Physics Laboratory I
Vp141

Exercise 4

Measurement of the Speed of Sound

1   Pre-lab Reading

Chapters 15 and 16 (Young and Freedman).

2   Objectives

The objective of this exercise to study three methods of measuring the speed of sound in air: the resonance method, the phase comparison method, and the time difference method. In addition, you will learn how to operate a function generator and an oscilloscope.

3   Background Information and Measurement Method

3.1   Basic Quantitative Characteristics of Sound Waves

Sound is a mechanical wave that propagates through a compressible medium. It is a longitudinal wave because the direction of vibrations of the medium (here, change in the density or the pressure) is the same as the direction of propagation. The frequency of sound perceptible to a human ear ranges from about 20 Hz to 20 000 Hz. Sound with the frequency higher than 20 000 Hz is called *ultrasound*. In this experiment an ultrasonic wave is chosen as the signal source, because its wavelength is short enough to make it possible for us to measure it in a teaching laboratory.

The phase speed v, the frequency f and the length λ of a wave are related by the formula

$$v = \lambda f. \tag{1}$$

For motion with constant speed v along a straight line, we have

$$v = \frac{L}{t}, \tag{2}$$

where L is the distance traveled over time t. Hence, if the distance and the time a wavefront travels is known, the phase speed may be found.

3.2   Measurement Method

The experimental setup consists of a signal source, two piezoelectric transducers S_1 and S_2, and oscilloscope arranged as shown in Figure 1.
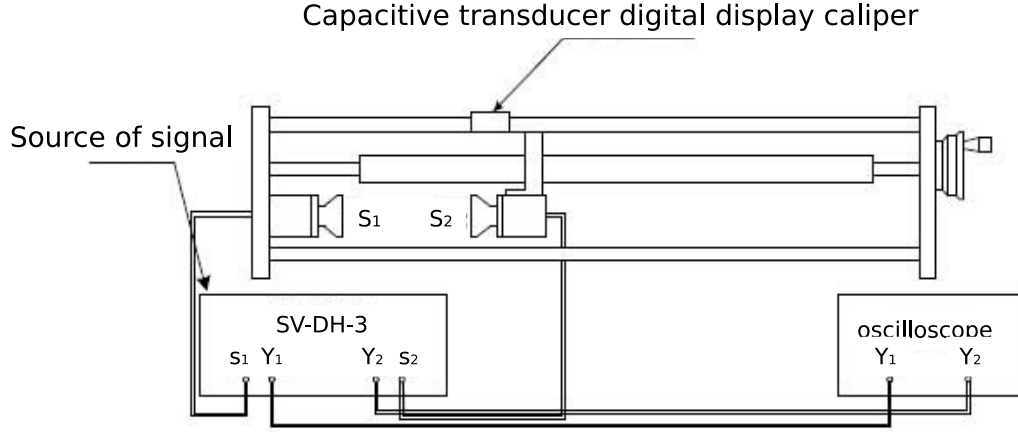
Figure 1. Experimental setup.

3.2.1 Resonance Method

The elements S_1 and S_2 are the wave source and the receiver (also reflector), respectively, placed a distance L from each other. If they are arranged parallel to each other, the sound wave is reflected. If

$$L = n\frac{\lambda}{2}, \tag{3}$$

where $n = 1, 2, \ldots$, $i.e.$ the distance is a multiple of half-wavelength, standing waves will form, and maximum output power will be observed in the oscillograph (Figure 2). always $\lambda/2$ apart. After the position corresponding to each maximum is measured, it is easy to find the wavelength and then, from Eq. (1), the speed of sound. The frequency f is displayed directly on the signal generator.
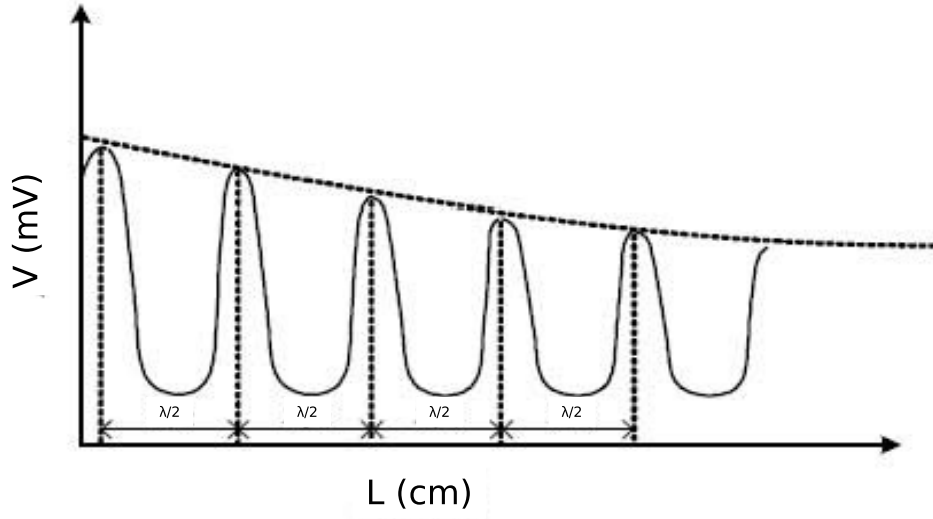
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V (mV)

λ/2   λ/2   λ/2   λ/2

L (cm)

Figure 2. Relationship between the signal voltage and the distance between the transducers.

3.3 Phase-comparison method

If the phase of the wave at two points on the wave propagation direction is equal, then the distance between these points L has to be a multiple of the wavelength, *i.e.*

$$L = n\lambda,$$

where $n = 1, 2, \ldots$. The experimental setup for the phase comparison method is the same as in the previous method (Figure 1).

Lissajous figures are used to identify the values of L. Lissajous figures (or Lissajous curves) are trajectories of a particle moving simultaneously in two perpendicular directions (for example, the axes x and y of a Cartesian coordinate system), so that the motion along each axis is simple harmonic (with different natural angular frequencies, amplitudes and initial phases, in general). Then $\mathbf{r}(t) = (A_x \cos(\omega_x t + \phi_x), A_y \cos(\omega_y t + \phi_y))$. When the two superimposed harmonic motions have identical frequency $\omega_x = \omega_y$ and phase difference $|\phi_x - \phi_y| = n\pi$, where $n = 0, 1, 2, \ldots$, the Lissajous figure will show as a straight line. For other values of the phase difference the figures will have corresponding elliptical shapes.

3.4 Time-difference method

When an ultrasonic pulse signal emitted by S_1 arrives at S_2, it is received and returned back to the processor. By contrasting the original signal with the received one, one can

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measure the time needed for the sound to travel from S_1 to S_2 over a distance of L. When the values of L and t are known, the phase speed of sound can be found from Eq. (2).

4   Measurement Procedure

4.1   Resonance Method

1. Set the initial distance between S_1 and S_2 at about 1 cm.

2. Turn on the signal source and the oscilloscope. Then set the following options on the panel of the signal source

    (1) Choose *Continuous* wave for *Method*.

    (2) Adjust *Signal Strength* until a 10 V peak voltage is observed on the oscilloscope.

    (3) Adjust *Signal Frequency* between 34.5 kHz and 40 kHz until the peak-to-peak voltage reaches its maximum. Record the frequency.

3. Increase L gradually by moving S_2, and observe the output voltage of S_2 on the oscilloscope. Record the position of S_2 as L_2 when the output voltage reaches an maximum.

4. Repeat step 3 to record 12 values of L_2 and find v by performing a linear fit to the data.

	L [mm]		L [mm]
1		7	
2		8	
3		9	
4		10	
5		11	
6		12	

Table 1. Data table for the resonance method.

4.2   Phase-comparison Method

1. Use Lissajous figures to observe the phase difference between the transmitted and the received signals. Move S_2 and record the position when the Lissajous figure becomes a straight line with the same slope.

2. Repeat step 1 to collect 12 sets of data and perform a linear fit to find v.

	L [mm]		L [mm]
1		7	
2		8	
3		9	
4		10	
5		11	
6		12	

Table 2. Data table for the phase-comparison method.

4.3 Time-difference Method (Air)

Note. *This part of the experiment is for illustration purposes only. Measurements will be done for sound waves propagating in a liquid (see the next section). Please follow instructions given in class.*

Since the pulse wave causes damped oscillations at the receiver, there will be significant interference if S_1 and S_2 resonate. The resonance can be observed on the oscilloscope.

1. Choose *Pulse Wave* for *Method* on the panel of the signal source.

2. Adjust the frequency to 25 Hz and the width to 500 μs.

3. Record the distance L_1 and the time t_1.

4. Move S_2 to another position and repeat step 3. Record L_i and t_i, $i = 2, 3, 4, \ldots$

5. Repeat step 4 to collect 12 pairs of L_i and t_i. Plot the $L_i = L_i(t_i)$ graph and use computer software to find a linear fit to the data. The slope of the line is the speed v.

4.4 Time-difference Method (Liquid)

1. Change the medium to water.

2. Adjust the frequency to 100 Hz and the width to 500 μs.

3. Use the cursor function of the oscilloscope to measure the time and the distance between the the starting points of neighboring periods. Record 12 pairs of data and perform a linear to find v_{water} .

	t [ms]	L [mm]
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		

Table 3. Data table for the time-difference method in liquid.

5 Caution

▶ Make sure that S_2 moves in only one direction during each part of the experiment to avoid the backslash error.

▶ When using the time-difference method, the initial distance between S_1 and S_2 should be greater than 10 cm.

▶ Prevent metal devices and callipers from contact with water when measuring the speed of sound in water.

▶ Make sure that the distance between S_1 and S_2 is always greater than 1 cm.

6 Preview Questions

▶ What is a longitudinal/transverse wave? Are sound waves longitudinal or transverse?

▶ What parameter of a compressible medium does determine the speed of sound in that medium? What is the magnitude of the speed of sound in air/water/steel?

▶ What is the phase speed?

▶ What is the wavefront?

▶ Briefly describe the idea of at least one measurement method.

▶ What are standing waves on a string? When a standing wave of length λ can form on a string of length L clamped at both ends?

► What are the Lissajous figures? Sketch the Lissajous figures for the system of parametric equations $x = \sin(\omega t + \delta)$ and $y = \sin \omega t$, with $\delta = 0, \pi/4, \pi/2, \pi$.

► What is the 'CURSOR' function on the oscilloscope used for?