JOINT INSTITUTE
交大密西根学院

Physics Laboratory
Vp141

Exercise 4

Measurement of the Speed of Sound

This lab manual is based on materials provided by the Department of Physics, Shanghai Jiaotong University. rev 5

Edited by: Qin Tian, Cao Jianjun, Yi Hankun, Mateusz Krzyzosiak

1 Pre-lab Reading

Chapters 17 and 18 (Young and Freedman).

2 Objectives

The objective of this exercise to study several 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 get familiar with the successive difference method in measurement data processing.

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 measure the speed of sound precisely.

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.

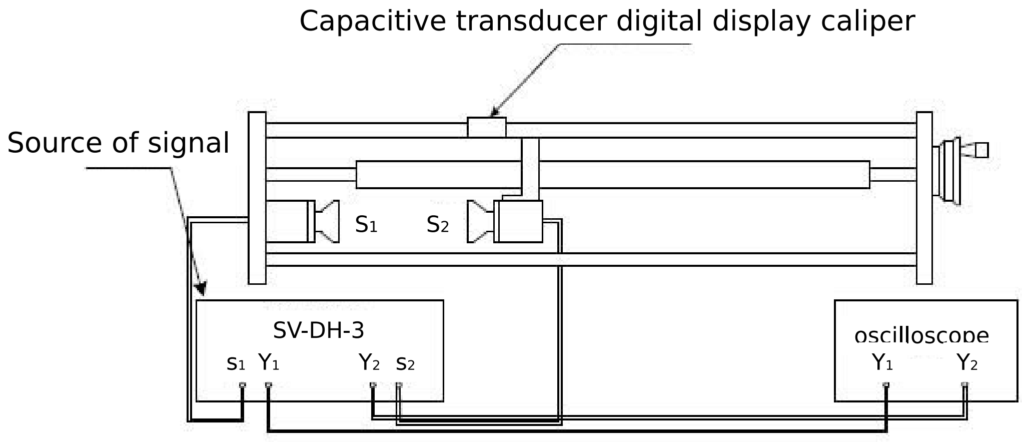

Figure 1. Experimental setup.

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). The distance between two successive maxima ($L_{i+1} - L_i$) is always $\lambda/2$. After the position corresponding to each maximum is measured, it is easy to find the wavelength and then the speed of sound by using Eq. (1). The frequency f is displayed directly on the signal generator.

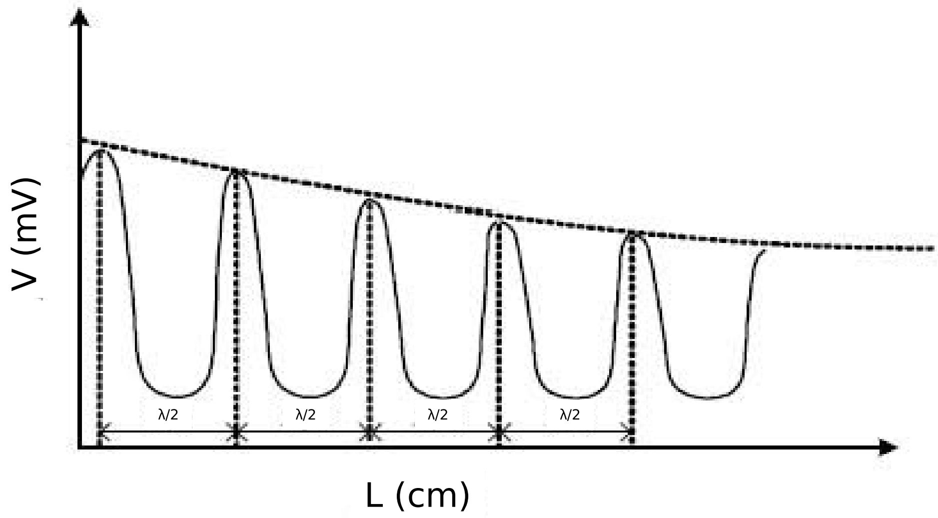

Figure 2. Relationship between the signal voltage and the distance between the transducers.

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 that moves in a plane so that *i.e.* it moves in a harmonic motion independently along two perpendicular directions (for example the axes x and y of a Cartesian coordinate system), so that $\mathbf{r}(t) = (A_x \cos(\omega_x t + \phi_x), A_y \cos(\omega_y t + \phi_y))$. 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 an elliptical shape.

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 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).

3.5 Successive Difference Method

The successive difference method is an effective method to increase the accuracy of the average value calculated from a series of measurement data. In this experiment, the usual method of calculating the average value, illustrated by the formula

$$\frac{\overline{\lambda}}{2} = \frac{[(L_1 - L_0) + (L_2 - L_1) + \cdots + (L_n - L_{n-1})]}{n} = \frac{L_n - L_0}{n}, \tag{4}$$

will be modified, because as Eq. (4) shows, the average value of the wavelength is determined only by the first and the last value, L_0 and L_n.

A modification of the formula by rearranging terms as

$$n\frac{\overline{\lambda}}{2} = \frac{\sum_{i=1}^{n}(L_{n+i} - L_i)}{n}, \tag{5}$$

produces more accurate results, as each value contributes to the final result.

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) Choose *Air* for *Medium*.

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

   (4) Adjust *Signal Frequency* between 34.5 and 37.5 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 20 values of L_2 and calculate v.

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. Use the successive difference method to process the data and calculate v.

	L [mm]		L [mm]
1		11	
2		12	
3		13	
4		14	
5		15	
6		16	
7		17	
8		18	
9		19	
10		20	

Table 1. Data table for the resonance method.

	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

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* and *Air* for *Medium* 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 in a Liquid

1. Change the medium to 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.

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 calculate v_{water}.

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

Table 4. 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.

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 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 $\delta = 0, \pi/4, \pi/2, \pi$.