

Lab 5 — Crane experiment

Agenda

| <i>Time</i> | <i>Item</i> |
|-------------|--|
| 10 min | Review agenda Introduce the crane experiment and apparatus |
| 95 min | Lab activity |
| | I'll try to give you a 5-minute warning before the end of the lab period to put all the chairs back where they belong, log out of the workstation computers, and pack up your laptops. |

Learning objectives:

By the end of the lab period, students should be able to:

- Collect residual swing angular velocity data for various configurations of an experimental crane apparatus with single and double move strategies.
- Compare experimental data for the maximum angular velocity of the crane's pendulum during its residual swing with results obtained through numerical simulation for single and double move strategies.

Background

In this lab, you will collect data for a crane apparatus, consisting of a pendulum with a moveable weight, to experimentally determine the relationship between the placement of the weight along the pendulum and the pendulum's maximum angular velocity after a prescribed motion of the trolley that the pendulum pivots about. The goal is to experimentally determine the optimal location of the moveable weight such that swinging of the pendulum is minimized following the trolley's programmed motion. This lab completes your study of the crane whose equation of motion you derived in Problem CP-1 from Homework 10 and that you simulated using MATLAB and Simulink for Lab 4. You will compare your experimental results to the results of your numerical simulation. If the experiment was carefully done and your numerical simulation was well constructed and executed, you should find that both methods of analysis yield similar results.

The experimental apparatus

The ME and ECE Departments share the Dynamic Systems and Controls Lab in room C-116. The lab equipment is precisely instrumented and includes real-time interface through desktop PCs running Simulink with Real Time Workshop. For this experiment, you will be using the ECP Rectilinear system (which has three moveable carts) with the inverted pendulum accessory mounted to Cart 1 (the "trolley") to mimic an overhead crane.

A schematic of the experimental apparatus is depicted in Figure 1. The pendulum accessory itself consists of three components: a rod that is pivoted about a point near its top end; an attached circular weight of diameter $d_w = 5$ cm whose position along the rod is adjustable; and an attached sensor with diameter $d_s = 2.5$ cm. The pivot axis passes through the center of the sensor, and the sensor's mass is negligible compared to the rod and weight. The location of the mass center for the circular weight relative to the pivot point is denoted by $L_{w,cg}$. The values for the various system parameters (rod mass and length, mass of the circular weight, etc.) are the same as those you used for your numerical simulation in Lab 4.

The pendulum accessory is mounted to Cart 1, and the software is configured such that, starting at approximately 1 second into the simulation, Cart 1 will move 4 cm to the left using two different move strategies, after which the maximum angular velocity of the pendulum's residual swing is recorded. In the single move strategy, Cart 1 moves 4 cm to the left in a single abrupt move. In the double move strategy, the cart moves in a sequence of two abrupt moves. The way the cart is moved goes a long way in eliminating residual pendulum swing. The double move strategy is a well known strategy for moving an overhead crane so that the apparatus arrives at the desired position without residual oscillation.

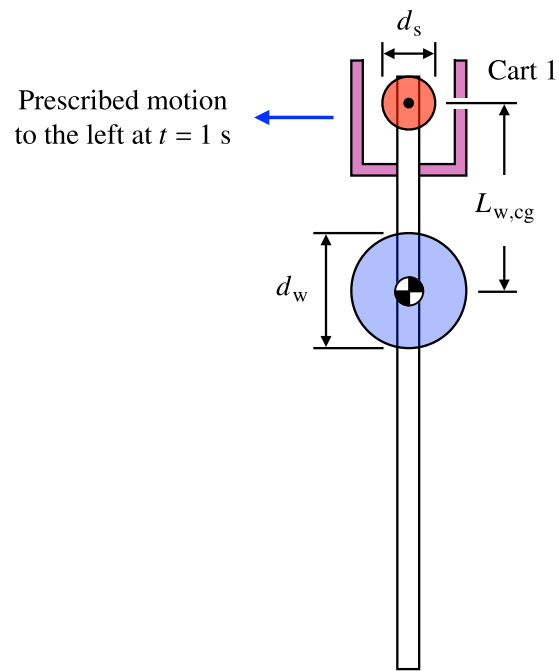


Figure 1. Schematic of the experimental crane apparatus.

During the lab, you will test the eight configurations of the crane's pendulum shown in Figure 2 (the pendulum is shown in a horizontal position for the sake of space), where the distance $L_{w,cg}$ from the pivot to the mass center of the moveable weight for each of the test configurations is given by the formula

$$L_{w,cg} = \frac{d_s}{2} + \left(n - \frac{1}{2}\right) d_w, \quad n = 1, 2, \dots, 8. \quad (1)$$

It may help to mark lightly in pencil the location of the bottom edge of the moveable weight for case n in order to precisely position it for case $n + 1$.

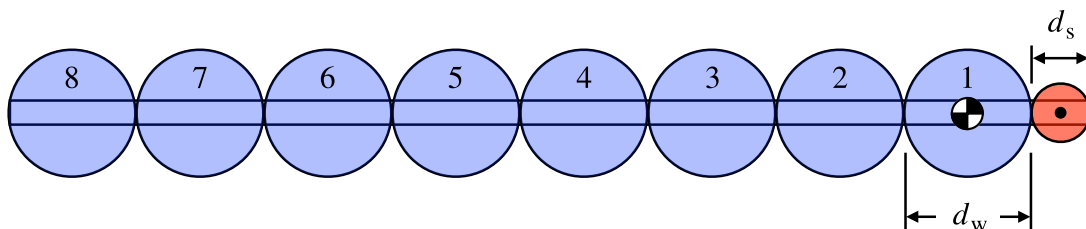


Figure 2. Experimental configurations of the crane's pendulum.

Lab activity

Getting started

1. If not already turned on, turn on the computer at your workstation and log in with the following information:

Username: student
Password: student

Also turn on the control box sitting above your workstation by pressing the black “ON” button.

2. Load the correct personality file for the experimental apparatus by doing the following:
 - a. Start the ECP32 program found under **Start > Programs > ECP > ECP32**. There may be a shortcut to ECP32 on the desktop.
 - b. Download the controller personality file by selecting **Utility > Download Controller Personality File**.
 - c. Navigate to **c:\Program Files\ECP Systems\cn\m210_rtwt3.pmc** and click “Open.”
 - d. Close the ECP32 software after the personality file has finished loading.
3. Launch MATLAB and change the working directory to the “es204” folder on the desktop.
4. Open the Simulink models `crane_single.mdl` (which executes the single move strategy), `crane_double.mdl` (which executes the double move strategy), and `ECPDSPResetmdl.mdl`. In all models, ensure the “External/Normal” window shows “External.” Rebuild the models by clicking the “incremental build” button shown in Figure 3 in the appropriate files. A bunch of stuff will be written to the MATLAB command window, ending with something like `### Successful completion of Real-Time Workshop build procedure for model: ECPDSPResetmdl` for the `ECPDSPResetmdl.mdl` model.
5. You are now ready to run the experimental trials. One group member should be the data recorder. You will record your data in the Excel spreadsheet posted on the course website. For convenience, the spreadsheet is set up to automatically perform calculations for you.

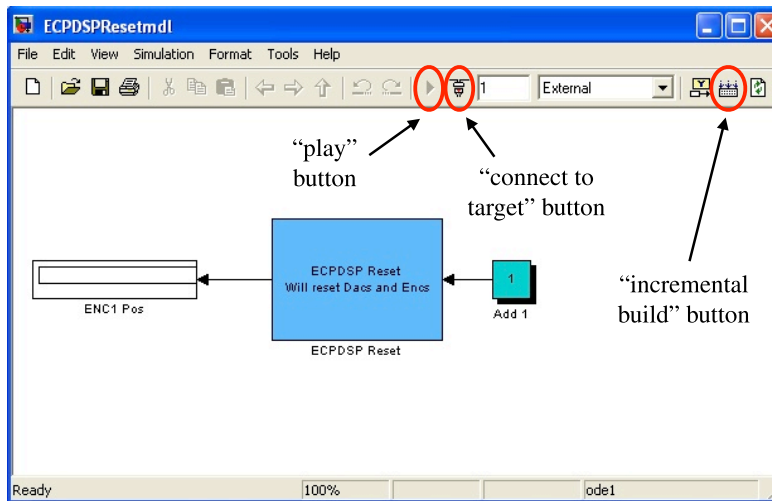


Figure 3. Locations of the “incremental build,” “connect to target,” and “play” buttons in the ECPDSPResetmdl.mdl window. These buttons are in the same place in the crane_single.mdl and crane_double.mdl windows.

Collecting data

For each experimental configuration, you will record the maximum angular velocity of the pendulum’s residual swing after the cart’s prescribed motion for three runs and the average the results, as there may be some experimental scatter. **For each move strategy and experimental run**, you need to do the following:

1. With the pendulum at rest in the **vertical** position and Cart 1 at least 2 cm right of center, run the file ECPDSPResetmdl.mdl. To do this, click the “connect to target” button, wait for the “play” button to turn black, click the “play” button, and then wait about two seconds (see Figure 3). You have just reset the system encoders. This is an important step in getting a precise measurement of the pendulum’s angular velocity.
2. Next, run the crane_*[strategy]*.mdl file: push the “connect to target” button and press the “play” button once it turns black. After the “play” button is pushed, the system should do nothing for 1 second, and then Cart 1 will move 4 cm to the left. The maximum angular velocity (in rad/s) of the pendulum’s residual swing will be displayed in the omega_final block (see Figure 4). Record this number in the appropriate location in your Excel data sheet. If you get a “too fast for this hardware” error message after a run, just ignore it, push close, and carry on – the system will usually continue to work properly.
3. Repeat Steps 1 and 2 three times for each configuration. Now you are ready to move the weight to the next configuration and repeat Steps 1 through 3.

Important Note: If Cart 1 rams into a limit switch or in any way appears unstable, reset the system according to Steps 2 through 4 in the “Getting started” section. Also, sometimes the angular velocity doesn’t show up properly in the omega_final block. Restarting MATLAB is usually all that is needed to solve this problem, but if it persists, reset the system.

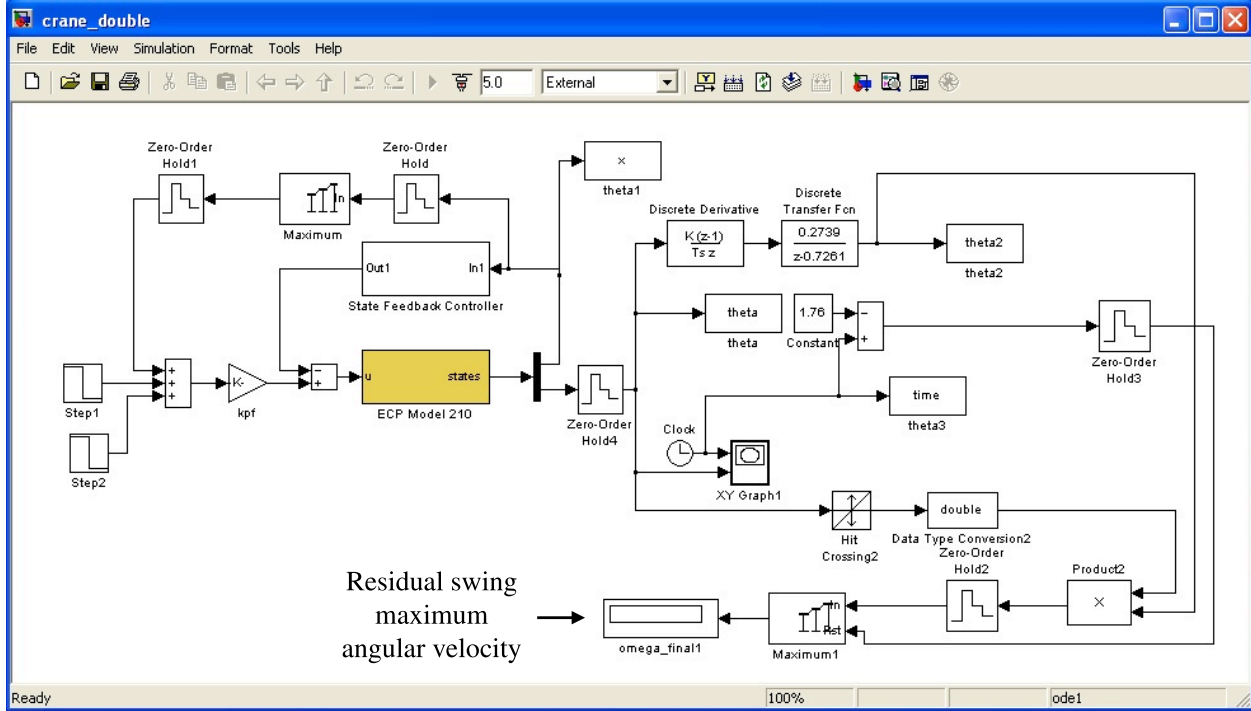


Figure 4. Location of the displayed maximum angular velocity in the crane_double.mdl window. This block is in a similar location in the crane_single.mdl window.

Data analysis

Once you have collected your data, do the following:

- Import your data into MATLAB and create a plot, one for each move strategy, that shows how the maximum angular velocity of the pendulum’s residual swing varies with the circular weight’s location *in centimeters* along the rod, $L_{w, cg}$ (that is, you should have the angular velocity on the vertical axis and weight location in centimeters on the horizontal axis).
- Use markers for the data points, and don’t connect them with a line. Also, be sure to label your axes and include units. Include your initials and the date in the title of each figure, and remove the gray border around the figures.

- **For the double move strategy only**, use your plot to estimate the experimental optimal location along the bar, L_{opt} , to place the circular weight so that the maximum angular velocity of the pendulum's residual swing is minimized. (The experimental optimal location may not be the same as the location determined by numerical simulation in Lab 4.)
- Test this estimated optimal configuration. Run three trials to calculate an average angular velocity, and record these trials on your data sheet. Update your plot to include the estimated experimental optimal location and the corresponding average angular velocity.
- Lastly, include your numerical simulation results from Lab 4 on your plots for comparison. Use different markers for the experimental data and simulation results. Be sure to include a legend to clearly identify what each set of markers represents in each figure. When finished, your plots should look similar to those shown in Figure 5.

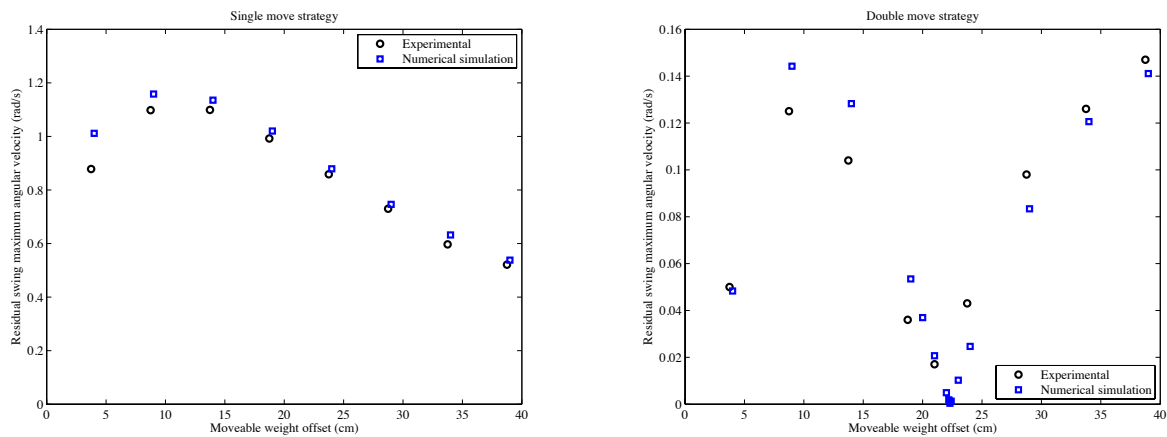


Figure 5. Comparison of experimental and numerical simulation results for the pendulum's maximum angular velocity during its residual swing with the circular weight placed at several locations along the rod for single and double move strategies.

Deliverables:

You will turn in the following items along with Lab 4 on Friday of Week 10:

1. A completed Lab 5 worksheet with numerical results (Table W1) and answers to all questions.
2. Two plots, one for each move strategy, illustrating how the maximum angular velocity of the pendulum's residual swing varies with the circular weight's location (in centimeters) along the rod, $L_{w,cg}$, for your experimental data and your numerical simulation results from Lab 4.
3. A printout of your Excel data sheet that has been **signed and dated** at the bottom.
4. A printout of your MATLAB m-file used to plot the experimental data and numerical simulation results for each move strategy in the same figure.