Periodic Motion - Hanging Mass on a Spring

Objective

When an object is subject to a restoring force that is proportional to the displacement of the object from some equilibrium position, the motion that results is called simple harmonic motion, which is a special case of periodic motion. While this may sound fairly dry, periodic motion is important to understanding many topics you will come across in this class and perhaps others. Waves, AC electric current, and molecules in a solid all provide examples of periodic motion.

In this lab you will study a very simple system that exhibits periodic motion, a mass hanging from a spring. The spring exerts a restoring force on the mass according to Hooke’s Law. You will use an ultrasonic range finder to generate and study position, velocity, and acceleration graphs for the oscillating mass.

Materials

1. 1-meter stick
2. Colored pencils
3. Hanging spring
4. Mass with eye hook (500g)
5. Pasco 550 Interface
6. Sonic ranger
7. Table clamp and rod
8. Three-hole bracket clamp

Procedure

Your setup should look something like the diagram in Figure 1. The ultrasonic range finder is laid on the floor, directly beneath the hanging mass. The mass will need to be at least 55 or 60 cm above the range finder. It cannot detect the range of objects closer than 40 cm and you need to leave room for the mass to oscillate. Your lab instructor will provide instructions for connecting the range finder to the computer. Once that is done, boot up Windows and double-click on the Pasco Capstone icon on the desktop.

On the "Tools" windows panel on the left side of the screen, click on "Hardware Setup". Click on digital input 1 on the interface and select “Motion Sensor II” from the drop-down.

Figure 1: Setup for the study of Simple Harmonic Motion
Double-click on “Graph” in the “Displays” window panel on the right side of your screen, then click on “Select Measurement” on the vertical axis of your graph and select “Position”.

**Part 1: Position vs Time**

1. Start your oscillation (verify that your sonic ranger is well positioned below the oscillating mass) and click “Record” in the “Controls” panel at the bottom of your screen to record data. Stop after 10 seconds.
2. Maximize the Position vs Time graph using the “Scale-to-Fit” tool. Does it look like you expected it to?
3. Your first task is to determine the amplitude of the motion. In order to do this, you will need to first determine the equilibrium position of the mass, by clicking on the “Coordinate” tool and selecting “Add Multi-Coordinates Tool” from the drop-down. Once you do that, measure the amplitude of the periodic motion.
4. Using the same position vs time graph from which you measured amplitude, measure the period of the motion. What value of the spring constant does this period give you?
5. Repeat the process of measuring amplitude and period (Part 1) two more times for two different amplitudes. Record your results for these three experimental runs.
6. In your lab summary comment on the relationship between amplitude and period based upon these results.

**Part 2: Velocity vs Time**

1. Think about when during the mass’s motion the speed of the mass would be the largest and when it would be zero. Before making measurements, you and your lab partner(s) should compare your predictions and agree on one. If you have differences of opinion try figuring out which is correct. Ask your lab instructor for help if you can’t agree.
2. Once you’ve done that, load the velocity vs time plot in the software by clicking on “Graph” and selecting “Velocity” as the physical quantity to be measured. Use the “Data Selector” tool to select which of the runs from part 1 you wish to display simultaneously on your velocity vs time graph. How accurate were your predictions?

**Part 3: Acceleration vs Time**

In this part what we are really interested in is the net force acting on the mass. But you should recall from Newton’s Second Law of Motion that the acceleration is proportional to the net force acting on the mass. In your pre-lab you predicted when, during the mass’s motion, the net force would be the largest and when it would be zero. Before starting on this part, you and your lab partner(s) should compare your predictions and agree on one. If you have differences of opinion try figuring out which is correct, ask your lab instructor for help.
1. Load the acceleration vs time plot. Now, the computer should simultaneously display the position, velocity, and acceleration graphs. (Make sure you use the data selector to choose the same run for all three graphs).

2. When acceleration is greatest, net force is greatest; and when acceleration is zero, net force is zero. Where was net force greatest and least?
   - What are the relationships between the position, velocity and time graphs?
   - What do these relationships mean in physical terms?
   - How accurate were your predictions?
   - Do the results you got agree with Hooke’s Law?

3. Pick three instants of the motion (make sure that they are at different points on the wave; in other words, do not pick three peaks or three troughs. And, to keep it interesting, do not pick just a peak, a trough, and an equilibrium.) and compare the net force you calculate from Newton’s Second Law \( F_{\text{net}} = ma \) with the calculated force exerted by the spring \( F = -kx \). How do the two calculations of force compare for these three instants? Comment on the physical significance of the minus sign in Hooke’s Law in your lab summary.

**Part 4: Energy Conservation**

Energy is an important and convenient concept for investigating motion. Recall that in the absence of non-conservative forces, mechanical energy \( E = KE + PE \) is a conserved quantity—that is, it does not change with time. We have \( KE = \frac{1}{2}mv^2 \) and \( PE = \frac{1}{2}kx^2 \). In the situation that we are studying, the two primary forces acting on the mass are gravity and the spring, both conservative forces. There is a small frictional force (non-conservative), but over the brief time we are looking at the motion (a few periods at most) its effects are negligible.

1. Have the computer graph position and velocity for another series of oscillations. Calculate and compare \( KE_{\text{max}} \) with \( PE_{\text{max}} \). Recall here that you may neglect gravitational potential energy. \( KE_{\text{max}} \) and \( PE_{\text{max}} \) should be close to one another, why is that?

2. Choose two other instants during the motion and calculate the mechanical energy at those instants. (Choose times when the mass is at some location other than equilibrium or its maximum displacement.)
   - How do your two calculated mechanical energies compare with one another? With \( KE_{\text{max}} \) and \( PE_{\text{max}} \)? Why is this so?

3. On one graph, neatly plot both kinetic and potential energies vs time for the periodic motion shown on your computer screen. It might be convenient to use fractions of the period for your time increments rather than seconds. Use different colors for kinetic and potential energy. Using a third color, add a plot of mechanical energy vs time to the same graph.
Your Lab Summary

Summarize what you learned about periodic motion in this lab. Additionally, there are several items listed in the lab that are to be specifically addressed in your summary.