How Does It Sound? Young Interferometry Using Sound Waves

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This paper describes an enjoyable, simple, and inexpensive way to perform Young's two-source experiment using sound waves. The wave source is a simple aluminum rod (a "singing rod").[1-3]

Introduction

Our experiment has two parts—one qualitative, the other quantitative. For the first (qualitative) part, students are asked to stand in a line and be the fringe sensors during the experiment. A qualitative two-source interference demonstration experiment can be performed by this means but the data are semi-quantitative at best. For the second part, the students are replaced with a microphone to determine quantitatively the fringe spacing of the interference pattern. In both experiments, the audio signal generator is a simple aluminum rod (a "singing rod") about 1 m long. Our rod has a diameter of 0.046 m, but this value is not critical. A singing rod undergoes longitudinal standing wave oscillations with antinodes at the rod's ends that behave as two coherent "point" sources of sound. The frequency of the longitudinal standing waves depends, to a first approximation, only on the rod length.[4] While singing rods have been commonly used to determine the speed of sound in aluminum and other metals,[3,5] we have not found any descriptions of their use in demonstrating two-source interference.

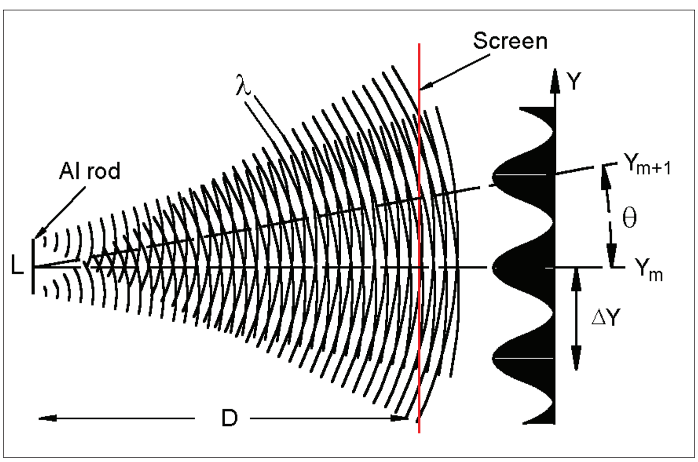

Fig. 1. Two-source interference pattern produced by a singing rod.

The spacing ΔY between adjacent maxima or minima in a two-source interference pattern (see Fig. 1) is given by[6]

$$\Delta Y = \lambda\left(\frac{D}{L}\right), \tag{1}$$

where λ is the wavelength of the waves, L is the distance between the sources (in our situation the length of the rod), and D is the perpendicular distance between the midpoint of the sources (here, the center of the rod) and the plane in which the interference pattern is measured. This relationship is valid only in the small angle approximation, $\tan\theta \approx \sin\theta \approx \theta \ll 1$, as defined in Fig. 1.

The wavelength λ of the waves in air is equal to v/f, where v is the speed of sound in air and f is the frequency of the waves. Therefore,

$$\Delta Y = vD/(fL)\ . \tag{2}$$

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Fig. 2. Students in the detection plane locate the positions of maximum and minimum sound intensity in the interference pattern. The horizontal oscillating rod is not shown.

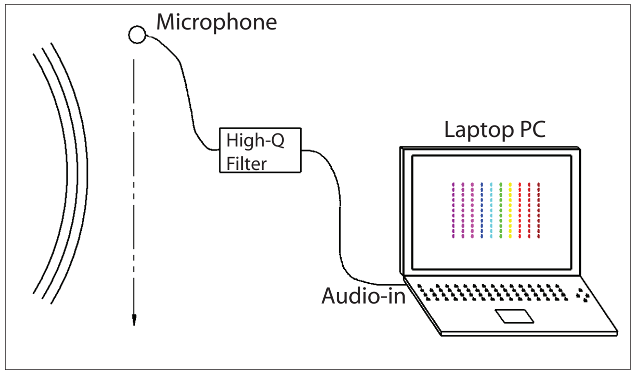

Fig. 3. Diagram showing the construction of the sound-level meter system.

Our two experimental setups—qualitative and quantitative—described below test the validity of Eq. (2).

Qualitative method. The aluminum rod is held in place at its midpoint using a piece of wire hanging down from a tripod. It is carefully balanced so that it remains parallel to the floor and the detection plane. Striking the end of the rod gently with a small hammer excites longitudinal waves in the rod.[7] Because the midpoint of the rod is fixed and the ends are free, there is a node at the midpoint and antinodes at the ends. Two coherent sound sources are created by this means, one at each end of the rod. Several longitudinal oscillation modes are produced simultaneously. The higher frequency oscillations decay rather quickly, while the fundamental mode (2350 Hz for our rod) persists considerably longer. It's important that the hammer hits the rod directly along its longitudinal axis in order to minimize any disturbance perpendicular to that axis. Any transverse oscillations can be damped out by lightly squeezing the rod at its center with the fingers and then gently sliding them down to one end; although this technique diminishes the intensity of the sound waves. The setup should be located in an open area to minimize wave reflections. With some practice it's possible to keep the rod from rotating or wobbling very much during the experiment.

Once you are familiar with this simple setup, choose eight to 10 enthusiastic students with good hearing to act as fringe sensors. Make sure they stand at the detection plane, far enough from the sound emitter to satisfy the small angle condition, $\theta \ll 1$ (In our case, $D \approx 9$ m). Tell the students to cover one ear (or use an ear plug) as they listen to the sound waves emanating from the oscillating rod. The students/sensors can locate the positions of the interference fringes by moving back and forth in the detection plane until they can distinguish points of maximum and minimum sound intensity. Tell pairs of students who have found adjacent maxima and minima to stand still facing each other with their uncovered ears toward the oscillating rod (See Fig. 2). Measure the average horizontal distance between successive uncovered ears. This corresponds to one-half of the inter-node spacing ΔY. The experimental value of ΔY can be compared to that calculated using Eq. (2). The distances D and L in that equation are measured with a tape measure, the speed of sound in air at room temperature can be looked up in a table, and a frequency meter can be used to find f. As might be expected, the difference between the measured and calculated values of ΔY is quite large. This is primarily because it is difficult for the students to determine accurately the positions of the maxima and minima of the interference pattern. However, after they have performed this part of the experiment, they are well-motivated to continue with the next method which gives much more accurate results.

Quantitative method. In this part of the experiment the acoustic signal is detected by a small condenser microphone attached to a home-made electronic filter. The filter is used to single out the fundamental frequency of the sound source. Three operational

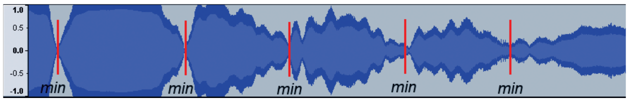

Fig. 4. Typical interference pattern as recorded by the microphone. The average time interval between successive minima is approximately 0.9 s.

amplifiers and some passive components are configured as a high-Q band-pass filter with the center frequency adjusted to closely match the fundamental frequency f of the oscillating rod. We connect the output of the amplifier/filter directly to a laptop computer,[8] thus creating an inexpensive hand-held sound-level meter (see Fig. 3).

The task of taking data for this part of the experiment is simple. A student (the "walker") holds the sound-level meter (with the microphone directed toward the rod) and walks a few meters at constant speed in a straight line parallel to the rod. A motion detector directly in front of the walker measures his/her position.[9] An interference pattern is displayed on the computer screen showing the sound intensity as a function of elapsed time. A typical pattern showing five minima and maxima is shown in Fig. 4. The spatial locations of the maxima and minima of the interference pattern are determined by correlating the intensity and position data. The positions of the interference minima are easier to locate than those of the maxima, and so those are used to find the inter-node spacing, ΔY_{exp}. The average value of ΔY_{exp} is determined from the second to the fifth minimum shown in Fig. 3. We used a total of 10 different interference patterns of this kind and calculated the average value of the inter-nodal spacing. The result was

$$\Delta Y_{exp} = 1.16 \pm 0.05 \text{ m.}$$

The experimental uncertainty shown above is the statistical standard deviation of the ΔY_{exp} measurements. The theoretical value of the inter-nodal spacing was calculated from Eq. (2) using the following:

$L = 1.095 \pm 0.001$ m
$v = 350$ m/s at $T = 30$°C (Ref. 6, p. 514)
$D = 8.90$ m ± 0.01 m
$f = 2350 \pm 30$ Hz

The frequency f was measured directly from the decaying waveform on the computer screen as seen with the microphone held stationary.

The result of our calculation is:

$$\Delta Y_{theo} = 1.19 \pm 0.04 \text{ m.}$$

A number of possible sources of experimental error were not considered. For example, the damping of the acoustic waves was ignored, the effects of reflected sound waves were neglected, and even though the rod was firmly held at its midpoint, some spurious frequencies may not have been completely blocked. While there may be ways in which the experiment could be improved, the agreement between the theoretical and experimental values of ΔY is very convincing.

References

1. H.A. Daw and R.J. Liefeld, "Driven singing aluminum rods," *Am. J. Phys.* **66**, 639–641 (July 1998).
2. Commercial sources of singing rod are Arbor Scientific (http://www.arborsci.com) and McCREL (http://www.mcrel.org/whelmers/whelm10.asp).
3. R.C. Nicklin, "Measuring the velocity of sound in a metal rod," *Am. J. Phys.* **41**, 734 (May 1973).
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5. S. Mak, Y. Ng, and K. Wu, "Measurement of the speed of sound in a metal rod," *Phys. Educ.* **35**, 439 (Nov. 2000).
6. Raymond A. Serway and John W. Jewitt Jr., *Physics for Scientists and Engineers* (Thomson Brooks Cole, 2004), pp. 1180–1181.
7. An attractive alternative is to use Nicklin's procedure (Ref. 3) of rubbing the rod with a wet piece of chamois or sponge.
8. The Audacity freeware package (audio software for recording and editing sound digitally) is installed on the computer; http://audacity.sourceforge.net).
9. Ours is a Go! Motion® detector, which is used to collect position, velocity, and acceleration data for moving objects. Go! Motion® is a registered trademark of Vernier Software and Technology; http://www.vernier.com.

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