Sonometer

Equipment Capstone, sonometer (with detector coil but not driver coil), voltage sensor, BNC to double banana plug adapter, set of hook masses, and 2 set of wires

CAUTION

In this experiment a substantial mass, supported by a wire, hangs over the floor. If the wire should break the mass will fall to the floor. PLEASE KEEP YOUR FEET AWAY FROM UNDERNEATH THE MASS.

1 Introduction

The experiment uses a PASCO Sonometer to measure how normal mode frequencies of metal wires fixed at both ends vary with length, mode number, tension, and mass per unit length of the wires. A sonometer (or monochord) is a device that holds a single wire under a desired tension and can detect the normal mode vibrations of a wire.

2 Theory

A string that is struck will vibrate in several harmonics at once. The fundamental harmonic will resonate with the greatest amplitude and will be accompanied by several lower harmonics. In this experiment you will observe and determine the fundamental harmonic when you change the length of string and wire tension. The sonometer has a string that is held at two adjustable ends that can be fixed. When the string is plucked, it will vibrate in its fundamental mode along with multiple modes of its fundamental harmonic.

The wire tension is T and can be varied by using different masses. Distance along the wire is denoted by x and distance transverse to the wire by y. Dispersionless waves propagate in the positive or negative x direction with the velocity $v = \sqrt{T/\mu}$, where μ is the mass per unit length. For a fixed wire that has a length of L, the time required for the fundamental harmonic to oscillate from the initial fixed end to the other and back, will be related to speed the wave propagates and two times the length between each end ($2L$). The total length will be equal to the fundamental harmonic wavelength.

Higher order fundamentals will occur when the wave propagates from one end to the other with λ of 2, 3, 4, etc. On the next page there is an image of the spectrum you will be viewing on Capstone. When you strum the string, the fundamental harmonic, as well as higher order modes, will oscillate.

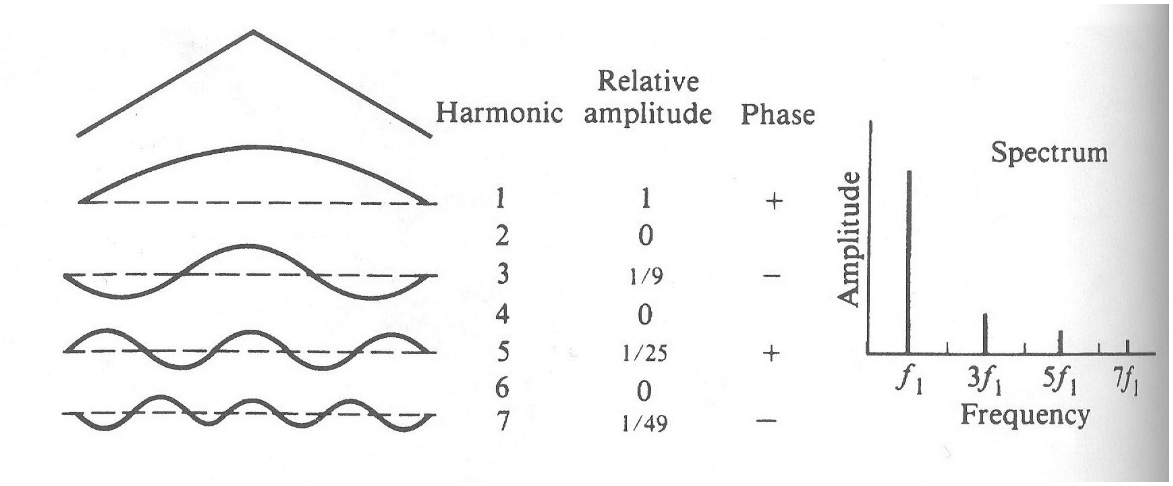


Image Credit: *Rossing, Moore, and Wheeler, The Science of Sound,(San Francisco: Addison Wesley), 2002*

In the figure above you can see the initial response of strumming the string for first seven modes. The normal mode wavelengths are then $\lambda_n = \frac{2L}{n}$ $(n = 1, 2, 3, \ldots)$ The speed of the fundamental harmonic will be related to the frequency and the wavelength. This means normal mode frequencies of the string can be determined with $v = f\lambda$ combined with the equation of the fundamental modes $\lambda_n = \frac{2L}{n}$ and the speed the wave propagates $v = \sqrt{T/\mu}$. The normal frequencies f_n in hertz are given by

$$f_n = \frac{n}{2L}\sqrt{\frac{T}{\mu}}. \tag{1}$$

This equation is the basis of this experiment. The normal mode frequencies depend on the 4 parameters n, L, T, and μ. With the sonometer it is possible to keep three of the parameters constant and investigate how the normal mode frequencies depend on the 4th parameter.

3 Apparatus

A horizontal view of the sonometer is shown in Fig. 1. It is a long rectangular box that holds a wire under tension.

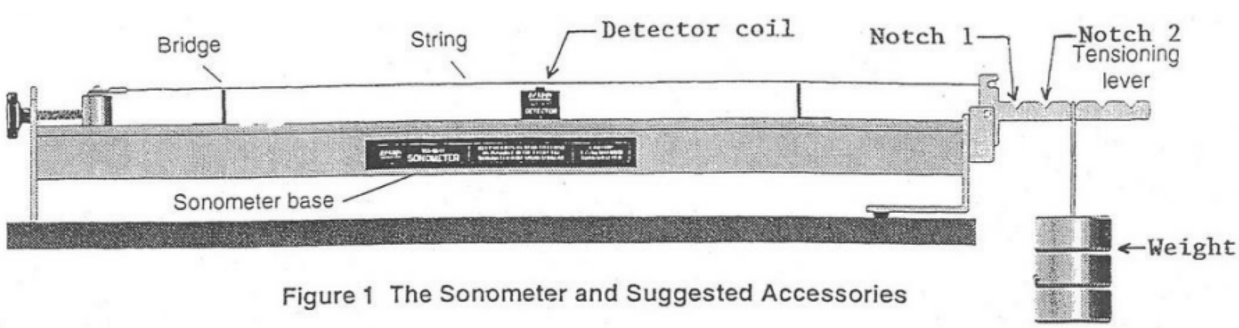


Figure 1 The Sonometer and Suggested Accessories

Each wire used has a lug with a hole in it at one end and a small cylinder at the other end. The lug end of the wire is attached at one end of the sonometer to a cylinder that can be moved along the length of the sonometer by turning a knob with a screw attached to it. The other end of the wire fits into a tensioning lever. This lever has 5 notches, we'll call the notch nearest the sonometer box notch 1, and the other notches 2, 3, 4, and 5 successively. The lever pivot point is the same distance from the wire as it is from notch 1. If the lever is horizontal and a mass M is hung from notch 1 the tension on the wire is Mg. If the mass M is hung from notch 2 the wire tension is 2Mg, and so forth. **Always adjust the position of the wire so that the tensioning lever is perfectly horizontal.**

There are 2 "bridges" which can be moved along the top of the sonometer which allow the points at which the wire is fixed to be changed. Adjusting the bridges changes the length the wave can propagate. A scale along the top of the sonometer allows the wire length to be easily determined. The top of the sonometer has magnetic strips which keep the bridges and detector coil from slipping.

The sonometer has 5 different strings. We list the diameter and linear mass density of only one string.

1. 0.022 inch (1.84 g/m) **The ends 0.022 inch wire are colored red**

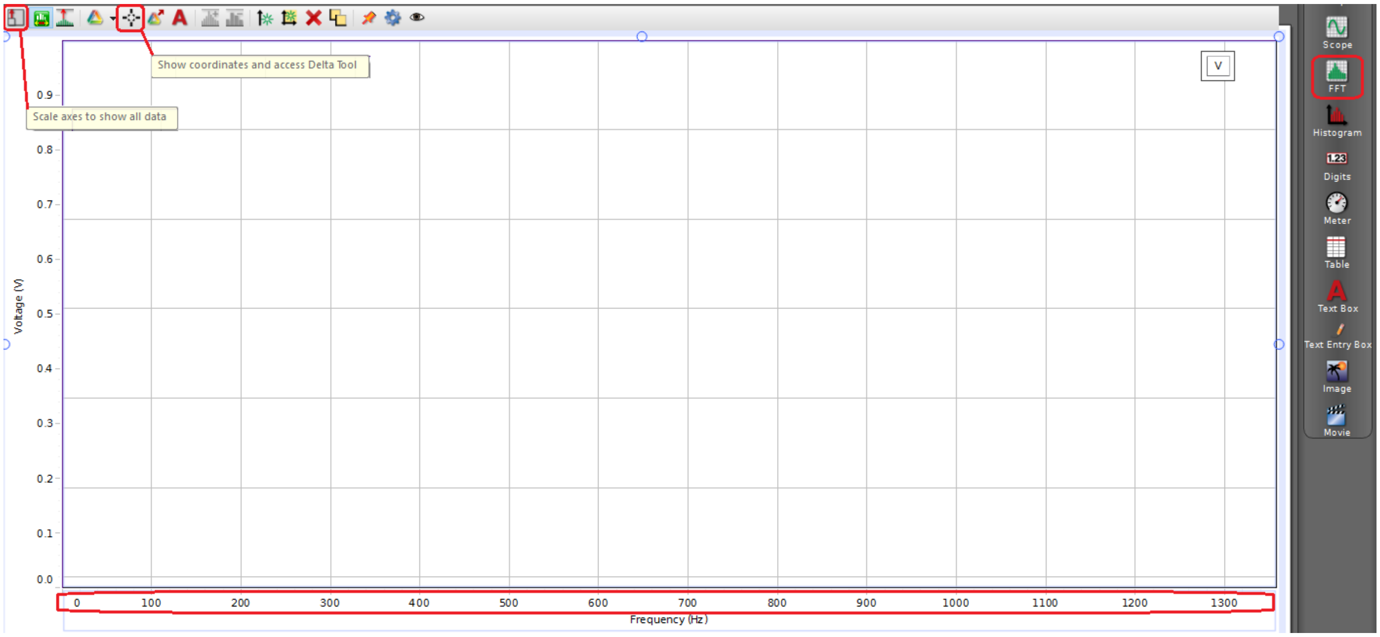
The wire oscillations are observed with a detector coil. This is a small cylindrical magnet that has many turns of fine wire around it. The detector coil is placed directly beneath the wire. The wire is magnetic. When the string vibrates it slightly changes the magnetic field in the coil, and by induction produces a small ac voltage across the coil terminals. A voltage sensor is used to detect this signal.

Capstone comes with a fast fourier transform (FFT) display. This is an algorithm that computes the frequencies present in a signal. If the signal from detector coil is observed with a voltage sensor, the frequencies present in the signal can be determined by using the FFT display. The FFT display window is opened in the usual way: drag the FFT display icon to the voltage sensor icon.

4 Setting up the Sonometer and using the FFT display

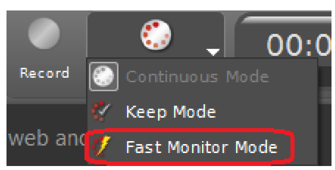
The procedures described here will show you how to use the FFT display to determine what frequencies a wire vibrates when it is plucked. For these preliminary measurements insert a 0.022 inch wire in the sonometer. Place the bridges at 10 and 60 cm and place the detector coil midway between the bridges and directly under the wire. Place 1 kg mass in notch 3. **Reminder: Adjust the length of the string so that the tensioning lever is horizontal.**

Check that the detector coil is connected to a voltage sensor by means of an adaptor plug, and that the voltage sensor is plugged into the interface. Program the interface for the voltage sensor. Open the FFT setup window by dragging the **FFT** icon in the **Displays** column to the center of the white screen. Click on the orange tack in the upper right corner to reduce the overlapping of windows. Next, click on **Select Measurements** and select "Voltage" from the voltage sensor. Now you will change the maximum frequency of the FFT display by clicking and dragging the mouse along x axis window. Click on the x axis and drag left to right and change the maximum frequency to around 1300 hz.



Keep in mind you will be using the two buttons circled in the illustration above.

Go to the lower screen of the program and change it to run in **Fast Monitor Mode**



Without plucking the string click **Monitor**. After, click on **Scale axis to show all data** button in top left of the FFT display. In a few seconds the spectrum of the stray voltages picked up by the detector coil of the spectrum will appear on the FFT screen. After the display has stabilized click **STOP**. Observe the stray frequencies that come up on the FFT screen and beware these are not the frequencies you will be recording. Click **Monitor** and again wait for the stray frequencies of the spectrum to settle down. Then pluck the string near the middle with your thumb and forefinger and observe new frequencies that appear on the display. These are due to the oscillations of the wire. When taking data, watch the display carefully and pick out the signals from the wire. As these signals start to drop note which peaks these are and click STOP. Use the **Scale axis to show all data** icon to scale the graph properly. Then use the **Show Coordinates and access Delta Tool** to determine the normal mode frequencies of the wire. The two buttons are located on top of the FFT display and they're circled in the illustration above.

Practice a bit. It takes skill to pluck the string to get a good signal from the string oscillations, good judgment when to click STOP, and good discrimination to pick out the string oscillations from the noise. Remember that the frequency amplitudes you are looking for get smaller because of string damping. **Higher frequency modes will be harder to spot as they damp more quickly.** As this happens, the FFT display starts increasing the gain so that the noise amplitudes rise. After a while the string amplitudes will disappear and only the noise will be present. Note that the display stays constant for a few seconds and is then "updated" as the computer completes a scan of the frequency spectrum.

5 Experiments

The experiments test the predictions of Eq.(1). In each experiment, 3 of the 4 parameters involved (n, L, T, and μ) are held constant. The 4th parameter is varied. In the tables you are asked to construct, items in the last column should be equal to each other if the results are according to theory.

To measure f_1's, the lowest frequency mode, a good place for the detector coil is in the middle of the wire. For some of the higher frequency modes you might want to use other positions.

In the FFT display, the maximum frequency should be the lowest one possible for the frequency you are measuring. This will give the greatest accuracy. This implies that you have to use more than one maximum frequency for determining the different frequencies in a given experiment.

5.1 Mode frequencies versus n

Use the 0.022 inch wire with a 1 kg mass in notch 3. Set the bridges at 10 and 60 cm. Measure f_1 through f_4. **How many higher normal mode frequencies can you determine?** Make a table with three columns designated by n, f_n (Hz), and f_n/n (Hz). Comment on your results.

Use Eq.(1) to calculate f_1 and compare this theoretical result to your experimental one.

5.2 First Mode Frequency versus L

Use the 0.022 inch wire with a 1 kg mass in notch 3. Keep one bridge at 10 cm. Measure the f_1's for the other bridge at 70, 50 and for three other lengths your teaching assistant will select. Make a table with columns labeled L (m), $f_1(Hz)$, and f_1L (m/s). Discuss your results.

5.3 First Mode Frequency versus Tension

Use the 0.022 inch wire. Set the bridges at 10 and 60 cm. Measure f_1 for a 1 kg mass in notches 1, 2, 3, 4, and 5. Make a table with columns labeled T (N), f_1 (Hz), $f_1/\sqrt{T}$ (Hz/$\sqrt{N}$). Discuss your results.

5.4 Mode Frequencies and Calculating Mass Density

Remove the 0.022 inch wire and setup the second wire. Use a 1 kg mass in notch 3. Set the bridges at 10 and 60 cm. Measure f_1 through f_4. Calculate the mass density for all four modes. To calculate the mass density rearrange equation 1. Take the average of all four mass densities to find the experimental value of μ.

6 Questions

1. In the first 3 experimental sections, what was the motivation for the combination of parameters in the last column? Explain.
2. To measure f_1, why do we place the detector coil midway between the bridges? What is the best location for the detector for higher order modes?
3. Explain why the string tension is given by 1-5 Mg as the mass is moved from notch 1 to notch 5.
4. If the tensior lever was not horizontal how would it effect the experiment?
5. Why has f_1 through f_4 changed for the wire in section 5.4 changed compared to 0.022 inch wire?
6. Work out equation 1 by using the equations for normal mode wavelengths and two equations for the speed of wave.

7 Historical Note

The Greek scholar Pythagoras (died about 497 BC) is well known for his theorem on right triangles. He is also credited with being the first person to observe consonances, or two tones that when played together have a pleasing sound. For this purpose he used a monochord or sonometer. He found that notes with frequency ratios of 2:1 (octave), 3:2 (fifth), and 4:3 (fourth), are consonances.

8 Finishing Up

Straighten and place the equipment back in proper order. Cheers.