## 5. Experimental Contents

1) Learn the principle of generating and receiving ultrasound
2) Measure the speed of sound in air using phase and resonance interference methods
3) Measure double-slit interference and single-slit diffraction of sound waves
4) Study the interference of reflected and original sound waves using a Lloyd mirror
5) Study acoustic reflection over different media or surfaces and measure reflectivity

## 6. Experimental Procedure

A. Measure the speed of sound in air

a) Adjust and measure resonance frequency

Set up the apparatus as per Figure 4 (connect one terminal of the two "Signal Output" terminals of the electric unit to the Ultrasonic Emitter using one BNC cable, connect the output of the Ultrasonic Receiver and the other "Signal Output" terminal of the electric unit to the two channels of an oscilloscope using BNC cables). Set the frequency of the sine wave at 40 kHz, and keep the emitter and the receiver as closely as possible (a maximum signal is observed on the oscilloscope).

Increase the distance between the emitter and the receiver to approximately 6-7 cm until a maximum signal is observed on the oscilloscope (now the receiver is at a wave node position).

Adjust frequency again to maximize the signal on the oscilloscope.

Finally, finely tune frequency to make the output signal of the receiver and the signal of the signal generator in phase.

Now, the output frequency of the signal generator equals the natural frequency of the two transducers. At this frequency, the emitter outputs strong ultrasonic waves.

b) Measure speed of sound at resonance frequency using resonance and phase methods

Place the receiver at 20 different locations ($L_i$) where maximum signals are observed on the oscilloscope. Then calculate the ultrasonic wavelength.

To use the phase method, connect the outputs of the receiver and the transmitter to the Y-axis and X-axis of the oscilloscope, respectively. The phase difference between the received wave and the emitted wave can be observed on a Lissajous graph. Properly adjust sensitivities of X axis and Y axis to achieve a satisfied Lissajous graph.

For the synthesis of two perpendicular simple-harmonic motion of equal frequency, the Lissajous graph changes from a straight line with a positive slope to an oval, and then from an oval to a straight line with a negative slope, as their phase difference changes from 0 to $\pi$.

Record the reading of the digital caliper each time when the Lissajous graph becomes a straight line. If the distance between the emitter and the receiver changes by a half of the wavelength, the Lissajous graph changes between straight lines of alternative slopes.

c) The temperature and humidity in the lab should be measured accurately, and the $p_w$ value can be found under this condition. Next, measure the air pressure value $p$ in the lab. Use Eq. (5) to calculate the speed of sound. **Note**: $p_w$ and $p$ do not need to be measured in dry climate.

d) Compare the results between the two methods, and calculate their errors relative to the recognized value.

B. Double-slit interference of sound waves (optional experiment)

a) Placement of double-slit board: the position of the double-slit board directly affects the experimental effect. The receiving side of the board should face the sonic emitter while the transmitting side of the board should be exactly under the rotation axis of the digital ruler (i.e. placing the indentation of the board under the screw of the rotation axis). The center of the double-slit should face the emitter.

b) Position adjustment of ultrasonic receiver: first, turn the digital ruler to zero-point, then move the ultrasonic receiver as far as possible away from the emitter but locate it at a resonant point.

c) Measurement: rotate the digital ruler while monitoring the change in signal intensity of the receiver. Record angles $\theta_1$ and $\theta_2$ under which the first and the second minimum signals are observed, respectively. Use formula $\lambda=d(\sin\theta_2-\sin\theta_1)$ to calculate the wavelength of the sound wave.

C. Reflection of sound wave (optional experiment)

a) Lloyd mirror experiment

Per Figure 2, arrange the emitter and the receiver with a proper angle by locating the reflection board at an angle of 20°~30° relative to the emitter. Observe the wave nodes of the interference graph produced by the direct wave and the reflected wave at the receiver. Then move the reflection board backward but parallel to its original location, peaks and valleys of signal intensity can be observed. By placing a piece of graph paper under the base and recording the positions of the reflection board, the wavelength of the sound wave can be measured.

b) Reflection and absorption of sound wave

Record reflected signal intensity using two reflection boards made of different materials, and understand the impact of material property and surface shape on sound absorption.

c) Observe diffraction of single–slit, and understand the physics of sound wave diffraction

## 7. Examples of Data Recording and Processing

Note: the following data are for reference purposes only, not the criteria for apparatus performance.

1) Measurement of speed of sound using phase method

Table 1 Measurement results of phase method (temperature: 28.05 °C, frequency: 40.574 kHz)

| No. ($i$) | $L_i$ (mm) | No. ($i$) | $L_i$ (mm) | $\Delta L_i$ (mm) | $\Delta\overline{L_i}$ (mm) |
|---|---|---|---|---|---|
| 1 | 0.00 | 11 | 43.46 | 43.46 | |
| 2 | 4.46 | 12 | 47.75 | 43.29 | |
| 3 | 8.76 | 13 | 51.85 | 43.09 | 42.948 |
| 4 | 13.18 | 14 | 56.10 | 42.92 | |
| 5 | 17.52 | 15 | 60.46 | 42.94 | |

| | | | | | |
|---|---|---|---|---|---|
| 6 | 21.89 | 16 | 64.69 | 42.80 | |
| 7 | 26.21 | 17 | 69.00 | 42.79 | |
| 8 | 30.48 | 18 | 73.15 | 42.67 | |
| 9 | 34.75 | 19 | 77.58 | 42.83 | |
| 10 | 39.08 | 20 | 81.86 | 42.78 | |

Calculated results: $\overline{\lambda} = 42.948 \times \frac{1}{5} = 8.5896$ mm, $V = 40.574 \times 8.590 = 348.5$ m/s

In dry air at 28.05 °C, the recognized speed of sound is $V_0$=348.4 m/s. So, the experimental error is very small.

2) Measurement of speed of sound using resonance interference method

Table 2 Measurement results of resonance method (temperature: 28.75 °C, frequency: 40.575 kHz)

| No. ($i$) | $L_i$ (mm) | No. ($i$) | $L_i$ (mm) | $\Delta L_i$ (mm) | $\overline{\Delta L_i}$ (mm) |
|---|---|---|---|---|---|
| 1 | 0.00 | 11 | 43.88 | 43.88 | |
| 2 | 4.36 | 12 | 48.76 | 44.40 | |
| 3 | 8.63 | 13 | 52.98 | 44.35 | |
| 4 | 13.40 | 14 | 57.42 | 44.02 | |
| 5 | 17.91 | 15 | 62.12 | 44.21 | 44.126 |
| 6 | 22.26 | 16 | 66.17 | 43.91 | |
| 7 | 26.66 | 17 | 70.58 | 43.92 | |
| 8 | 30.87 | 18 | 74.89 | 44.02 | |
| 9 | 35.14 | 19 | 79.31 | 44.17 | |
| 10 | 39.76 | 20 | 84.11 | 44.35 | |

Calculated results: $\overline{\lambda} = \overline{\Delta L_i}/5 = 8.825$ mm, V =40.575×8.825=358.1 m/s.

In dry air at 28.75 °C, the recognized speed of sound is $V_0$=348.5 m/s. So, the experimental error is about 2.8%.

3) Measurement of double-slit interference of sound wave

Distance between the centers of the two slits $d$=41 mm, temperature $t$=27.3 °C

| 1st order minimum $\theta_1$ (°) | 2nd order minimum $\theta_2$ (°) | λ (mm) |
|---|---|---|
| 6.1 | 19.0 | 8.99 |
| 5.0 | 17.0 | 8.41 |
| 5.2 | 17.8 | 8.82 |

Averaged result: $\overline{\lambda}$ =(8.99+8.41+8.82)/3=8.74 mm.

In dry air at 27.3 °C, the speed of sound is 347.6 m/s and the frequency of sound is 39.927 kHz, so, $\lambda_0$=347.6/39.927=8.71 mm, which is very close to the measured value.

4) Single-slit diffraction of sound wave

The width of the single slit is 25.0 mm, which is about 3 times of the ultrasound wavelength. From Eq. (8), the angle of the 1st order minimum can be estimated. Release the fastening screw of the rotation bar and then rotate the bar until the angle satisfies Eq. (8), so that the 1st order minimum can be observed. By increasing the angle, the 1st order maximum can also be observed.