Motion Sensor

Introduction:

Part of the Eisco series of hand held sensors, the motion sensor allows students to record and graph data in experiments on the go.

This sensor uses an ultrasonic transducer to transmit an ultrasonic wave and measure the time of the echo return. In this way, the sensor measures the distance to an article located against it.

Using the module software, it is able to calculate also the object’s velocity and acceleration. Therefore the sensor has three modes of operations: Distance, Velocity and Acceleration.

Sensor Specs:

Distance: 0.25 - 6 m | 5 mm resolution | 100 max sample rate
Velocity: -10 - 10 m/s | 0.2 m/s resolution | 100 max sample rate
Acceleration: -100 - 100 m/s² | 0.08 m/s² resolution | 100 max sample rate
Activity – Simple Harmonic Motion

General Background:

A certain type of motion is found in objects that have a restoring force when displaced from an equilibrium position. When there is a restoring force, that is a force which acts on the object to direct it back to its resting position, that is proportional to the displacement, we say that the object undergoes simple harmonic motion. This is the type of motion of a mass on a spring, or a swinging pendulum bob. The motion is sinusoidal in time, and moves with a single frequency.

For a spring, the restoring force is given by Hooke’s Law, which simply states that the force pushing or pulling the mass on the end of a spring is proportional to the displacement, or \( F = -kx \). When solving this force equation to determine the motion, one finds that the motion of the mass on the spring can be described by the following equation:

\[
x(t) = A \sin(2\pi ft),
\]

where \( x \) is the displacement of the mass, \( A \) is the amplitude of the motion (maximum displacement), \( f \) is the frequency of the motion, and \( t \) is time. The period of the motion, \( T \), (the time it takes for the spring to complete one full cycle of back and forth motion) is related to the frequency by the equation \( T = 1/f \).

In this activity, we will discover whether it is the mass hanging from the spring, or the amplitude of the spring which determines the length of the period of the motion.

Required Materials:

- Eisco Motion Sensor & Handheld Unit
- Eisco Base Retort Stand [CH0654A]
- Eisco Stainless Steel Rod – 100 cm [CH0659D]
- Eisco Pendulum Clamp [PH0308]
- Eisco Harmonic Motion Spring [PH0713]
- Eisco Slotted Mass Set [PH0037HSS]
- Eisco Slotted Mass Hanger [PHSSH100]
- Balance or digital scale
- String or long twist tie
- Computer and graphing software (such as Microsoft Excel)
Procedure:

1. Set up a base retort stand, 100 cm rod, and pendulum clamp as shown in Figure A. Use of a large mass as a counter balance is recommended to prevent tipping. Hang the harmonic motion spring from one of the pendulum knobs.

2. Measure the mass of the slotted hanger and the Eisco Motion Sensor plus hand unit using a balance or digital scale.

3. Attach the slotted mass hanger to the Eisco hand held sensor base unit Wi-Fi panel cover. One method is to use a string to secure as shown in Figure B. Alternatively, long twist ties can be used to affix. Insert port cover into base unit. BE SURE THE PORT COVER IS SECURELY AFFIXED. Hang the Eisco Motion Sensor from the harmonic spring using the hook on the slotted mass hanger.

4. Attach one 100 g slotted mass to the hanger. Record the total mass hanging off the harmonic spring (i.e. the hanger, the slotted mass, and the motion sensor unit) in the table below.

5. Turn on the Eisco motion sensor, set it to measure distance.

6. With the motion sensor at rest in its equilibrium position, record the distance of the motion sensor from the surface of the table. Record in the table below.

7. Configure the Eisco motion sensor to record data for 10 seconds of data with a sample rate of 100 S/sec.

8. Lift the Eisco sensor approximately 5 cm (a partner can hold a meter stick adjacent to the sensor). Hit record on the touch screen and then release the motion sensor. The sensor should oscillate smoothly, and only in the vertical direction. If the sensor swayed, or otherwise did not produce a smooth sinusoidal shaped graph, repeat until successfully produced.

9. Repeat step 8 with an initial displacement of 10 cm instead of 5 cm.

10. Add 100 g slotted mass to the hanger. Record the new equilibrium position. Repeat step 8 for an approximately 5 cm initial displacement.
Data

<table>
<thead>
<tr>
<th>Run</th>
<th>Total Mass, M (g)</th>
<th>Equilibrium Position, ( x_0 ) (m)</th>
<th>Amplitude, A (m)</th>
<th>Period, T (sec)</th>
<th>( f ) (Hz)</th>
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<tbody>
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Analysis

1. Export each of the runs into a separate .csv (comma separated value) file.
2. Import the runs into a graphing program (i.e. Excel).
3. Graph each run in a separate plot.
4. For each of the runs determine the amplitude, A (maximum displacement – minimum displacement) / 2, and period, T. Record in the data table.
5. Calculate the frequency for each run (1 / T) in Hz. Record in the data table.

Questions

1. What is the equation describing the motion of each for each of the three runs?
2. What is the variable which determines the frequency of the motion, is it the mass of the oscillator or the starting displacement (amplitude)?
Sample Results

These are examples of possible results. Due to the many variables involved, exact reproduction is unlikely, but students should find similar trends.
### Sample Data

<table>
<thead>
<tr>
<th>Run</th>
<th>Total Mass, $M$ (g)</th>
<th>Equilibrium Position, $x_0$ (m)</th>
<th>Amplitude, $A$ (m)</th>
<th>Period, $T$ (sec)</th>
<th>$f$ (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>350</td>
<td>0.392</td>
<td>0.050</td>
<td>1.3</td>
<td>0.77</td>
</tr>
<tr>
<td>2</td>
<td>350</td>
<td>0.392</td>
<td>0.075</td>
<td>1.3</td>
<td>0.77</td>
</tr>
<tr>
<td>3</td>
<td>450</td>
<td>0.290</td>
<td>0.052</td>
<td>1.44</td>
<td>0.69</td>
</tr>
</tbody>
</table>
Answers to Questions

1. Recall that each equation of motion has the following form: \( x(t) = A \sin(2\pi ft) \),
   Plugging in the results from the above sample data table, the equation for each run is:
   Run 1: \( x(t) = 0.05 \sin(2\pi \cdot 0.77t) \),
   Run 2: \( x(t) = 0.075 \sin(2\pi \cdot 0.77t) \),
   Run 3: \( x(t) = 0.052 \sin(2\pi \cdot 0.69t) \).

2. Runs 1 and 2 have the same mass oscillator, but different starting amplitudes.
   The frequencies of the motion were equivalent, so starting amplitude does not effect the period.

   Runs 1 and 3 have the same starting amplitude, but different mass oscillators.
   The frequency of the motion for the more massive oscillator in Run 3 has a shorter frequency (longer period) of motion than in Run 1. Thus the frequency depends on mass, and not starting amplitude.