DW16: Standing Waves on a String

Objective:

- Demonstrate properties of standing waves, including the concept of a resonance frequency and the medium dependence of wave speed.
- Demonstrate the idea of sampling, and how this impacts the information we obtain.

Apparatus:

- PASCO Sine Wave Generator (WA-9867, https://bit.ly/47diep8, Manual on OneDrive)
- PASCO String Vibrator (WA-9857A, https://bit.ly/3XqA5FG, Manual on OneDrive)
- PASCO Strobe (ME-6982, https://bit.ly/4cMsN3w, Manual on OneDrive)
- Elastic String
- Two leads
- Hanging masses (entire set)
- Two rings stands (that clamp to the table)
- Pulley (e.g., the ones from ST2)

Method

The setup is shown in the images below. Attach the string vibrator to a ring stand, approximately 1.3 m from the end of the bench. Attach the pulley to another ring stand at the end of the bench. Tie the elastic string to the string vibrator, and run it over the pulley, with the end hanging off of the bench. Hang two, 200 g masses to the end of the string to set the tension. Connect the leads from the string vibrator to the sine wave generator. Plug in the strobe to be used later in the demo.

Figure 1: Full setup

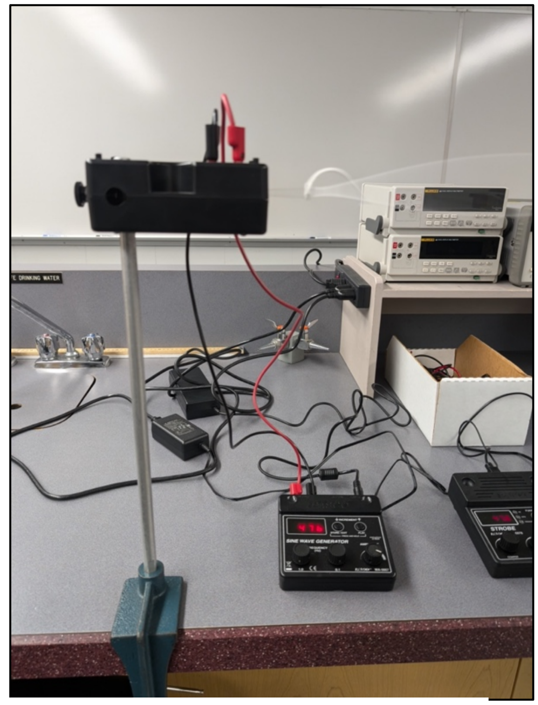

Figure 2: String vibrator connected.

Figure 3: Mass and pulley connected.

To operate the demo:

- Adjust the frequency of the sine wave generator to obtain standing waves. Once the fundamental frequency is found, the frequency can easily be increased to find higher order modes. The string length and tension can be adjusted as well, if needed. See the notes below for some recommended settings.
- By turning of the light and illuminating the string with the strobe light, it is possible to freeze the string. Matching the vibration frequency of the sine wave generator will freeze a single pattern. Making slight adjustments to the strobe frequency will lead to "slow" oscillations. If the strobe frequency is set to twice (three times, four times etc.) the resonance frequency, two (three, four etc.) patterns will be seen simultaneously. See the images below.

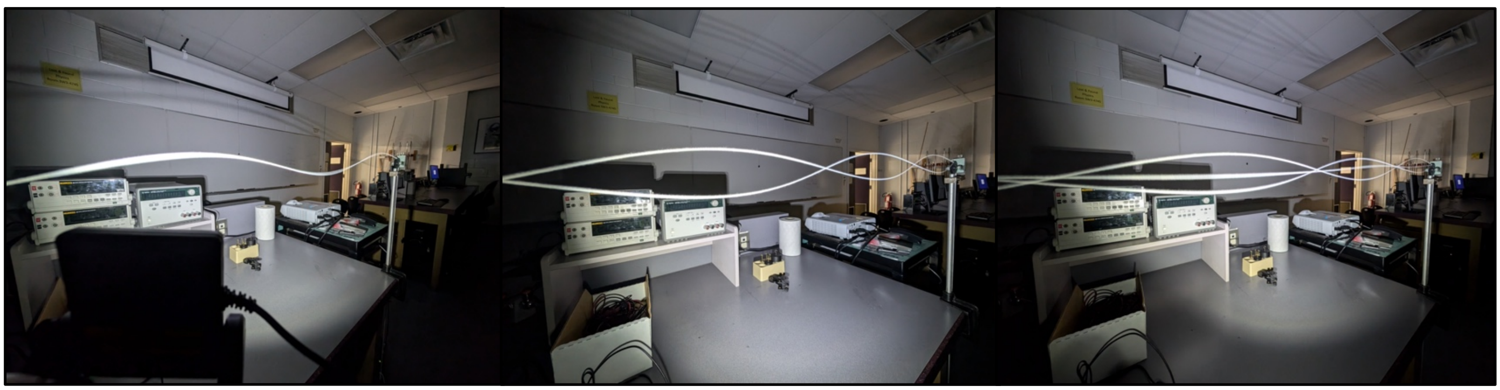

Figure 4: The frequency of the n = 4 mode in this configuration was 47.2 Hz. From left to right the strobe frequencies are set to 47.2 Hz, 95.2 Hz and 142.8 Hz, corresponding to the f_4, $2f_4$ and $3f_4$ respectively. Note that not all antinodes are shown due to the camera angle, but there were four antinodes in this configuration. We can see the effect of sampling at one, two and three times per cycle. Note that the string actually does appear static when viewed live, just like in these photos.

Notes

- There are many adjustments that can be made to tune the resonance frequency, the wavespeed is given by $v = \sqrt{T/\mu}$, and can therefore be adjusted by using a string with different linear mass density, or by adjusting the hanging mass to control the tension. The harmonics are given by $f = \frac{nv}{2L}$, and therefore they can further be adjusted by controlling the length of the string between the two end nodes.
- A nice configuration for the white elastic PASCO strings is
    - String length = 1.30 m (pulley to string vibrator)
    - Hanging mass = 400 g
    - With this setup, the fundamental frequency is approximately 11.6 Hz, and the n = 4 mode is at approximately 47.6 Hz.

- Benefits of this range for a setup:
    - When the frequency of the sine wave generator is too low, e.g. < 15 Hz, the string vibrator tends to have large oscillations and does not act as a good node.
    - If the frequency is too high, the amplitude of the antinodes will be too small.
    - 4 – 6 antinodes tends to look the best, e.g., it is a good balance between several antinodes while still having a large amplitude.
    - A frequency of > ~40 Hz will mean the strobe frequency is too high to be seen directly, and it is therefore easier on the eyes when the strobe is on.
- More elastic strings work best since they can produce a larger amplitude to better see the antinodes.
- It is nice to have the wave high above the table so that it is easy for students to see.

String Details

- The thin black strings we use for some other labs have a measured $\mu = 4.72 \times 10^{-4}\ \mathrm{kg/m}$. With a hanging mass of 100 g, the wave speed is therefore $v = \sqrt{T/\mu} = \sqrt{(1.96\ \mathrm{N})/(4.72 \times 10^{-4}\ \mathrm{kg/m})} = 64.4\ \mathrm{m/s}$. The harmonics can be calculated as $f = \frac{nv}{2L}$. Resonance frequencies up to the 12th harmonic can be measured and agree well with the calculation. At low frequencies the string vibrator tends to be a "bad node", i.e., the string vibrator moves and is not an actual node. This tends to make direct measurements of the fundamental frequency difficult.
- The white elastic string that ships from Pasco has $\mu = 3.84 \times 10^{-3}\ \mathrm{kg/m}$. With a hanging mass of 100 g, the wave speed is therefore $v = \sqrt{T/\mu} = \sqrt{(1.96\ \mathrm{N})(3.84 \times 10^{-3}\ \mathrm{kg/m})} = 22.6\ \mathrm{m/s}$. The harmonics can be calculated as $f = \frac{nv}{2L}$. Resonance frequencies up to the 18th harmonic can be measured and agree well with the calculation. At various frequencies the string vibrator tends to be a "bad node", i.e., the string vibrator moves and is not an actual node. This tends to make measurements at low frequencies. The issue can be partially resolved by reducing the amplitude.