EXPERIMENT 11: OSCILLATIONS

Objective:

To measure the fundamental properties of oscillatory motion, including the force constant, the period of oscillation, and the maximum velocity of a mass executing simple harmonic motion.

Experiment:

For many important physical systems, ranging from molecular structures to electronic circuits to satellite orbits, the response to a disturbance from an equilibrium configuration is oscillatory motion with a frequency that depends upon the restoring force and the mass. This week we investigate the behavior of an oscillatory system, namely, a mass moving under the influence of springs. For such a system the force acting on the mass is $F = - kx$ and Newton's second law tells us that $F = ma$, so

$$ma = - kx$$

where k is the force constant of the spring (or springs), and x is the "stretch" of the spring or, equivalently, the displacement of the mass from its equilibrium position.

The apparatus consists of a low-friction cart attached by springs to the ends of a horizontal track. Times are measured with photogate timers. Check that the cart moves freely, the track is level, and that the photogates give consistent readings. (Do not set the photogate timer to 0.1 ms precision, the switch on the bottom of the base. It does not correctly record the integer to the left of the decimal point.)

Procedure:

Work in groups of two students to a track. Note, the empty cart has a mass of 0.5 kg and each load bar has a mass of 0.5 kg.

You will first determine the force constant for the system of springs attached to the cart.

1. Restoring force constant:

   A. Connect the cart by springs to the ends of the track. Record x_0, the equilibrium position of the cart.

   B. Apply a force to the cart by attaching a string to the cart and passing the other end over a pulley to a hanging mass of 0.050 kg. Measure the change in the cart's equilibrium position. At equilibrium the net restoring force exerted by the springs has the same magnitude as the weight of the hanging mass. Repeat in 0.050 kg steps until the spring at the pulley end of the track is relaxed, about a 0.30 m displacement.

   C. Plot net force exerted by the springs vs. cart displacement from its equilibrium position. You should see a linear relation: $F(x) = kx = mg$. Evaluate the force constant k. Use appropriate SI units.

Next, you will determine how the period of this system depends on (a) the amplitude of the oscillation, and (b) on the mass of the oscillating object.

2. Period -Amplitude relation:

   A. Remove the string and hanging mass. Line up a photogate timer at the center of the flag on the cart with the cart at its equilibrium position.

   B. Measure the period (time for one complete cycle) with three different amplitudes (release points): A=($x_{release} - x_0$)=0.10 m, 0.20 m, and 0.30 m. Set the photogate to "pendulum" mode and the precision to 1 ms (if this is an option on your timer) to avoid the display problem mentioned earlier.

   C. The theoretical value for the period is

   $$T = 2\pi\sqrt{M / k}$$

   check that this agree with all three of your results within the measurement uncertainty.

3. Period-Mass relation:

   A. Keeping the amplitude constant at 0.30 m, determine the period when the mass of the system (cart plus weight) is 0.5 kg, 1.0 kg and 1.5 kg.

   B. Repeat your period measurement three times for each mass and use the average in your plot.

   C. Plot the measured period as a function of mass. Evaluate and show on the graph the theoretical value:

   $$T = 2\pi\sqrt{M / k}$$

   Note that this is *not* a linear relationship, so do not attempt to draw a best fit line to your data.

Finally, you will show that the energy of the system is related to the amplitude of the oscillation by determining the maximum speed. Note that when the cart goes through the equilibrium position it has zero potential energy so all of the energy is kinetic. At this point, its velocity is a maximum.

4. Amplitude – maximum speed relationship.

   A. Set the photogate timer mode to "gate" and the memory switch to "on". For the same three release points as in part 2, measure the speed of the cart as it goes through the equilibrium position.

   B. Plot measured V_{max} as a function of amplitude. Add to this graph the values obtained from the simple harmonic motion model:

   $$V_{max}(A) = \omega A = \left(\sqrt{k / M}\right)A$$

Report:

In addition to the standard elements of a well written lab report described in the introduction to this manual, your report must include:

1) The data from each of the three experiments in neat, well organized tables, which include units and measurement uncertainty.
2) The three graphs; each must include a title and a statement at the bottom of the graph providing an explanation of the observations.
3) A conclusion stating how close your values for the period and the maximum velocity agree with the theoretical functions you plotted. State other sources of error not previously mentioned in your data tables.