

Lab 3 — *Swinging pendulum experiment*

Agenda

<i>Time</i>	<i>Item</i>
10 min	Review agenda Introduce the swinging pendulum 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 swing time data for various configurations of an experimental pendulum apparatus.
- Compare experimental data for the average swing time of a pendulum apparatus with results obtained through numerical simulation.

Background

In this lab, you will collect data for a swinging pendulum apparatus with a moveable weight to experimentally determine the relationship between the placement of the weight along the pendulum and the time it takes for the pendulum to swing from the horizontal position to vertically downward. This lab completes your study of the pendulum system you simulated using MATLAB and Simulink for Lab 2 and analyzed in Problem 4.9 from Homework 5 using conservation of energy. You will compare your experimental results to the results of your numerical simulation and your theoretical results from Problem 4.9. If the experiment was carefully done, your numerical simulation was well constructed and executed, and you correctly applied conservation of energy in Problem 4.9, 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. 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.

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 2.

The pendulum accessory is mounted to Cart 3 (which is held fixed) of the ECP Rectilinear system, and an extension bar is attached to Cart 1. The extension bar is used to hold the pendulum just barely above the horizontal position. The software is configured to automatically release the pendulum at approximately 4 seconds into the simulation. It will then record the times at which the pendulum reaches the horizontal and vertical positions. Since the release point is slightly above horizontal, the angular speed when crossing the horizontal position is very small, and so it will be considered negligible.

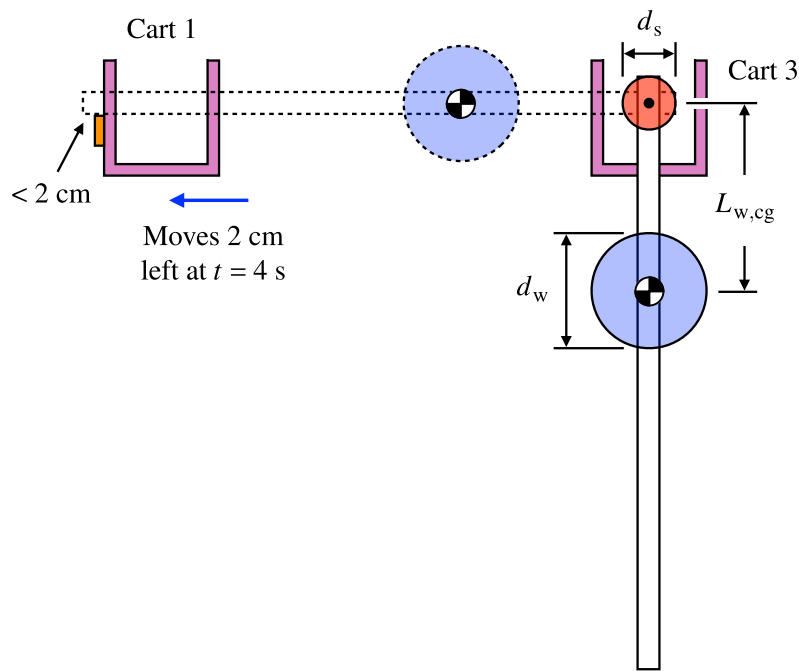


Figure 1. Schematic of the experimental pendulum apparatus.

During the lab, you will test the seven pendulum configurations shown in Figure 2, 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

$$L_{w,cg} = \frac{d_s}{2} + \left(n - \frac{1}{2}\right) d_w, \quad n = 1, 2, \dots, 7. \quad (1)$$

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 $n + 1$.

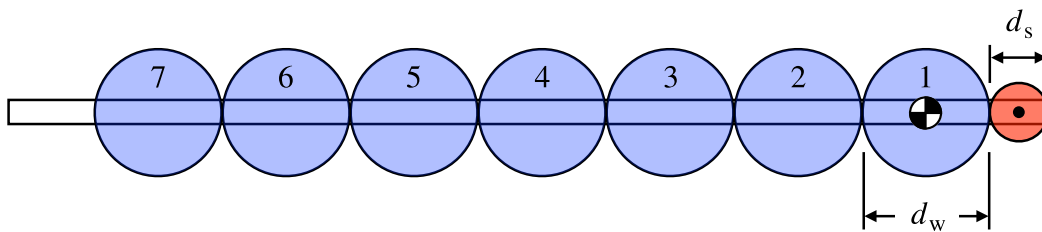


Figure 2. Experimental configurations of the pendulum.

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 `final_four.mdl` and `ECPDSPResetmdl.mdl`. You should have two `.mdl` windows on your screen – if you have three, close the small one with the green box showing. In both models, ensure the “External/Normal” window shows “External.” Rebuild both models by clicking the “incremental build” button shown in Figure 3 in both 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.

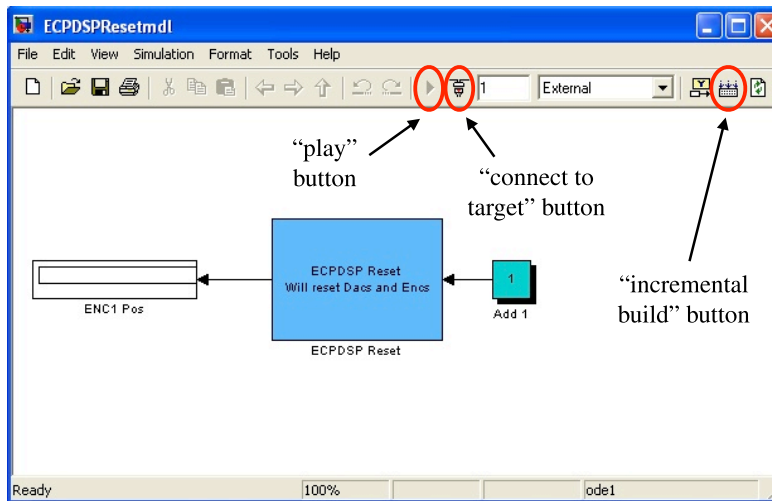


Figure 3. Locations of the “incremental build,” “connect to target,” and “play” buttons in the ECPDSPResetmdl.mdl window. These buttons are in the same place in the final_four.mdl window.

Collecting data

For each experimental configuration, you will record the times when the pendulum crosses the horizontal and vertical positions for three swings, calculate the corresponding swing times by taking the difference, and then average the results, as there may be some experimental scatter. For each swing, you need to do the following:

1. With the pendulum at rest in the **vertical** position and Cart 1 at approximately zero, 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 when the pendulum crosses the horizontal and vertical positions.
2. Now, swing the pendulum **clockwise** up to the horizontal position, and move Cart 1 so that the extension bar supports the pendulum and is within 2 cm of the end of the pendulum.
3. Next, run the final_four.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 4 seconds, and then Cart 1 will move to the left to release the pendulum. The times at which the pendulum crossed the horizontal and vertical positions will be displayed in the t_1 and t_2 blocks, respectively (see Figure 4). Record these numbers in the appropriate locations 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.

- Repeat Steps 2 and 3 three times for each configuration. Now you are ready to move the weight to the next configuration and repeat Steps 1 through 4.

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 crossing times don’t show up properly in the t_1 and t_2 blocks in the `final_four.mdl` window. Restarting MATLAB is usually all that is needed to solve this problem, but if it persists, reset the system.

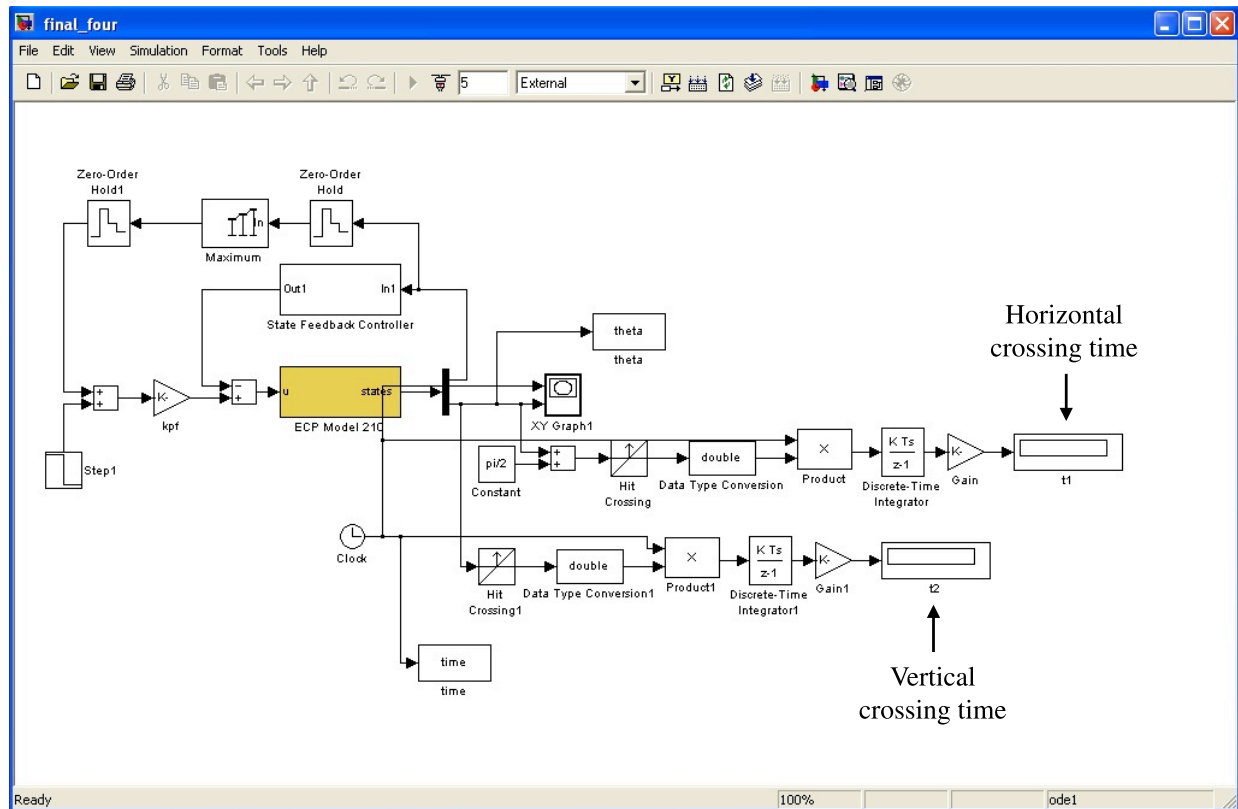


Figure 4. Locations of the displayed horizontal and vertical crossing times in the `final_four.mdl` window.

Data analysis

Once you have collected your data, do the following:

- Import your data into MATLAB and create a plot that shows how the pendulum’s average swing time, Δt , varies with the circular weight’s location *in centimeters* along the rod, $L_{w,cg}$ (that is, you should have swing time 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 your figure, and remove the gray border around the figure.
- Using your plot, estimate the experimental optimal location along the bar, L_{opt} , to place the circular weight that yields the fastest average swing time. (The experimental optimal location may not be the same as the locations determined analytically in Problem 4.9 and by numerical simulation in Lab 2.)
- Test this estimated optimal configuration. Run three trials to calculate an average swing time, and record these trials on your data sheet. Update your plot to include the estimated experimental optimal location and the corresponding average swing time.
- Lastly, include your numerical simulation results from Lab 2 on your plot 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. When finished, your plot should look similar to the one shown in Figure 5.

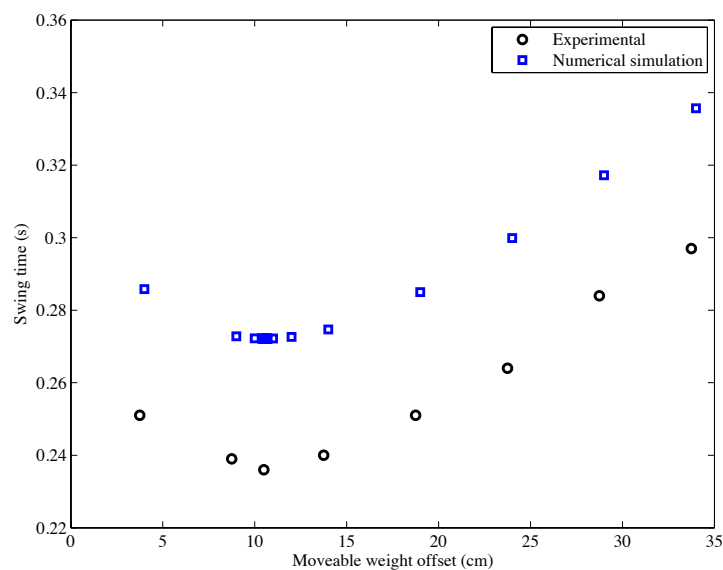


Figure 5. Comparison of experimental and numerical simulation results for the time it takes the pendulum to reach the bottom of its swing when released from rest in the horizontal position with the circular weight placed at several locations along the rod.

Deliverables:

For this lab activity, you need to turn in the provided worksheet with a completed section of numerical results (Table W1), answers to all questions, and all requested plots and documentation attached.