Physics 221 Lab #2: Standing Waves & Resonance

The picture above is the Tacoma Narrows Bridge shortly before it collapsed. A moderate wind initially excited small ripples that grew into violent oscillations. Eventually, these tore the bridge apart. This was a spectacular case of resonance.

Objectives

1. To observe the phenomenon of resonance and standing waves on strings and for sound waves.
2. To understand how the wave properties of speed, wavelength, and frequency are related.
3. To experimentally determine the speed of sound in air.

Overview

The speed of a traveling wave is the rate at which a crest travels. It is related to its frequency and wavelength by $v = f\lambda$. This speed depends on the medium in which the wave is traveling.

The theoretical value for the speed of a wave transmitted along a string is $v = \sqrt{\frac{T}{m/L}}$, where $T$ is the tension and $(m/L)$ is its mass per length.
The speed of sound in air depends most strongly on the temperature. Factors such as changes in humidity don’t affect it as much. If the temperature is measured in Kelvin, the theoretical value of the speed of sound in a gas is\[ v = \sqrt{\frac{\gamma k T}{m}} \], where \( k = 1.38 \times 10^{-23} \text{ J/K} \) and \( m \) is the mass of a gas molecule. Air is mostly diatomic molecules, so \( \gamma = c_p/c_v = 7/5 \).

A standing wave is when the wave crests don’t appear to travel along the medium (string, or air). Instead, points of no displacement, a.k.a. nodes, stay put and the crests, a.k.a. antinodes, oscillate between maximum and minimum. A simple example is people swinging a jump rope: the ends in the people’s hands hardly go anywhere (nodes) while the rope in the middle swings around (antinode). Standing waves occur when the right number of wavelengths “fit” into the available length of medium. For sound waves in a pipe, a closed end will be a node of displacement (the air can’t be pushed through the pipe’s capped end.) and an open end will be an antinode. When the conditions for a standing wave are met, there will be a resonance and the amplitude of the wave will become large. For sound waves this means a louder sound.

**PART ONE: Waves on a String**

1. The setup of the string and driver will be similar to that pictured below. The length of the string between the post and pulley should be about 0.5 meter. Set the function generator to produce a sinusoidal wave. Its output signal should go into one of the amplifier’s inputs, then the cables connecting to the string’s ends should go into one of the amplifier’s outputs. Be sure that the amplifier’s input selector (Tuner, CD, or Phono) is set to the input you plugged the Function Generator into.
2. Hang a mass in the range of 1 to 4 kg on the end of the string and start with a low frequency. Gradually increase the frequency until the string starts to oscillate strongly. You should increase and decrease the frequency to find the value that gives the largest amplitude. Note: if you are having difficulty finding the first resonance frequency, one approach is to tune by ear – hook a speaker up to the function generator and compare the tone it makes to the tone the string makes when you pluck it. Adjust the function generator’s frequency until the two are very similar – this will at least get you in the right ball-park.

3. Find four resonances and measure the distances between consecutive nodes (points where the string is stationary) to fill in the first two columns below. Also draw the shape of each standing wave below

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>Distance between nodes (m)</th>
<th>Wavelength (m)</th>
<th>Speed of wave (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1

2

3

4
4. Fill-in the table above by measuring the wavelength for each standing wave and using that and the frequency to calculate the wave speed. Show your first calculation.

5. Take the average of the speeds that you have found.

\[ v_{\text{avg}} = \text{___________ m/s} \]

6. Determine the mass per unit length of the string. You will note a small colored ring at one end of the string. Mass densities are correlated to the ring colors as follows:

<table>
<thead>
<tr>
<th>Color</th>
<th>m/L  (kg/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gold</td>
<td>$4.8 \times 10^{-3}$</td>
</tr>
<tr>
<td>Red</td>
<td>$3.1 \times 10^{-3}$</td>
</tr>
<tr>
<td>Purple</td>
<td>$3.8 \times 10^{-4}$</td>
</tr>
<tr>
<td>Black</td>
<td>$1.4 \times 10^{-3}$</td>
</tr>
<tr>
<td>Green</td>
<td>$9.0 \times 10^{-4}$</td>
</tr>
<tr>
<td>Silver</td>
<td>$2.5 \times 10^{-4}$</td>
</tr>
</tbody>
</table>

Record the value appropriate for your string:

\[ m/L = \text{___________ kg/m} \]

**Question:** How does the average measured speed compare to the theoretically predicted value? Show your work.
PART TWO: Sound Waves

1. The apparatus you will use is pictured to the right. Slide the reservoir as high up as it will go. Slowly fill the reservoir until the glass tube is nearly full (within about 10 cm). Be sure that there are no kinks in the rubber tubing. The water level in the glass tube can be adjusted by raising or lowering the supply tank. This allows you to vary the length of the column of air & thus the resonant wavelengths.

2. Position the speaker over the glass tube and connect it to the function generator. Make sure the function generator is set to produce a sinusoidal wave. Set the frequency between 500 and 1000 Hz and turn the speaker on at a low volume. Record the frequency selected below.

   \[ f = \text{___________ 1/s} \]

3. Before proceeding, use \( v_{\text{sound}} \sim 343 \text{ m/s} \) to calculate approximately what wavelength you expect to find and what \( \frac{1}{4} \) of that is (the column height where you expect resonance).

   \[ \lambda/4_{\text{expected}} \sim \text{_______________ m} \]

4. Keeping the frequency constant, slowly lower the water level until the first resonance is reached and the sound becomes much louder. Determine the position of the resonance by slightly raising and lowering the water level until you are sure that the sound is at maximum intensity.

5. **Warnings:** It is easy to overshoot the first resonance and find the second instead – you should find it near your expected value. Also, if the speaker is particularly beaten-up, it will produce higher harmonics of your chosen frequency & the tube can resonate to those too (you’ll hear a higher note emerge if that is the case).

6. Repeat the above procedure for the entire length of the glass tube and enter the results in the first column of the table below. Be careful to increase the length of the air column so
that you don’t miss a resonance! (Note: at some point, you’ll need to pour out some water.)

<table>
<thead>
<tr>
<th>length of air column (m)</th>
<th>Number of wavelengths ($\lambda$) in column</th>
<th>Wavelength (m)</th>
<th>speed of wave (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1/4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

7. Sketch the water level and the standing waves for the displacement of the air for each of the resonances. (The first one is done for you.) In the table above, enter the number of wavelengths or fractions of wavelengths are in each standing wave. (The first one is done for you.)

8. For each standing wave, calculate the wavelength and use that to find the speed of the sound wave and enter it in the table above. Show your first calculation below.

9. Take the average of all of your measurements for the speed of sound.

$$v_{avg} = \text{__________ m/s}$$
10. Measure the temperature of the room in Celsius.

\[ T_C = \text{__________} ^\circ C \]

**Question:** How does your experimental measurement of the speed of sound compare with the theoretical value? Show your work. The average mass of a molecule in air is \( 4.799 \times 10^{-26} \text{ kg} \). Give me a percent difference.