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Section: Phys 233 - Thursday
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Lab 3: Standing Waves

1 Purpose

This week's lab was an introduction to wave interference and standing waves. Again, the format was three separate experiments (exercises) split in to three lab stations. First, we looked at a system with two harmonic oscillators (carts connected by springs) and noticed two types of resonance modes. Second, we observed resonance in a vibrating string at each of its harmonic frequencies. Finally, we empirically determined the relationship of each component that describes the fundamental frequency of a vibrating string under tension.

2 Procedure

2.1 Exercise 1

Our station was setup with a low friction track with two carts attached together by springs driven by an oscillating hanging mass. Using a function generator, we were able to control the frequency of the hanging mass which in turn changed the frequency of the two carts. Our task was to estimate the two fundamental frequencies of the system, each describing a mode of motion.

2.2 Exercise 2

Here we had a piece of string under tension which could be vibrated via a driver at frequencies controlled by a function generator. Under these conditions, and knowing the fact that $f_n = nf_1$, we experimentally discovered the first six resonant frequencies, comparing them to the theoretical values aforementioned.

2.3 Exercise 3

At this station, our setup was very similar to exercise two, although we had much more control of the variables of the string. Using a notched lever we were able to adjust the tension force, T, on the string, by swapping out thicker/thinner wires, we could adjust the density, μ, and by moving the bridges we adjusted the length, l. Within this exercise were three tasks, one for each parameter. In each case, we held all parameters constant except one, and determined the fundamental frequency in each one. In this we were could describe the relationship between said variable and fundamental frequency.

3 Data

3.1 Exercise 1

The first mode , f_1, was found to have a period of about 2.3 $\pm$ 0.05 seconds which is equal to 0.43 Hz. To minimize error, we changed the amplitude of the oscillation by adjusting the moment arm on the oscillating hanging mass.

For f_2, the second mode, we found the period to be 1.36 $\pm$ 0.05 seconds, equal to a frequency of 0.74 Hz.

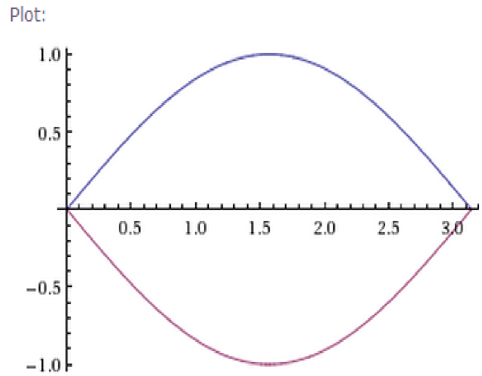
Finally, for the situation where only one cart is allowed to move, we measured a period of 1.75 $\pm$ 0.05 seconds, giving $f_0 = 0.57$ Hz.

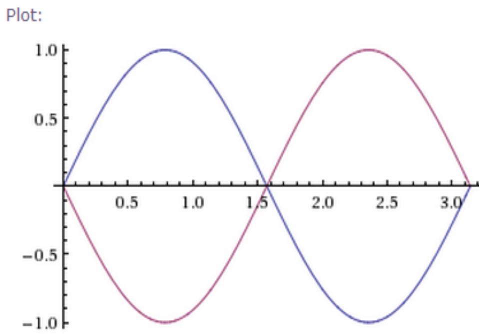
3.2 Exercise 2

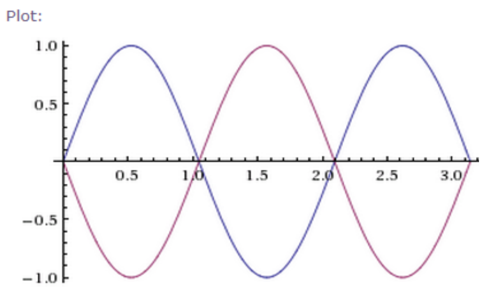
Here are the frequencies of the fundamental frequency and following 5 harmonics for the string. Note the following values have an error of about $\pm$ 0.5 Hz.

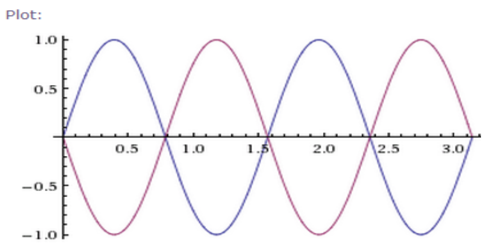
$f_1 = 24$ Hz
$f_2 = 47.9$ Hz
$f_3 = 72.9$ Hz
$f_4 = 95.5$ Hz
$f_5 = 118.5$ Hz
$f_6 = 142.5$ Hz

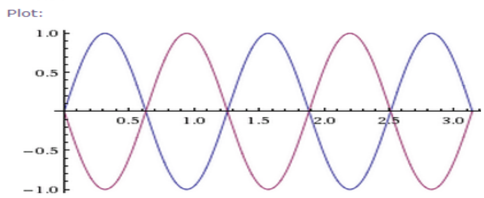
The following graphs describe the shape of each harmonic frequency in the same order as listed above (notice the decrease in amplitude.)

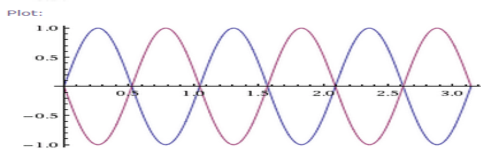












3.3 Exercise 3

The next three tables hold the data from the three sub-exercises of exercise 3. Note that l is length of the string, T is the tension, μ is the mass density of the string, and f is the measured value of the fundamental frequency for that particular setup. Also note that our frequencies have an error of about ± 0.5 Hz

l	T	μ	f
60cm	4Mg	μ_0	237.6 Hz
50cm	4Mg	μ_0	278.2 Hz
40cm	4Mg	μ_0	347.4 Hz
30cm	4Mg	μ_0	453.8 Hz

l	T	μ	f
60cm	4Mg	μ_0	237.6 Hz
60cm	3Mg	μ_0	196.0 Hz
60cm	2Mg	μ_0	160.6 Hz
60cm	1Mg	μ_0	112.6 Hz

l	T	μ	f
60cm	4Mg	μ_0	237.6 Hz
60cm	4Mg	$1.5 * 10^{-2}$	201.8 Hz
60cm	4Mg	$1.84 * 10^{-2}$	185.6 Hz

4 Analysis

4.1 Exercise 1

After measuring the fundamental frequency of each of the three modes in this system: carts moving together (f_1), carts moving opposite (f_2), and only one cart moving (f_0), we were asked to compare these to the theoretically predicted values using the expressions:

$f_0 = \frac{1}{2\pi}\sqrt{\frac{2K}{m}}$ $f_1 = \frac{1}{2\pi}\sqrt{\frac{K}{m}}$ $f_2 = \frac{1}{2\pi}\sqrt{\frac{3K}{m}}$

Using our experimental value for f_0, which was 0.57 Hz, we can solve for $K/M = 6.45$. Using this in the other expressions yields:

$f_1 = 0.4$ Hz
$f_2 = 0.7$ Hz.

Both of these values lie within 0.05 Hz of our experimentally found versions. Timing the period of an oscillation is tricky to do by eye with a stop watch, which most likely accounted for the majority of the error in our approximations. Also, it's possible friction played a role as well.

4.2 Exercise 2

In this exercise, we simply measured the fundamental frequency of the oscillating string as well as the next five harmonics. Assuming our measurement of the fundamental frequency was mostly accurate, the expression $f_n = nf_1$ should provide values roughly equal to our measurements for the following harmonics:

f_n	experimental	theoretical (nf_1)
f_1	24 Hz	24 Hz
f_2	47.9 Hz	48 Hz
f_3	72.9 Hz	72 Hz
f_4	95.5 Hz	96 Hz
f_5	118.5 Hz	120 Hz
f_6	142.5 Hz	142 Hz

As we can see above, our experimental values of the harmonics match up quite well with the theoretically expected ones (within 1 Hz in the worst case).

4.3 Exercise 3

Using the expression $\frac{1}{2l}\sqrt{\frac{T}{\mu}}$ we found the theoretical values for each set of parameters in this exercise. Rather than list out all of the parameters here, the table will simply consist of our measured frequency and theoretical value associated with it.

f experimental	f theoretical
237.6 Hz	220.592 Hz
278.2 Hz	264.71 Hz
347.4 Hz	330.888 Hz
453.8 Hz	441.183 Hz
196.0 Hz	191.038 Hz
160.6 Hz	155.982 Hz
112.6 Hz	110.296 Hz
201.8 Hz	190.613 Hz
185.6 Hz	172.103 Hz

So, while our experimental values don't match up perfectly, there was a lot of room for error in this experiment. With so many variables, the actual values are not likely to match up perfectly. More importantly, though, the trends are the same. In this first case, the fundamental frequency was inversely proportional to the length l. Secondly, it was directly proportional to the square root of the tension force. Finally, it was inversely proportional to the square root of the mass density.

5 Conclusion

By completing the exercises of this lab in order, we were first introduced to the fundamental frequency by observing different modes of an oscillating system. Next we measured this fundamental frequency and its harmonics in a vibrating string. Finally, in exercise three, we are able to make very general observations about the relationships between the fundamental frequencies and parameters of an oscillating system (these were noted at the end of the analysis section.)