Standing Waves on a String

Objectives

Measure the frequency, wavelength, and speed of standing waves on a string. Examine how string mass, tension, and length affect the resonant frequency.

Apparatus

Light and heavy strings, masses, pulley, function generator, amplifier, loudspeaker, 2meter stick, strobe light.

Introduction

Vibrating strings have been used throughout the world, for thousands of years, to produce sound waves, or music. Familiar examples include the violin, piano, ukulele, zither, and harp. In this lab you will investigate some of the basic phenomena common to all stringed instruments.

When a string under tension is disturbed by a source (for example plucking the string, or stroking it with a bow), a complicated wave train is produced which travels along the string away from the source. When the wave reaches the end of the string it is reflected and travels toward the other end of the string where it can be reflected again, and so on. The reflected waves can interfere with new waves coming from the source in a complicated way and in general, no regular wave pattern appears on the string. However, for certain frequencies, which depend on the wave speed and string length, the reflected wave will be *in phase* with new waves from the source. In this case we get a *resonance* known as a *standing wave*. When we are at a resonant frequency, the wave amplitude grows much larger than it would be for just a single wave, and the pattern seen on the string is very regular.

Standing waves are produced any time two sinusoidal waves of the same amplitude and frequency travel through a medium in opposite directions. The waves traveling in opposite directions always interfere constructively at certain places (called *antinodes*), and destructively at other places (called *nodes*). If we are dealing with *transverse* waves on a string, then at the antinodes the string moves back and forth at right angles to the direction of wave propagation. At the nodes the string does not move. The resulting pattern on the string looks like a wave, but no motion along the length of the string is apparent, hence the name standing waves. The nodes and antinodes of a standing wave are evenly spaced along the string. An analysis of the interference of two waves traveling in opposite directions shows that the distance between a node and an adjacent antinode is 1/4 of a wavelength.

Equipment

In this experiment we will produce standing waves on a string clamped at one end and pulled over a pulley and attached to a hanging mass at the other end, as shown in the photos below. The wave source consists of a modified loudspeaker connected to a function generator and power amplifier, similar to the equipment you used last week in the Resonance lab. The output of the frequency generator is connected to an oscilloscope as well as to the amplifier. A rod attached to the loudspeaker presses against the string, and as the speaker moves back and forth it produces a periodic wave disturbance on the string.



Procedure

A. Qualitative observations of standing waves.

1. Turn on the function generator. Adjust the amplitude control on the function generator to about 1/8 - 1/4 of maximum. You can adjust this setting later if you want more or less amplitude, but do not exceed 1/2 maximum, or you might blow out the speaker.

Check that the 100 button is pushed in "Range" area on the function generator. Start with the frequency dial set at about 0.02 (2 Hz since the x100 button is pushed in). Slowly increase the frequency of the function generator. At low frequencies you will not hear any sound coming from the loudspeaker, but if you look at the string or gently touch it near the speaker you should be able to tell that it is vibrating. At certain frequencies you should see standing waves develop. Continue increasing the frequency up to a maximum of 200 Hz (2.0 on the dial). Notice how the standing waves change as the frequency increases. *Briefly* record your observations, but do not make any measurements yet.

- B. Quantitative observations-the harmonic series.
- 1. Adjust the frequency of the function generator so that the string vibrates with as large an amplitude as possible in the simplest, or *fundamental* mode the standing wave of lowest frequency. (This mode is also called the *first harmonic*). Sketch the vibration pattern of the string. Measure the distance between the two nodes of the standing wave. Note: the "speaker node" is not very well defined. Do the best you can; it may be reasonable to have a fairly generous uncertainty in λ for the fundamental mode. Record the wavelength with uncertainty.
- 2. Now record the frequency of the wave from the scope. Detune the frequency and then refind the frequency where the standing wave amplitude is a maximum. Record the new frequency. Repeat this procedure several times in order to get a measure of δf.
- 3. From the frequency and wavelength data, find the wave speed with uncertainty.
- 4. Tune the function generator to produce the second harmonic (or first *overtone*). Determine λ, using the node at the pulley end and the node in the middle of the string. Estimate δλ. Determine f and δf as you did before. Include a sketch of the pattern on the string. Calculate the wave speed with uncertainty.

- 5. Continue the process! Determine the frequency, wavelength, and speed of the third, fourth, fifth, and sixth harmonics. With every wave, think carefully about the most precise way to measure λ .
- 6. Write a summary of your findings, describing how frequency, wavelength and speed depend upon harmonic number.
- 7. Find the average, standard deviation, and standard error of your six wave speeds. Write the speed in standard form, using the standard error as the uncertainty.
- 8. You are provided with a spare piece of the same string. Measure its mass and length (with

uncertainties, of course!). The wave speed is given by the formula $v = \sqrt{\frac{T}{\mu}}$, where T is the

tension in the string and μ is the mass per unit length. Calculate $v \pm \delta v$, making use of the appropriate error propagation rules. Does your calculation agree with your measurement (step 7), or do you see evidence of a systematic error? Explain.

C. Playing a guitar (or any stringed instrument).

For this section just make <u>qualitative</u> observations. Explain each observation in terms of the equations $v = f\lambda$ and $v = \sqrt{T/\mu}$.

- 1. TUNING: When playing a stringed instrument the first thing a musician usually does is tune the strings so that the fundamental mode of each string is at the desired frequency. This is done by adjusting the string tension. To see how tension affects the frequency of the fundamental mode, start with the string vibrating in the fundamental mode. Increase the mass on the end of the string by 500 g. Do you have to increase or decrease the frequency to make the string again vibrate with maximum amplitude?
- 2. PLAYING: To play a guitar, a musician produces different notes by pressing down on the strings at particular locations. This effectively shortens the length of the vibrating string. Hold the string about 30 40 cm from the pulley end. Do you have to increase or decrease the frequency to make the string again vibrate with maximum amplitude?
- 3. CHANGING STRINGS: Not all strings on a guitar are the same. Some are thin with a small mass per unit length and some are thick with a larger mass per unit length. This is done to provide a greater range of notes than would be possible with just one string thickness. Replace the string you have been using with the lighter one. Hang 1000 g on the end of the string. Adjust the function generator to obtain the fundamental mode. How does the frequency compare to the frequency of the fundamental mode of the heavier string?
- D. Making a standing wave stand still.

For this section a strobe light is required.

1. Put the heavier string back in place. Tune the function generator to produce the third harmonic. Using your previously measured frequency, calculate the frequency of the wave in *oscillations per minute*, since this is the frequency unit used by the strobe light.

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2. Set the frequency of the strobe light to match that of the standing wave. Make slight adjustments to the frequency until the string appears to stand almost completely still. Sketch what you observe, paying particular attention to how the string in one section of the standing wave is related to the string in an adjacent section. Explain why the strobe makes the string appear to stand still.