Lab 3

Standing Waves on a String

Experimental Objectives

In this experiment, the conditions required for the production of standing waves in a string will be investigated in order to

- empirically verify the relationship between the frequency (f), wavelength (λ), and speed of a standing wave (v), for a series of normal modes of oscillation, and
- use the two relationships of the speed of the wave

$$v = \sqrt{\frac{F_T}{m/L}} \tag{3.1}$$

$$v = \lambda f \tag{3.2}$$

  to empirically relate the string tension (F_T) and the wave velocity (v), for one mode of oscillation, specifically the fundamental mode.

A wave is the propagation of a disturbance in a medium. In a transverse wave, the disturbance of the medium is perpendicular to the direction of the propagation of the wave. In this experiment, transverse waves will be propagated along a taut flexible string. The frequency of the waves is determined by the source, the wave generator, which is driving one end of the string. The speed of the waves, v, is determined by the medium itself; namely the linear mass density of the string, (m/L), and the tension in the string which is determined by the static force of a mass suspended from the other end of the string, F_T. This is expressed by Equation (3.1) above.

Upon hitting at the fixed end of the string, the transverse waves will reflect back along the string. If the end of the string is rigidly held then the reflected waves will be inverted 180°. The initial propagated waves and the reflected waves will interfere constructively and destructively. At particular string tensions and/or wave frequencies, this wave superposition will give rise to waves called standing waves or stationary waves. There are many different standing waves patterns (normal modes) possible which have different wavelengths. The different modes are characterized by the number of nodes or antinodes in the wave. At one of the normal modes of oscillation, the amplitude of oscillation can become rather large, much larger than the amplitude of the original propagated wave. This phenomenon is called resonance. In this experiment, each end of the string will be close to a node position. The fundamental frequency (mode n=1) exhibits a wave pattern with one antinode. The second harmonic (mode n=2) exhibits a wave pattern with two antinodes, and so forth.

3.1 Pre-Lab Work

- Define the following terms: **standing wave**, **node**, and **antinode**.

- Draw a set of pictures of a standing wave on a string with two fixed ends showing the fundamental frequency ($n = 1$), and the harmonics $n = 2, 3, 4$, and 5. Label a wavelength, the nodes, and the antinodes on each picture.
- Given Equation (3.1), predict what will happen to the velocity of the wave as the static hanging mass (providing the tension) increases, decreases, or stays the same.
- Given Equation (3.2), how can measurements of λ and f be plotted to determine the wave velocity from the graph? (There is more than one way to do this; one way in particular produces a line.) How should the axes of the graph be labeled? Explain your reasoning.

3.2 Fixed Tension

In order to verify Equation (3.2), you can fix F_T and compare multiple f to the corresponding λ.

3.2.1 Procedure

- If you have not already done so, measure the mass and length of the string in order to calculate the linear mass density (m/L). You might note Question 3.4.3.
- A mechanical vibrator, driven with a (variable frequency) function generator, will be the wave source. Use a string slightly greater than the length of the table. Connect one end of the string to a post such that the vibrator can wiggle the string near that end. Hang the other end over a pulley. Keeping the string horizontal by adjusting the height of the pulley and the location of connection at the other end. The height of the vibrator will determine the height you need the ends to be.
- Set up the system with some particular string tension (like 450 grams). This tension will be kept constant for this entire part.
- Produce 5 different normal modes by changing the frequency of the vibrator. Adjust the standing wave amplitude until it is at its maximum. Record the corresponding frequency for each normal mode.
- Measure the corresponding wavelengths for each normal mode, directly from the string with a meter stick. The vibrator end of the string is not a true node because the string is vibrating a small amount. Take this into account when measuring the wavelengths.
- Try touching the string at a node and at an antinode. What happens to the wave in each case?
- Optional: Try measuring the frequency of the vibrator with a strobe lamp.

3.2.2 Analysis

- Determine the mathematical relation between the wavelength of the standing wave and the frequency of the vibrator that will produce a straight line ($y = mx + b$) when graphed.
- Comment on the significance (and units) of the slope and intercept of this graph. Determine both the precision and the accuracy of the slope and of the intercept; are they consistent with what you expect? (Your expectation should be based on the "other" equation which we are not testing here.)
- Use one or both of these (slope and intercept) to determine the velocity (with uncertainty) of the standing wave. Relate this (%-error) to the expected value based on the tension you chose for your specific string.

3.3 Fixed Wavelength

In order to verify Equation (3.1), you can fix λ and compare multiple F_T to the corresponding v.

3.3.1 Procedure

- If you have not already done so, measure the mass and length of the string in order to calculate the linear mass density (m/L). You might note Question 3.4.3.
- A mechanical vibrator, driven with a (variable frequency) function generator, will be the wave source. Use a string slightly greater than the length of the table. Connect one end of the string to a post such that the vibrator can wiggle the string near that end. Hang the other end over a pulley. Keeping the string horizontal by adjusting the height of the pulley and the location of connection at the other end. The height of the vibrator will determine the height you need the ends to be.
- Place 150 grams (including the hanger) on the end of the string. (If you start with too little mass, the string stretches different amounts — changing the string's effective density — during the experiment, causing unaccounted for curving in the graph.)
- Adjust the frequency of the generator until the $n = 2$ mode is observed and is at its maximum amplitude. Record the frequency and corresponding wave velocity.
- Repeat the previous step for 6 hanging masses up to about 1200 grams.

3.3.2 Analysis

- Determine the mathematical relation between the hanging mass (F_T) and the wave velocity (v) that will produce a straight line ($y = mx + b$) when graphed.
- Determine which variables the slope and intercept of this graph should be related to. Determine both the precision and the accuracy of the slope and of the intercept; are they consistent with what you expect? (The equation we are testing should imply what to expect.)

3.4 Questions

1. What are the necessary and sufficient conditions for the production of standing waves?

2. Is it valid to consider the tightening of the string to be the same as a change of medium? (Does tightening the string change the way waves move or the way standing waves are produced on the string?) Why or why not?

3. When you measure the length of string, remember that the string will be under tension (pulled on) and may have some "give" to it. It may be possible for it to stretch by nearly 10%. If you don't account for this (if you measure the unstretched length) will your value of density be incorrect too large or incorrect too small? Can you account for this either in the value of the length or in the uncertainty of the length. Will this affect comparison to either of your graphs?

4. Consider the Fixed Tension graph. We noted that the vibrator end of the string should not be considered to be a node. This means that the node might be a little in front of the post or a little behind the post and therefore your wavelength values might be a little wrong, but your error bars should already include the amount the values could be off. Based on the error bars on your Fixed Tension graph, would shifting the wavelength data a little larger or a little smaller have made a difference to the values of slope or intercept that you calculated? If so, would it have increased the value or decreased the value? If not, why not?

5. If the tension and the linear density of the string remain constant, but the pulley is shifted further from the post (so that the region which is vibrating lengthens), how is the resonant wavelength affected? How is the velocity of the wave affected?

6. What was the experimental velocity (and uncertainty) of the waves in part I of the experiment?

7. What will happen to the velocity of the wave if the tension is fixed but the frequency is changed.

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A PDF version might be found at standingwaves.pdf (103 kB)