

ES 204 Lab 5 Crane Experiment

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 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 you simulated in Working Model for Lab 4 and analyzed in Problem CP-1 from Homework 10. You will compare your experimental results to the results of your Working Model simulation and your theoretical result from Problem CP-1. If the experiment was carefully done, your Working Model system was well-built, and you correctly applied the analytical tools from class in Problem CP-1, you should find that all three 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. This 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.

The software is configured such that, starting at approximately 1 second into the simulation, Cart 1 will move 4 cm to the left in a sequence of two abrupt moves. This is a well known strategy for moving an overhead crane so that the apparatus arrives at the desired position without residual oscillation. The overall system is depicted in Figure 1.

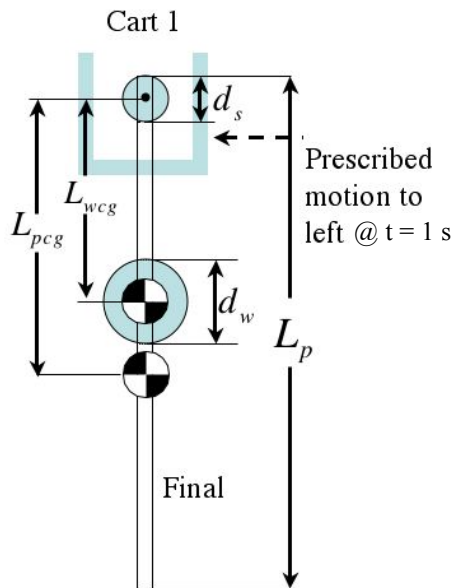


Figure 1: Schematic of the crane apparatus.

Values for the various system parameters are provided in Table 1.

Table 1: Crane system parameters and their values.

Parameter	Value	Units
Pendulum mass, m_p	68.5	g
Moveable weight's mass, m_{add}	88	g
Pendulum length, L_p	43.2	cm
Sensor diameter, d_s	2.5	cm
Moveable weight's diameter, d_w	5	cm

Note that the pivot axis goes through the center of the sensor, so the mass center of the pendulum rod is located at a distance $(L_p - d_s)/2$ from the pivot. During the lab, you will test the 8 configurations shown in Figure 2. (The pendulum is shown in a horizontal position for the sake of space.) The mass center of the moveable weight is depicted only for the first configuration. Noting the dimensions above, the minimum distance from the pivot to the moveable weight's mass center is $L_{cgmin} = d_s/2 + d_w/2$. The distance L_{wcg} from the pivot to the mass center of the moveable weight for each of the 8 test configurations is given by the formula

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

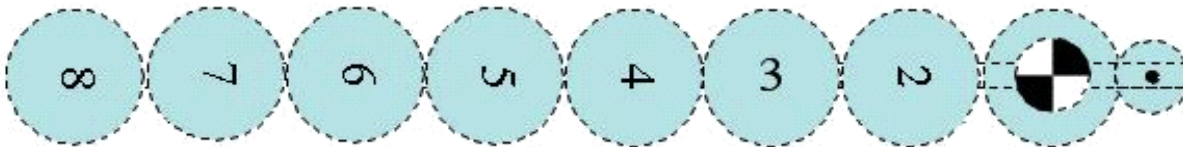


Figure 2: Experimental configurations for the crane's pendulum.

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 $n + 1$.

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. Open MATLAB (there should be an icon on the desktop) and change the working directory to the folder 'es204' on the desktop.
3. Open the files 'ecpdspresetmdl.mdl', 'crane_single.mdl', and 'crane_double.mdl'.
4. You are now ready to run the experimental trials. One group member should be the data recorder. You will record your experimental data in the Excel (.xls) file available in the Lab 5 section of the Labs page on the ES 204 website.

Collecting data

You will run each of the 8 configurations using a single 4 cm move strategy and then using the double 2 cm move strategy. You will find that there is little difference between configurations for each strategy; however, the way the trolley is moved goes a long way in eliminating residual pendulum swing. **Use the ‘crane_single’ file to run the single move strategy. For the double move strategy, run the file ‘crane_double’.**

For each experimental configuration, you will record the pendulum’s final angular velocity for three runs and then average the results since 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 ‘ecpdsresetmdl’. 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 precise measurements of the pendulum’s angular position and velocity.

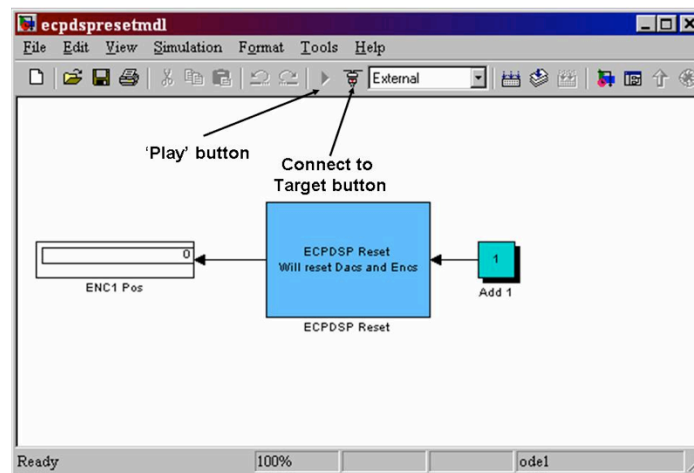


Figure 3: Screenshot of the ‘ecpdsresetmdl’ Simulink window.

2. Next, run the ‘crane_[strategy]’ 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 pendulum’s final angular velocity (in rad/s) will be recorded in the omega_final1 block (see Figure 4). Record this number in the appropriate location in your Excel spreadsheet. If you get an ‘internal 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 1-3.

Important Note: If Cart 1 rams into a limit switch or in any way appears unstable, reset the system using the steps below. Note that we are using a feedback controller to precisely move the cart 4 cm to the left. This system is very dependent on reliable measurements from the sensors, so if something isn’t properly reset, it could result in damage to the equipment.

- Quit MATLAB.
- Start the ECP32 program found under Start > Programs > ECP > ECP32. There may be a shortcut to ECP32 on the desktop.
- Download the controller personality file by selecting Utility > Download Controller Personality File.
- Navigate to c:\Program Files\ECP Systems\cn\m210_rtw3.pmc and click Open.
- Close the ECP32 software after the personality file has finished loading.
- Restart MATLAB.
- Change the working directory to the 'es204' folder, open the Simulink files, and rebuild 'crane_single.mdl' and 'crane_double.mdl' by clicking the 'compile' icon just to the right of the dropdown menu that says 'External'. A bunch of stuff will be written to the MATLAB command window, ending with: `### Successful completion of Real-Time Workshop build procedure for model: crane_[strategy].`
- Now try doing a trial run to make sure the system is working properly.

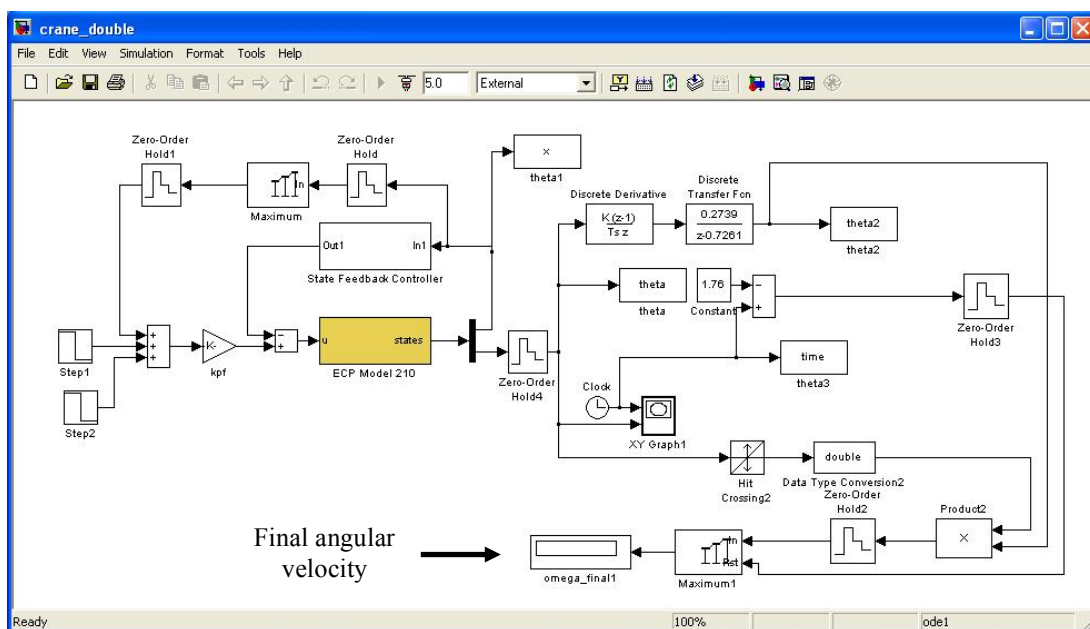


Figure 4: Screenshot of the 'crane_double' Simulink window.

Data analysis

Once you have collected all of your data, calculate the distance L_{wcg} and the average final angular velocity ω of the pendulum for each configuration and move strategy. The Excel spreadsheet contains a blank scatter plot of ω as a function of L_{wcg} for each move strategy. Place your L_{wcg} and ω values in the provided to update the plots with your experimental data. You may need to adjust the given axes limits to clearly see all of your data. **For both plots, connect the data points by a smooth line by changing the chart type to 'Scatter with Smooth Lines and Markers' (this is not the same as a best-fit trendline).** If your plots loop over themselves, you may need to order your data to be in increasing order.

Finally, **for the double move strategy**, find the *experimental* optimal location along the pendulum to place the moveable weight so that the pendulum's final angular velocity is minimized. Start by estimating where the optimal location is by using your plot, and test this configuration. Keep trying locations until you find the optimal location, all the while running three trials per try to calculate an average final angular velocity ω . Be sure to record all of the data from your attempts to find the optimal location. The experimental optimal location may not be exactly the same as the theoretical location you calculated in Problem CP-1 from Homework 10.

Deliverables

Lab 4 results (Working Model simulation), Lab 5 results (experiment), and a **COPY** of your solution to Problem CP-1 from Homework 10 are all due Friday of Week 10. A coversheet for your deliverables is available on the Labs page of the ES 204 website. You will be required to submit the following:

1. A printout of your Lab 5 Excel spreadsheet, complete with experimental data and plots of the (average) final angular velocity ω of the pendulum as a function of the distance L_{wcg} for both move strategies.
2. A printout of your Lab 4 Excel spreadsheet, complete with Working Model simulation data and plots of the final angular velocity ω of the pendulum as a function of the distance L_{wcg} for both move strategies.
3. A snapshot of your Working Model simulation.
4. A **COPY** of your solution to Problem CP-1 from Homework 10. (Don't forget to turn in the original with Homework 10!)

In addition to the above, include a thoughtful discussion that addresses the following questions:

1. Is there a difference between the experimental and theoretical result for the optimal location? If so, what may have been the cause(s) for this discrepancy?
2. Compare your experimental results from Lab 5 to those from your Working Model simulation in Lab 4. How do your plots of the pendulum's final angular velocity ω as a function of the distance L_{wcg} generated by experimental data compare to your plots from Working Model simulation data? If there is a difference, what may have been the cause(s)?