Measuring The Speed of Sound Wave Using Standing Waves

Suni Yao

Contents

1 Background

In a tube of length L with both ends fixed, when a sound source of frequency f is placed inside, the sound waves reflect between the fixed ends. At certain specific lengths (when the tube is resonant), the reflected waves combine with the incoming waves to form a standing wave. Both fixed ends are displacement nodes. The resonance condition for the tube is given by:

$$L = \frac{n\lambda}{2}$$

where n is an integer indicating the number of half-wavelengths fitting within the tube. This happens because a standing wave forms only when the tube's length is a multiple of half-wavelengths, with nodes at both ends.

From this resonance condition, the wavelength λ can be determined as:

$$\lambda = \frac{2L}{n}$$

With this wavelength, the speed of sound v can be calculated using the formula:

$$v = f \cdot \lambda$$

Here, v is the speed of sound, f is the frequency, and λ is the wavelength obtained from the resonance condition.

2 Aim

In this experiment, we aim to calculate wavelength for different frequencies through standing waves and by this, derive the speed of sound wave.

3 Apparatus

- sound signal generator
- glass cylinder about 35cm long with a movable piston aside from it
- half-meter stick
- thermometer
- vernier software
- sound sensor

4 Procedure

1. Adjust the sound signal generator to a specific frequency about $f = 1500$Hz.
2. Turn on the sound sensor.
3. Move the piston back and forth. When the amplitude reaches its local maximum, record the length of the glass tube.
4. Repeat steps 1-3 for different frequencies about $f = 1200$Hz and $f = 860$Hz.

5 Data Collection

Frequencies (Hz)	Length_1 (± 0.5mm)	Length_2 (± 0.5mm)	Length_3 (± 0.5mm)
1526 (1500)	275	161	46
1206 (1200)	51	193	322
853 (860)	227	22	N/A

Table 1: Raw data table of length where we got the maximum intensity of sound wave.

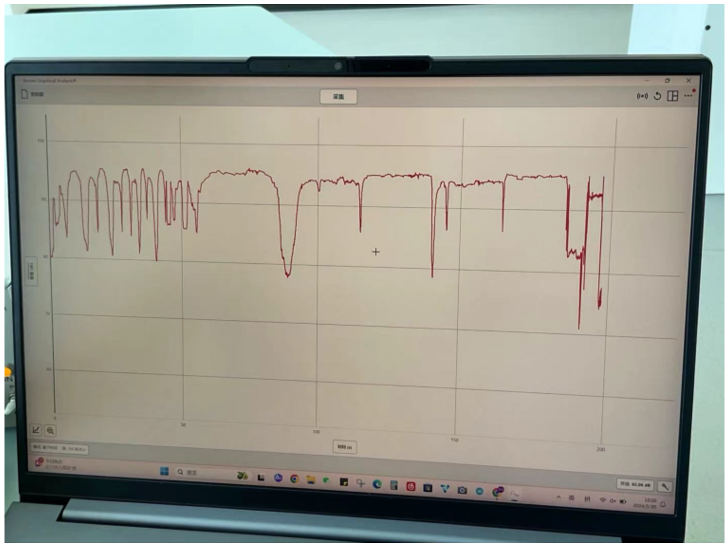

Figure 1: Sample of Data Collection

6 Data Processing

6.1 Example of Data Processing

We take the frequency equals to 1526Hz as an example. The points that have the largest intensity are the nodes. We calculate the average distance of adjacent nodes: $\frac{(275-161)+(161-46)}{2} = 114.5$mm.

Therefore, the wavelength should be 2 times the distance:

$$\lambda_1 = 2 \cdot 114.5 = 229\text{mm}.$$

According to the formula $v = \lambda f$,

$$v_1 = \lambda_1 \cdot f_1 = 0.229 \cdot 1526 = 349.5\text{m/s}.$$

6.2 Processed Data Table

Frequencies (Hz)	Corresponding Sound Speed (m/s)
1526	349.5
1206	326.8
853	349.7

Table 2: Procesed data table, of frequencies and their corresponding sound speed calculated.

Therefore, we can calculate the average speed of light.

$$v = \frac{v_1 + v_2 + v_3}{3} = \frac{349.5 + 326.8 + 349.7}{3} \approx 342.0\text{m/s}$$

7 Conclusion and Evaluation

The experiment is taken under a temperature of $20°C$. The standard sound speed in air and a room temperature of $20°C$ is about 343m/s.

The error between the theoretical value and the experimental value is

$$\frac{v_{\text{theoretical}} - v_{\text{experimental}}}{v_{\text{theoretical}}} = \frac{343 - 342}{343} \approx 0.29\%.$$

This slight percentage discrepancy demonstrates that our experimental measurements are highly accurate compared to the anticipated theoretical value. However, in our experiment, the $f = 1206$Hz data does not show closeness to the theoretical value, as the speed calculated is 326.8m/s.

The error may be a result of the environmental conditions such as variations in temperature, humidity, or air pressure within the laboratory setting. These factors could have influenced the speed of sound. Additionally, errors in measuring the length of the air column or inaccuracies in pinpointing the exact positions of nodes and antinodes might have led to slight deviations in the calculated speed. Moreover, if the sound sensor and other equipment used were not perfectly calibrated, this lack of calibration could have compromised the precision of the collected data.

Also, one strange phenomenon we observed is that in the middle of nodes that are chosen in the table for $\text{length}_{1,2,3}$, there also exist positions in between that cause a relative larger intensity of sound compared to other positions.

Therefore, to enhance the accuracy and reliability of future experiments, several improvements are recommended. Conducting the experiment in a more controlled environment, where temperature and humidity are consistently monitored and maintained, would help mitigate the impact of environmental factors. Using more precise measurement instruments, ideally with digital readouts, could reduce human error in recording lengths and frequencies, thereby improving measurement accuracy. Furthermore, ensuring that all experimental equipment is regularly calibrated and properly maintained is essential for preserving the integrity of the measurements.

The findings from this experiment not only corroborate the theoretical predictions regarding the speed of sound but also emphasize the vital importance of precise measurement and control in experimental physics.