STANDING WAVES IN STRINGS

The purpose of this experiment is to illustrate the general appearance of waves by means of standing waves in a string and to investigate the behavior of standing waves. This type of wave is very important because many of the vibrations of bodies, such as the prongs of a tuning fork or the strings of a piano, are standing waves. You will also study the relation between stretching forces and wavelength in a vibrating string and determine the frequency of a string vibrator by means of standing waves.

THEORY:

Standing waves, or stationary waves, are produced by the superposition, and subsequent interference, of two wave trains of the same wavelength, velocity, and amplitude traveling in opposite directions through the same medium. The necessary conditions for the production of standing waves can be met in the case of a stretched string by having a train of waves, set up by some vibrating object, reflected at the end of the string and then interfere with the oncoming waves.

A stretched string has many normal modes of vibration. It may vibrate as a single segment; then its length is equal to one-half the wavelength of the vibrations produced. It may also vibrate in two segments with a node at each end and one in the middle; then the wavelength of the vibrations produced is equal to the length of the string. It may also vibrate in many segments. In every case the length of the string is some whole number of half wavelengths.

When standing waves are produced, a condition of resonance exists between the vibrating body and the string, that is, the frequency of vibration of the body is the same as the frequency of that particular normal mode of vibration of the string. Corresponding to this frequency, there is a particular wavelength λ (Greek letter lambda) such that $V = \lambda f$, where f is the frequency and V is the speed of the wave in the string. This velocity is given by

$$V = \sqrt{T/\mu} \qquad \textbf{(1)}$$

where T is the tension in newtons and μ is the mass per unit length of the string in kg/m. If the tension is varied while the driving frequency remains the same, there will be a change in the velocity of the wave, and hence in the wavelength; thus a different mode of vibration can be produced. The relationship between the wavelength of a standing wave and the tension in the string is

$$\lambda = \frac{\sqrt{T/\mu}}{f} \qquad \textbf{(2)}$$

In this experiment standing waves are set up in a stretched string by the vibrations of an electrically-driven string vibrator operated by a 60 Hz alternating current. Since the blade of the vibrator is attracted toward the pole face once during each half cycle, its frequency will be double that of the supply current or 120 Hz. The tension in the string is provided by the weight of masses suspended over a pulley by means of a hanger and is altered by changing these masses. Since the distance between consecutive nodes ($d = l/n$, l is the length of the string and n is the number of segments) is equal to a half wavelength, the equation for experimentally calculating the frequency of vibration becomes

$$f = \frac{1}{2d}\sqrt{T/\mu} \qquad \textbf{(3)}$$

These relations between the wavelength, the tension, and the length of the vibrating segment apply to each mode of vibrating segment corresponding to a particular tension.

APPARATUS:

Electrically driven string vibrator	Meter stick	String
Source of 120 V, 60 Hz AC electricity	Pulley	
Set of slotted masses and hanger	Balance	

PROCEDURE:

1. Measure the length of the piece of string provided by your instructor. (Obviously the string should be the same type used in the experiment and should have no knots.) Measure the mass of the string. **NOTE: All groups in the lab use the same piece of string.**

2. Suspend the string attached to the vibrator over the pulley, which is mounted in a clamp about a meter away, and attach the mass hanger to it.

3. Connect the vibrator to a power outlet. Vary the tension by adding or removing masses on the hanger until the string vibrates in four segments. Adjust the tension using small masses until the amplitude of the segments is maximized. Measure the distance from the point where the string is attached to the vibrator to the point directly over the center of the pulley. Record this length of the vibrating string (l), the number of segments, and the hanging mass.

4. Take a series of measurements with different tensions, so adjusted as to make the string vibrate in 2, 3, 4, 5, 6, 7, 8, etc. segments, as possible. In each case, adjust the tension carefully so as to produce segments of maximized amplitude. Record the number of segments and the hanging mass for each set of segments.

CALCULATIONS:

1. From Procedure 1, determine the mass per unit length of the string in kg/m.

2. From each observation, calculate and enter in a table the following:
   a) the tension in newtons (this should be the weight of the hanging masses)
   b) the wave velocity, from equation (1), in m/s
   c) the experimental wavelength in meters ($2l/n$).
   d) the experimental frequency of vibration.

3. Calculate the average value of the frequency obtained from your experiment and compare it with the known frequency by calculating the percent error.

4. Plot a curve using the wavelength as ordinate and the square root of the tension as abscissa. State the shape of the curve, and numerically compare the basic parameters of the curve to the "physics" values of the experiment.

QUESTIONS:

1. What is meant by resonance?

2. A copper wire 1.00 m long with a mass of 1.00 g vibrates in two segments when under a tension of 2.00 N. What is the frequency of this mode of vibration?

3. If the frequency of the vibrator is doubles, how will the parameters of the curve in Calculation 4 be affected?