ES 204 Lab 3
Swinging Pendulum Experiment

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 in Working Model 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 Working Model simulation and your theoretical results from Problem 4.9. If the experiment was carefully done, your Working Model system was well-built, 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. 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.

The pendulum accessory is mounted to Cart 3 (which is held fixed) 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 small, and so it will be considered negligible. The overall system is depicted in Figure 1.

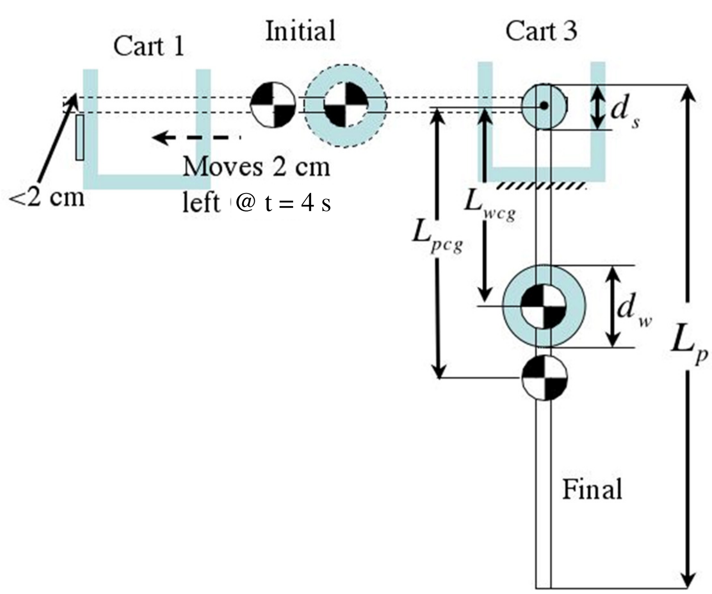

Figure 1: Schematic of the pendulum apparatus.

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

Table 1: Pendulum 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 7 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 $L_{\text{cgmin}} = d_s/2 + d_w/2$. The distance L_{wcg} from the pivot to the mass center of the moveable weight for each of the seven test configurations is given by the formula

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

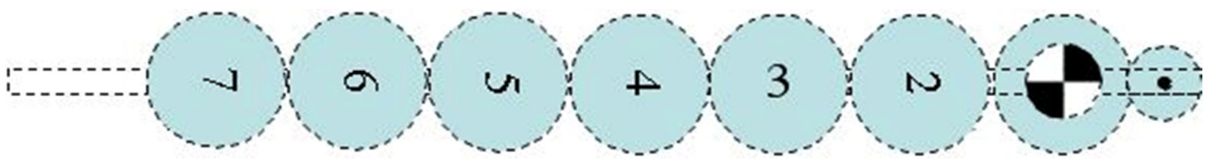

Figure 2: Experimental configurations for the swinging pendulum.

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' and 'final_four.mdl'. You should have two .mdl windows on your screen. If you have three, close the small one with the green box showing.

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 3 section of the Labs page on the ES 204 website.

Collecting data

For each experimental configuration, you will record the times when the pendulum crosses the horizontal and vertical positions for three swings and then average the results since 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'. 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 horizontal and vertical.

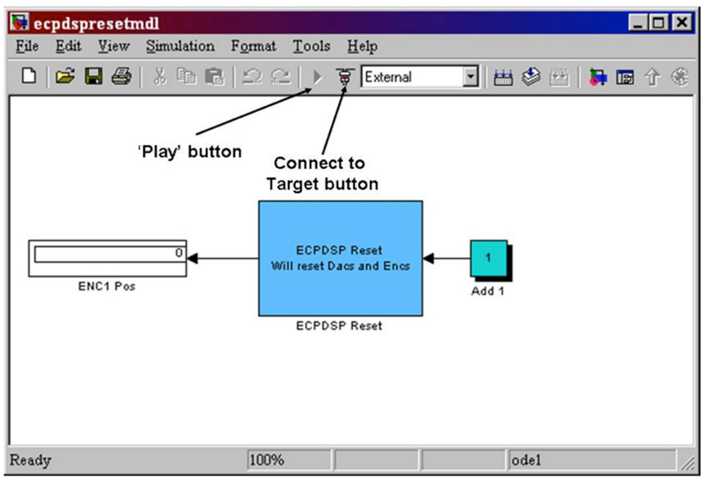

Figure 3: Screenshot of the 'ecpdspresetmdl' Simulink window.

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' 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 t1 and t2 blocks, respectively (see Figure 4). Record these numbers 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.

4. 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 1-4.

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 2 cm to the left to release the pendulum. 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.

The following reset procedure can also be used if MATLAB keeps displaying errors or the times don't show up properly in t1 and t2 blocks in the 'final_four' window. However, usually restarting MATLAB is all that is needed to solve the problem.

- 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_rtwt3.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 'final_four.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: final_four*.
- Now try doing a trial run to make sure the system is working properly.

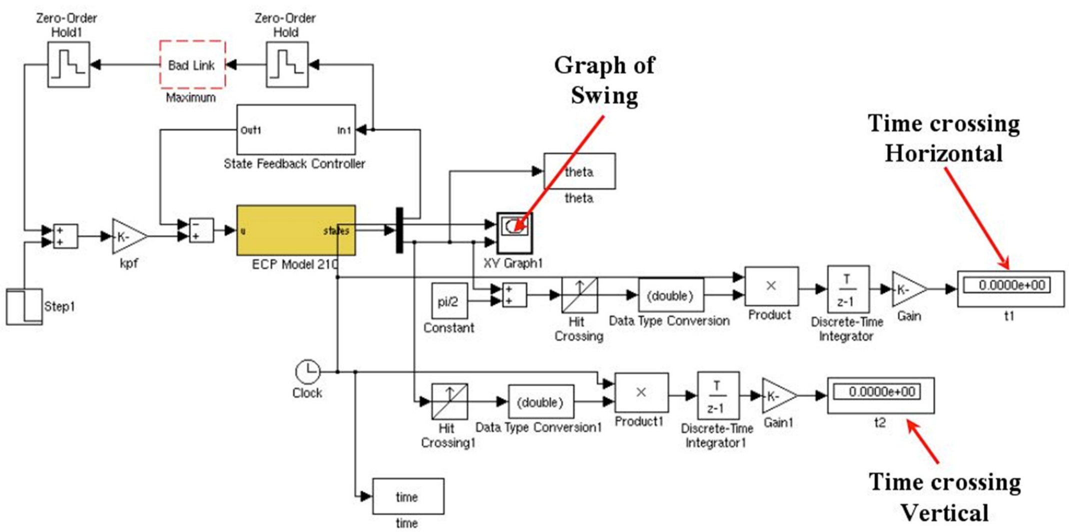

Figure 4: Screenshot of the 'final_four' Simulink window.

<u>Data analysis</u>

Once you have collected all of your data, calculate the distance L_{wcg} and the average swing time Δt for each configuration. The Excel spreadsheet contains a blank scatter plot of Δt as a function of L_{wcg}. Place your L_{wcg} and Δt values in the table to the left of this plot to update the plot with your experimental data. **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 plot loops over itself, you may need to re-order your data to be in increasing order.

Finally, find the *experimental* optimal location along the bar to place the moveable weight that yields the fastest swing time. 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, and then run three trials to calculate an average swing time Δt. 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 4.9 from Homework 5. **Update your plot to include the experimental optimal location and the corresponding average Δt.**

Deliverables

Print out and turn in the worksheet/Excel spreadsheet containing all of your collected data, a completed plot, and answers to all questions. Include a description of any observations you made during the lab and a reasonable discussion of your results. The discussion should address the difference (if any) between the experimental and theoretical result for the optimal location and what may have been the cause(s) for any discrepancy. Also, compare your experimental results to those from your Working Model simulation in Lab 2. How does your plot of swing time Δt as a function of the distance L_{wcg} generated by experimental data compare to your plot from Working Model simulation data? If there is a difference, what may have been the cause(s)?