main window using the **back** button (C).
5. Record data with the same procedure as the previous labs.

Input shaper edit form					
	Amplitude	Time (ms)		Amplitude	Time (ms)
	A	B			
Impulse 1:	50	0	Imp 11:	0	0
Impulse 2:	50	500	Imp 12:	0	0
Impulse 3:	-50	2000	Imp 13:	0	0
Impulse 4:	-50	2500	Imp 14:	0	0
Impulse 5:	0	0	Imp 15:	0	0
Impulse 6:	0	0	Imp 16:	0	0
Impulse 7:	0	0	Imp 17:	0	0
Impulse 8:	0	0	Imp 18:	0	0
Impulse 9:	0	0	Imp 19:	0	0
Impulse 10:	0	0	Imp 20:	0	0

**C**  
BACK

**Figure 3: Shaper Design Interface**

## Part II. Input Shaping on the Mobile Tower Crane

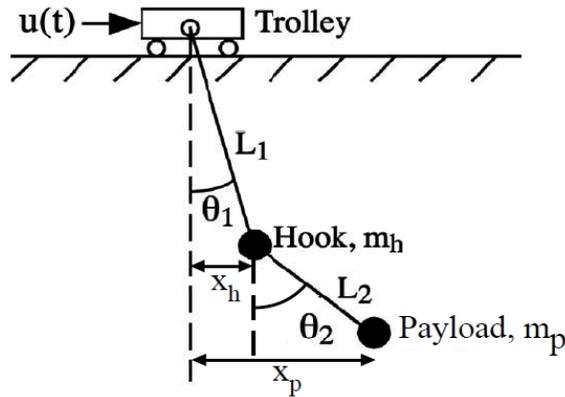
### Objectives:

1. Investigate input shaping for multi-mode systems and rotational movements

### Background:

Certain crane payload configurations, like the one shown in Figure 4, can result in double-pendulum, two-mode responses. Unlike single pendulum oscillations, these two-mode oscillations are nearly impossible to eliminate by a human operator without assistance. This makes it essential to account for both vibratory modes.

Figure 4 shows a point-mass double-pendulum system. The hook suspension length and the payload rigging lengths are  $L_1$  and  $L_2$ , respectively. The mass of the hook and payload are  $m_h$  and  $m_p$ , respectively.



**Figure 4 Double-pendulum Model**

The linearized natural frequencies of this system are given by (assume zero damping):

$$\omega_{1,2} = \sqrt{\frac{g}{2}} \sqrt{(1+R) \left( \frac{1}{L_1} + \frac{1}{L_2} \right) \mp \beta},$$

$$R = \frac{m_p}{m_h}$$

$$\beta = \sqrt{(1+R)^2 \left( \frac{1}{L_1} + \frac{1}{L_2} \right)^2 - 4 \left( \frac{1+R}{L_1 L_2} \right)}.$$

The parameters for this lab are shown in Table 1.

**Table 1 - Hook and Payload Information**

Hook mass, $m_h$	0.210 kg
Payload mass, $m_p$	0.180 kg
$L_1$	0.9 m
$L_2$ (eye of hook to payload center)	0.71 m

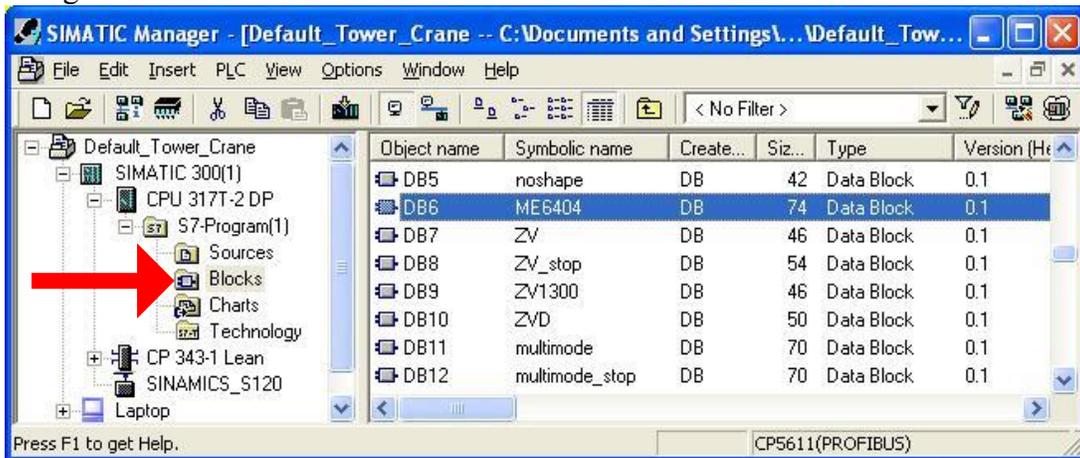
### Lab Tasks:

1. Use Up/Down buttons to make the suspension length 0.9 m (you can use **Hoist Pos** as a guide) Then, **slew** (use CW/CCW buttons) the crane using an implementation of the pulse velocity profile with 100% speed (see step 2 in the Lab Procedure below) and  $t_f = 4000\text{ms}$  (make sure there is enough space). Do this for three different radial trolley positions on the jib (use the In/Out buttons): “**Trolley Pos**” = **500mm, 700mm, and 900mm**. Measure the residual hook oscillations.
2. Repeat step 1 with the same  $t_f$ , the same Hoist Pos, the same three Trolley Positions, and using **only one** ZV shaper of your own design that you think will best minimize the hook (and payload) oscillations.
3. Repeat step 1 with the same  $t_f$ , the same Hoist Pos, the same three Trolley Positions, and using **only one** robust shaper (SI, EI, ZVD, ZVDD) of your own design that you think will best minimize oscillations.
4. Repeat step 1 using a two-mode shaper of your own design.

### Lab Procedure:

1. Sign up for sessions using the tower crane Google Calendar.

2. Use the “Default Tower Crane GUI” shortcut on the desktop.
3. Use the Remote User mode and select “ME6404” from the “Velocity Profile” drop down box. Use this option to implement the pulse velocity profiles and other shapers that you design.
4. Open “SIMATIC manager” from the desktop. The “Tower Crane Nov 2011” project should be open. If not, use File>Open>Browse... and browse to file path “D:\Tower Crane GUI and PLC program 2016\Tower Crane Nov 2011” it should be one of the last ones opened.
5. Navigate to the **DB6 ME6404** data block as shown and double click.



6. Go to **View>Data View** and you should see the following window. Modify the impulse times and amplitudes by changing the “**tap\_times**” and “**tap\_vals**” under the “**Actual Value**” column.

Address	Name	Type	Initial value	Actual value	Comment
0.0	num_of_taps	INT	0	20	number of taps
2.0	tap_times[0]	INT	0	0	tap times in milliseconds
4.0	tap_times[1]	INT	0	1168	
6.0	tap_times[2]	INT	0	0	
8.0	tap_times[3]	INT	0	0	
10.0	tap_times[4]	INT	0	0	
12.0	tap_times[5]	INT	0	0	
14.0	tap_times[6]	INT	0	0	
16.0	tap_times[7]	INT	0	0	
18.0	tap_times[8]	INT	0	0	
20.0	tap_times[9]	INT	0	0	
22.0	tap_times[10]	INT	0	0	
24.0	tap_times[11]	INT	0	0	
26.0	tap_times[12]	INT	0	0	
28.0	tap_times[13]	INT	0	0	
30.0	tap_times[14]	INT	0	0	
32.0	tap_times[15]	INT	0	0	
34.0	tap_times[16]	INT	0	0	
36.0	tap_times[17]	INT	0	0	
38.0	tap_times[18]	INT	0	0	
40.0	tap_times[19]	INT	0	0	
42.0	tap_vals[0]	INT	100	50	tap vals in percent
44.0	tap_vals[1]	INT	0	50	

7. Do not modify “**num\_of\_taps**”. It should be set to 20. If you choose to use a shaper with less number impulses than the maximum number that is offered, simply set the “**tap\_vals**” of all unused impulses to zero.
8. Click the “**Download**” button shown by the red arrow to download the values to the PLC. The **ME6404** shaper is now modified.
9. Record data the same way as Lab 1B.

## **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:

### **Portable Bridge Crane:**

Part A:

Compare the residual oscillations for all trials. 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:

Compare the residual oscillations for all trials. Explain any trends in the data and make reasonable conclusions. You must justify and explain your selection and design of the ZV and robust shaper. Include appropriate and relevant plots.

### **Mobile Tower Crane:**

Compare the residual oscillations for all trials. In addition, address the following questions: How does the slewing motion affect the residual oscillations? Does the radial distance of the trolley on the jib have any effect? How did the slewing motion (as opposed to translational) affect the design of your shaper? **Select the best shaper** for this application and explain why it is the best. Use experimental data that you collected and consider the various tradeoffs in your discussion.

**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 lab on September 23rd**