Centripetal Force on a Pendulum

Objective

The purpose of this experiment is to analyze the motion of a pendulum and to gain additional experience using graphical analysis to extract quantitative information.

Materials

1. 1-meter stick
2. Force transducer with half inch rod
3. Hooked masses (100g, 500 g, 1000 g)
4. Pasco 550 Interface
5. Photogate and stand
6. Right-angle clamp
7. Table clamp and rod
8. Vernier caliper

Procedure

Getting Set Up

In this experiment we will have the computer and force transducer measure the force exerted by a string on a swinging pendulum bob. We will also use a photogate timer in determining the speed of the pendulum. We will then check the consistency of these measurements with the prediction of Newton's Second Law. You should have the force transducer connected to the analog Channel A of the interface. The photogate should be plugged into the digital Channel 1.

First, we will arrange to have the computer assign the appropriate number of Newtons to the voltage it receives from the transducer. Select a heavier mass to use in the calibration and provide a string with loops at each end for hanging the masses from the hook of the force transducer. (A length between about 0.3 m and 0.5 m will be convenient for later work with the pendulum.) Double-click on the "Pasco Capstone" icon on your desktop. Click on "Hardware Setup" (in the "Tools" window panel on the left side of screen). Click on digital input #1 on the interface and select "Photogate" from the drop-down menu. This should place a picture of a photogate in digital input #1 of your interface. Now click on analog input A on the interface and select "Force Sensor, Student" from the drop-down menu. This should place a picture of a Force Sensor in analog input A of your interface.

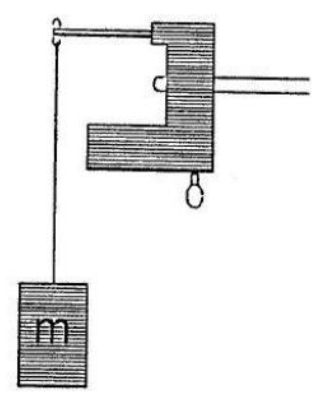

Figure 1: *Transducer supporting a* suspended mass.

Calibrating the Photogate

First measure the diameter of your hanging mass using the Vernier caliper. Click on the "Timer Setup" icon, in the "Tools" window panel on the left side of screen. In step 1, click on "Pre-Configured Timer" and select "Create a pre-configured timer" from the drop-down menu. Click next and go to step 2. The available, connected timing devices for the timer: "Photogate, Ch 1" icon should have been checked here. Click on next, and in step 3, click on "Select Timer" and select "Pendulum Timer" from the drop-down menu. In step 4, check the "Speed" icon and click next. In step 5, type in the diameter of the hanging mass in the "Pendulum Width" text entry box and click next. In the final step, specify the timer's name, as it already has in the text entry box as "Pendulum Timer". Click on "Finish" and this will end the timer setup of the photogate.

Calibrating the Force Transducer

Click on the "Calibration" icon in the "Tools" window panel. In step 1 of the calibration menu, select "Force" as the measurement you would like to calibrate. It defaults to Force there. Select next and you will automatically go to step 3 as it will again default to Force Measurements in step 2. In step 3, select "Two Standards (2 point)" as the type of calibration you would like to perform and select next. In step 4, to calibrate the first point, enter 0.98 in Standard Value text entry box and hang the 100 g mass on the pendulum string. As the current value gets close to your Standard Value, click on "Set Current Value to Standard Value". In step 5, to calibrate the second point, hang 1000 g mass and enter the weight of the mass (9.8 N) in the Standard Value text entry box. When the Current Value gets close to your Standard Value, click on "Set Current Value to Standard Value" and in the final step (6), you can review the values and accept the values if they are correct and click on Finish. Remove the 1000 g mass from the pendulum string. This will end the calibration.

Checking the Calibration

On the "Displays" window panel, double-click on "Graph". Click on "Select Measurement" on the vertical axis of your graph and choose "Force". Hang the 500 g mass from the string, and press "Record" button at the bottom of the screen. (Let it run for a couple of seconds then press "Stop."). Look at your force graph to see if the weight was measured correctly. If it was not the correct weight, then you'll need to re-calibrate (you may need to ask your instructor for help). You will want to get rid of this data run. To do this, click on the "Delete Last Run" icon at the bottom of your screen, and/or select "Delete All Runs."

The Experiment

Position the photogate so that at the bottom of its swing the center of mass of the pendulum bob will block the infrared beam. Now click on your Force vs. time graph and select the "Add new plot area to the graph display" icon.

This will give you a second graph below the first graph. Click on "Select Measurement" on the vertical axis of your second graph and choose "Speed". Now, being careful not to let the mass hit the photogate, release the pendulum from rest with the string at about 25° to 30° from vertical. Try to do this smoothly without introducing any wobbles (which would show up as bad data on the graphs). Swing the pendulum a few times to make sure that it travels through the center of the photogate each time. When you are satisfied with the motion of your pendulum, click the "Record" button, and let it run for a few seconds, then click "Stop".

You may need to use the auto-scale button to locate your data on the graph. Select the "Add a coordinates tool" and click on the "Add Multi-Coordinates Tool", from the drop-down menu.

This will add coordinates on both graphs and when moving, both coordinates will move together. Click and drag the coordinates on the graphs to read the tension on the string, F_T , and the speed of your bob, v. You are interested in the maximum tension and the speed that corresponds with that time. To increase the decimal places of your force and speed measurements, right click on the chosen reading and select "Tool Properties", then select "Numerical Format", and select "Vertical Coordinate" from the drop-down menu. There you can increase the number of decimal places to an appropriate value.
What error in speed could be introduced by the uncertainty in the computer's measurement of time? According to Newton's Second law (see Figure 2), for the pendulum bob at its lowest point the string force, F_T , should satisfy

$$F_T - mg = m\frac{v^2}{l}$$

where the radius of the circular arc, l, is measured from the support point to the center of mass of the bob. Therefore

$$F_T = m(g + \frac{v^2}{l})$$

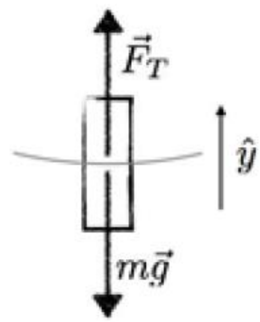

Figure 2: *Free Body Diagram for the mass m at the bottom of its oscillation.*

Does this agree with your measured values? What is the percent error between these two tension values? Why does your tension vs time graph look the way it does? Using your plot of tension vs time, calculate the angle of the pendulum bob at its highest point. Hint: What is the velocity of the hanging mass at its highest point?