PocketLab Voyager: Vibrating Meter Sticks and Music Boxes

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Most everyone has heard the shrill, somewhat tinny sound of a music box playing a tune after being wound up. Common during the Holiday season, they are often programmed to play carols. The most expensive music boxes are highly complex devices with a set of gears serving a variety of purposes. Regardless of price, however, the physics of the sounds produced by these music boxes is relatively straight forward and worth studying in curriculums based upon NGSS (Next Generation Science Standards).

Sound is produced when the prongs (called tines) on a metal comb are plucked by pins on a rotating cylinder, as shown in Figure 1. The longer the tine, the lower the frequency of the sound produced. From the engineering point-of-view, each of the tines is a ***cantilever***, a long projecting beam that is supported only at one end. Common examples include beams that support balconies on high rises, diving boards, airplane wings, and flagpoles mounted to the side of a building. In any case, when a music box tine is plucked, it has a tendancy to vibrate at the lowest natural frequency of a cantilever. This frequency depends upon several characteristics of the cantilever—the elastic modulus of the material, the moment of inertia about the fixed vibration point, the mass per unit length, and the length of the supported cantilever.

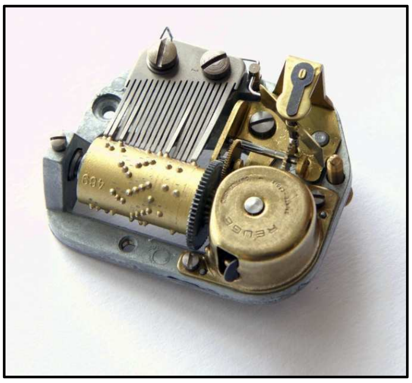

Figure 1

In this lesson, a meter stick clamped to overhang the edge of a solid table, as shown in Figure 2, serves as our cantilever or tine. Voyager is mounted to the free end of the meter stick using removable mounting squares or tape. When the meter stick's free end is "plucked", Voyager's acceleration sensor records data allowing determination of the period (or frequency) of oscillation. The data collection rate in points per second is set to the highest allowed value. Voyager's light weight makes it perfect for this experiment since its mass is relatively small compared to the mass of the meter stick. The author found that a white plastic meter stick is much better than a wood meter stick, as it is more elastic, allowing for frequencies that are within the limits of Voyager's data point rates. A long stick of balsa wood also works well, though it is comparable in mass to Voyager.

Figure 2

The purpose of this investigation is two-fold:

1. To determine the relationship between the *period* of the cantilever and the *overhanging length,* and equate this to tines in a music box.
2. To determine the relationship between the *period* of the cantilever and the *mass of a load* near its free end, and consider why such "weighting" of a music box tine is useful.

Results

Figure 3 shows a snapshot taken of combined data and video produced by the PocketLab app. The orientation of Voyager on the meter stick implies that the x-acceleration is of interest for determining the period. The z-component of angular velocity could also have been used since the meter stick cantilever is rotating about the point where it is fixed to the table with a g-clamp. However, for the small angle of the oscillations, angular velocity data is not as clean or as easy to read. Note that a blue level has been optionally placed in the background, just to show the horizontal.

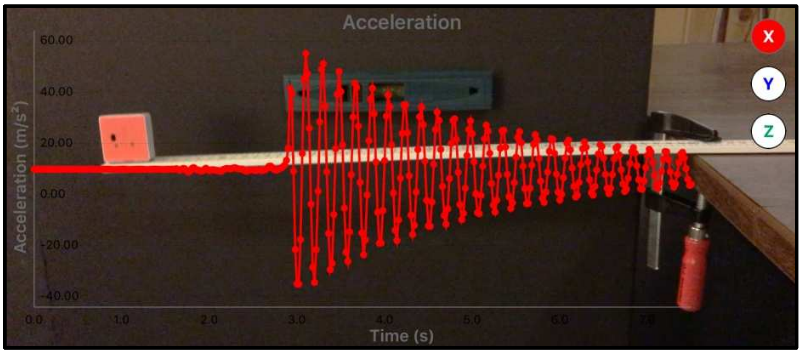

Figure 3

The amplitude of the oscillations decreases as the acceleration decreases. With analogy to a music box, this would correspond to a decrease in the sound level after a tine has been plucked. The low frequencies of a vibrating plastic meter stick are below what is generally perceived as sound by most people. A stiffer wood meter stick may be better at producing what could be considered sound, but the higher frequencies of vibration are then outside of the range of Voyager's ability for properly detection, even at the highest data point rates and especially for short lengths. If you want your students to hear sound from a cantilever and don't have access to a music box, then a 12-inch plastic ruler, such as NSTA's "Science Rules!" ruler, works well.

Period vs. Overhanging Length

Using the PocketLab app, separate runs are done for overhanging plastic meter stick lengths ranging from 90 cm down to 30 cm by increments of 10 cm. Below 30 cm, the data collection rate of 50 points per second was insufficient. As an example, Figure 4 shows an Excel chart constructed from the PocketLab app csv file for an overhanging length of 40 cm. The period was found to be 0.124 s. The primary advantage of using PocketLab rather than a stopwatch for these timings relates to accuracy—no need to worry about reaction time, human judgment, and errors in counting cycles.

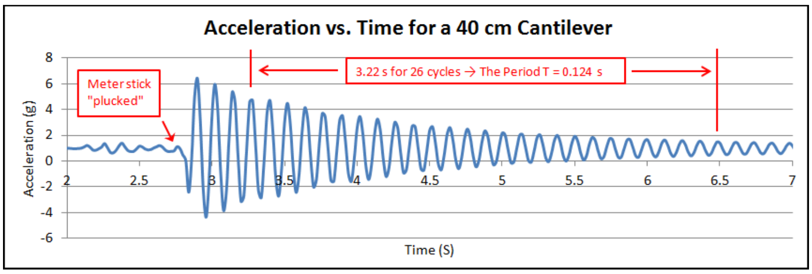

Figure 4

If you ask your students to hypothesize on the relationship between period and overhanging length prior to performing the experiment, those who have previously studied a *simple pendulum* may suggest that the period is proportional to the square root of the length. They may be surprised to find out that this is not the case for a cantilever! Figure 5 shows an Excel graph of period vs. length obtained from data collected from the PocketLab runs. A trendline with a power regression type shows that the period (y) is proportional to the cantilever length (x) to the power 1.8199. It is interesting that this power is close to 2, suggesting that the period may be proportional to the square of the cantilever length. Engineers, in fact, tell us that the period of a cantilever is proportional to the square of its length. Since f = 1/T, we then find that the *frequency is inversely proportional to the square of the length*—the shorter the length, the higher the frequency. Therefore, for a music box, shorter tines result in higher frequency sounds.

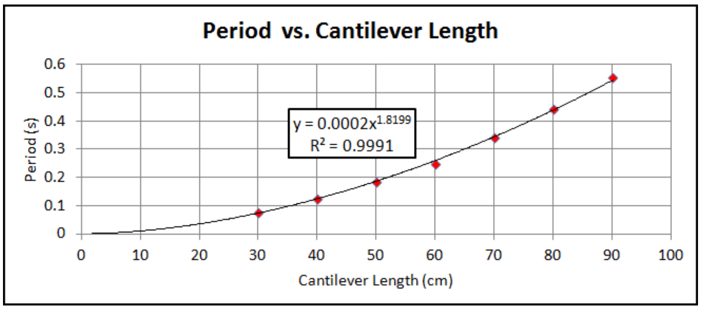

Figure 5

Period vs. Mass of Load

The author studied the effect of mass on the cantilever's period by loading the end of the cantilever with a varying number of zinc washers, as shown in Figure 6. The washers were kept in place by using removable poster tape.

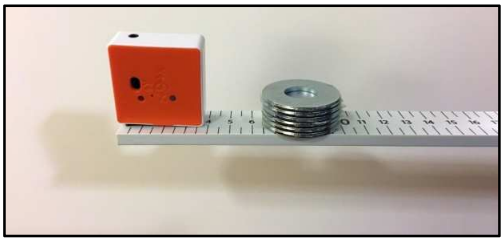

Figure 6

Figure 7 shows an Excel graph of period vs. load obtained from data collected from the PocketLab runs. With a range from 0 to 10 washers, the period seems to be roughly linear to the number of washers. The slope of the straight line of best fit is about 0.03 s/washer. Therefore, increasing the load appears to increase the period, or alternatively, decreases the frequency. Relating this fact to a music box, it means that loading the end of a tine with extra mass decreases the frequency of the sound produced. This is advantageous in the design of a music box, as it allows making the music box *smaller* since *shorter* tines could be used for low pitched sounds. In addition, the pitch of a given tine can be carefully controlled by very slight changes of the loaded mass.

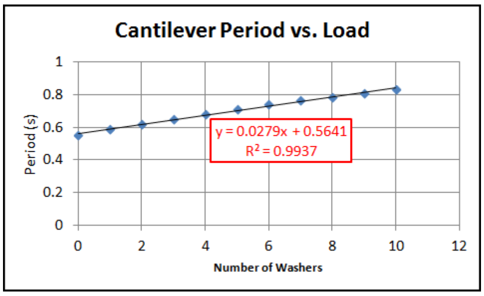

Figure 7