4C Lab – Standing Waves on a Sonometer

Goal: To examine standing waves on a string and determine the velocity of the wave.

Equipment List:

Pasco sonometer base, 2 bridges, driver and detector coil
(1) Wire
1 kg mass with a small loop of cord
Fluke oscilloscope
Pasco function generator
(2) BNC – BNC connectors, (1) BNC tee
Bubble level
Digital mass balance for the class to share
Meter stick
Micrometer for the class to share

Pre lab exercise: Derive expression (1)

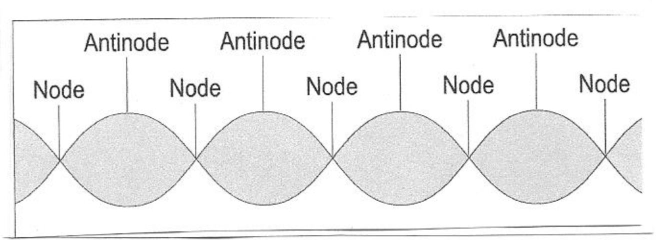
Background: When two traveling waves with the same amplitude, wave number and frequency travel different directions on a string which is fixed at both ends, the principle of superposition yields:

$$Y(x,t) = Y_1(x, t) + Y_2(x,t) = 2A\cos\omega t \sin kx \qquad (1)$$

where

$$Y_1(x,t) = A\sin(kx - \omega t) \quad \text{and} \quad Y_2(x,t) = A\sin(kx + \omega t)$$

Equation (1) describes a waved fixed in space with an amplitude varying in time according to *2Acos(ωt)*. This is a standing wave. The wave will have positions of zero amplitude (nodes), and positions of maximum amplitudes (antinodes).



The velocity of the wave on the string is given by:

$$v = \sqrt{\frac{F_T}{\mu}} \qquad (2)$$

Where F_T is the tension and μ is the mass per unit length. The velocity of the wave on the string can also be expressed in terms of the wavelength and frequency as follows:

$$v = \lambda f \qquad (3)$$

Resonance, or the standing wave condition is met when there are an integer times ½ the wavelength contained in the length, *L*, of the string. Or:

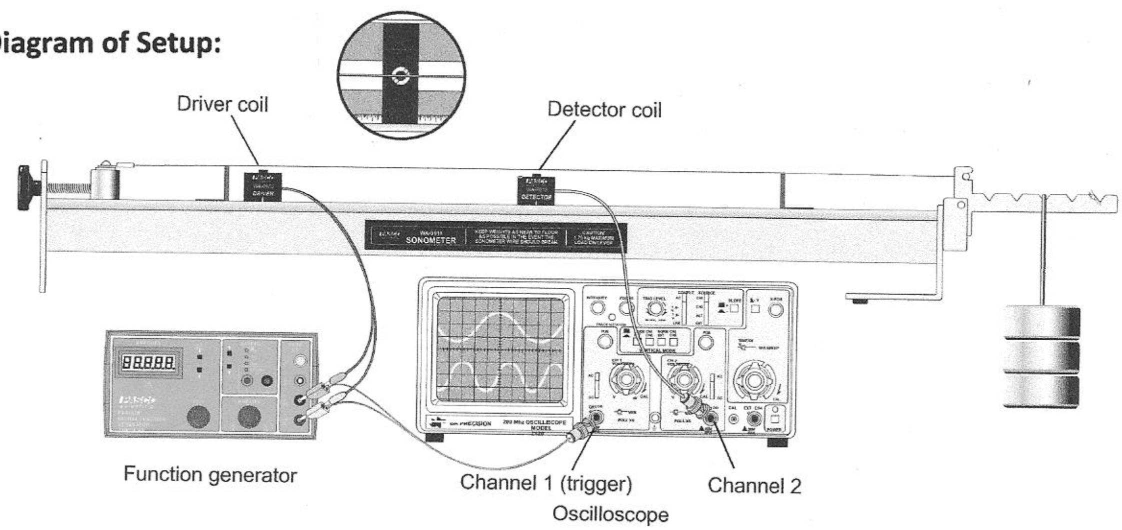
$$\lambda = 2L/n \quad \text{for } n = 1, 2, 3, 4.... \qquad (4)$$

As *n* goes up, the wavelength goes down, but the velocity, the product of the frequency and the wavelength, is constant. Thus:

$f_n = nf_o$ where f_o is the fundamental frequency (n = 1) and n = 1, 2, 3, 4 ... (5)

If the resonant frequency its and corresponding wavelength can both be measured, the velocity of the wave on the string can be determined.

Diagram of Setup:



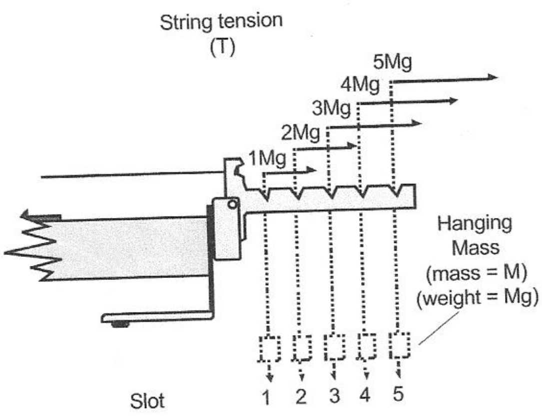
Procedure:

1. Set up the sonometer as shown.
2. Choose a string from the bag. Measure the total mass of the string including lug nuts.

Subtract the mass of the connectors on the ends: longer style ring: 0.89 g, shorter style ring: 0.70g. Measure the length and diameter. Compute μ and compare with Pasco's values:

-- 0.010" (0.39 gm/m)
--0.014" (0.78 gm/m)
--0.017" (1.12 gm/m)
--0.020" (1.50 gm/m)
--0.022" (1.84 gm/m)

3. Place the string on the sonometer base with the bridges 60 cm apart. The distance between the bridges is L. Hang the 1kg mass from the tensioning lever and level the tensioning lever. Record the notch number.



4. Connect the driver coil to the function generator and detector coil to the oscilloscope. You may monitor the driver coil on the oscilloscope also, but the calculations involve only the detector coil frequency.
5. Place the driver approximately 5 cm from one bridge and the detector in the center of the string. With the function generator on sin output, start at about 25 Hz and slowly increase the frequency until resonance is observed. Try to find the fundamental frequency. It should be very clear to see.
IMPORTANT!!! The string often vibrates with a frequency twice that of the input frequency. RECORD the frequency of the response of the string using the oscilloscope measurement.
The fundamental frequency has a corresponding wavelength $\lambda = 2L = 120\ cm$. Record λ and f.
6. Increase the frequency and find the next resonant frequency. Move the detector coil to observe on the oscilloscope the nodes and antinodes. There is, of course, always a node at each bridge. For n = 2, you expect a node in the center of the string. What about for n = 3? The wavelength, λ, is always twice the node spacing. Do you see why?
7. Repeat for a total of five resonant frequencies and the corresponding five wavelengths.

Analysis:

1. Calculate the tension: $F_T = Notch\# * mg$
2. Calculate the velocity of the wave on the string using the tension and mass per unit length. Determine the uncertainty of this value using error propagation techniques.
3. Calculate the velocity for each pair of frequency and wavelengths. You should have five values for the velocity corresponding to the five frequencies $f_n = n f_o$ and $\lambda_n = 2L/n$ for $n = 1, 2, 3, 4, 5$
4. Calculate the average velocity and the standard ~~deviation of the~~ velocity.
error of the sample mean

Conclusion:

Are your results within uncertainty of one another? Why or why not?