Kundt's Tube Experiment

Under-Graduate Science Laboratory – BS 192 (Group - 7)

Birudugadda Srivibhav – 22110050
Vubbani Bharath Chandra – 22110293
Ankeshwar Ruthesha – 22110024
Kirtankumar Patel – 22110185

1 Objective

To determine the speed of sound in air using Kundt's tube, a known frequency sound wave is generated in the tube. Instead of lycopodium powder, a movable piston connected to a reflector and a microphone is used to detect sound intensities. The distance between the nodes, where the sound intensity is minimum, is measured to find the wavelength (λ).

The speed of sound (v) is then calculated using the formula:

$$v = f \times \lambda$$

where f is the frequency of the sound wave and λ is the wavelength.

2 Apparatus Description

- **Transparent Tube:** A *transparent tube* with a diameter of 59 mm and a length of 1000 mm, marked with a *reading scale* for precise measurements.
- **Loudspeaker:** A *loudspeaker* is attached to one end of the tube to generate sound waves that travel through the tube.
- **Movable Piston with Reflector:** A *movable piston* connected to a reflector and a microphone is attached to the other end of the tube, allowing adjustment of the tube length.

- **Piston on Long Rod:** A *long rod* attached to the piston is used to create tubes of varying lengths by adjusting the piston's position.
- **Kundt's Tube Amplifier with Oscillator Unit:** This *amplifier unit* is used to interface with the microphone, loudspeaker, headphones, and a *digital storage oscilloscope (DSO)*.
- **Support Blocks:** *Support blocks* are used to hold the tube horizontally above the workbench, ensuring stability during the experiment.

Figure 1: Apparatus for Kundt's Tube experiment[1].

3 Theory

3.1 Historical Background[2]

Theory: Kundt's tube is an experimental acoustical apparatus invented in 1866 by German physicist August Kundt, designed for measuring the speed of sound in gases or solid rods. The apparatus consists of a long, transparent tube through which sound waves are generated by a loudspeaker and reflected by a movable piston at the other end. This setup creates standing waves within the tube, which can be observed by the accumulation of fine powder at the nodes, where the air movement is minimal. The presence of air or another gas inside the tube is crucial, as it serves as the medium for sound wave propagation, enabling the formation and visualization of these standing waves.

The experiment remains a valuable educational tool in acoustics because it visually demonstrates longitudinal waves in a gas, which can be challenging to visualize otherwise. Although the practical use of Kundt's tube for precise measurements has been largely replaced by more advanced technologies, it continues to be used primarily for teaching purposes. It effectively illustrates standing waves and acoustical forces, providing an interactive way to study wave phenomena and the speed of sound based on wavelength and frequency.

3.2 Principle

Sound waves generated by an audio frequency generator are fed into the Kundt's tube through a speaker at one end, while the movable piston at the other end serves as a reflecting wall. This setup allows standing waves to form within the tube as the sound waves reflect off the piston. The effective length of the tube can be adjusted by moving the piston, which alters the positions of nodes and antinodes. Unlike standing waves on a stretched string with fixed ends, the air in the tube is driven continuously by the audio generator, resulting in driven waves that oscillate at the frequency of the generator.

To determine the speed of sound, the number of nodes and antinodes is counted, and the initial and final positions of the microphone for nodes and antinodes are measured. The wavelength (λ) of the sound waves is calculated using the formula:

$$\lambda = \frac{2 \cdot (X_2 - X_1)}{n - 1}$$

where X_1 and X_2 are the initial and final positions of the microphone, and n is the number of nodes or antinodes. The speed of sound (V) is then determined using:

$$V = \nu \times \lambda$$

where ν is the frequency of the sound waves. and λ is the wavelength of the sound waves.

4 Experimental Procedure

1. **Initial Setup:**
   - Place the Kundt's tube apparatus on a flat, vibration-free surface to ensure stability and accurate measurements.

- Connect the speaker, headphones, and microphone to the Amplifier-Oscillator Unit. Ensure all connections are secure for proper signal transmission and reception.
- Set the oscillator to a specific frequency within the range of 0.200 kHz to 5 kHz. Record this frequency as ν, which will be used to calculate the speed of sound.

2. **Adjusting Volume and Piston:**

- Adjust the volume of the headphones and speaker to a level where the sound is clearly audible. This helps in detecting the resonance condition more effectively.
- Start with the piston close to the speaker and gradually pull it out. Listen carefully through the headphones to find the position where maximum loudness, indicating resonance, is heard.

3. **Measuring Tube Length and Microphone Position:**

- Note the position of the piston where maximum loudness is observed. This position represents the tube length L, which is the distance from the speaker to the reflector.
- Move the microphone close to the speaker and gradually pull it back. Record the position where maximum (antinodes) or minimum (nodes) sound is heard. This position will be noted as X_1 or X_2.

4. **Counting Nodes/Antinodes:**

- Continue pulling the microphone back slowly and count the number of positions where maximum or minimum sound is heard. This count, noted as n, represents the number of nodes or antinodes in the tube.
- Note the position of the nth point where maximum or minimum sound is observed. This measurement helps in determining the wavelength of the sound waves.

5. **Calculating Wavelength and Speed of Sound:**

- Calculate the wavelength λ using the formula:

$$\lambda = 2 \times \frac{X_2 - X_1}{n - 1} \tag{1}$$

where $\frac{X_2 - X_1}{n}$ represents half the wavelength in millimeters.

- Determine the speed of sound V using the relation:

$$V = \nu \times \lambda \tag{2}$$

where ν is the frequency of the sound waves.

6. **Repeating the Experiment:**

- Repeat the experiment for different frequencies and tube lengths to ensure consistency and accuracy of the results. This helps in understanding the relationship between sound speed, frequency, and tube dimensions.

5 Results and Discussion

We have seen that the wavelength (λ) and velocity ($\mathbf{V}$) can be calculated using equations 1 and 2, respectively.

The data acquired from the experiment is shown in Table 1. The values of Tube Length, Initial Position of Microphone (X_1), Final Position of Microphone (X_2), and Wavelength (λ) are measured in mm.

ν (Hz)	Tube Length	X_1	X_2	n	Lambda	Velocity (m/s)
1000	710	126	595	3	313	313
1500	710	83	626	5	217	326
2000	710	64	661	7	171	342
2500	710	52	671	9	138	345
3000	710	51	681	11	115	345
3500	710	42	686	13	99	347
4000	710	41	692	15	87	348
4500	710	46	696	17	76	342
5000	710	48	698	19	68	340

Table 1: Measured values from the Experiment

From Table 1, we can get the average speed of sound V_{avg} as:

$$V_{\text{avg}} = \frac{313 + 326 + 342 + 345 + 345 + 347 + 348 + 342 + 340}{9}\,\text{m/s} = 339\,\text{m/s}$$

5.1 Error Analysis using Std

The standard deviation or error in V is given by:

$$\Delta V = \sqrt{\frac{\sum(V - V_{\text{avg}})^2}{n}} \text{m/s}$$

Therefore, the percentage error for V is:

$$\frac{\Delta V}{V_{\text{avg}}} \times 100 = \frac{10.95}{339} \times 100 = 3.23\%$$

So, the final value of the speed of sound V is:

$$V = 339 \pm 11 \,\text{m/s}$$

5.2 Error Analysis for Wavelength and Velocity (Maximum Error)[3]

The wavelength λ is calculated using the formula:

$$\lambda = 2 \times \frac{X_2 - X_1}{n - 1} \tag{3}$$

The least count of X_2 and X_1 is 1 mm. The error in λ is:

$$\Delta\lambda = 2 \times \frac{\Delta X_2 + \Delta X_1}{n - 1}$$

Given that $\Delta X_1 = \Delta X_2 = 1$ mm, we calculate the error for each data point. Here are the example data points:

n	X_1 (mm)	X_2 (mm)	λ (mm)
3	126	595	313 ± 2
5	83	626	217 ± 1
7	64	661	171 ± 0.67
9	52	671	138 ± 0.50

For the data set with $n = 3$, the error in λ is the highest, $\Delta\lambda = 2$ mm. We will now use this maximum error to calculate the error in velocity. The velocity V is calculated using the formula:

$$V = \nu\lambda \tag{4}$$

For the maximum error case, we take $\lambda = 313$ mm and $\nu = 1000$ Hz. The error in V is:

$$\Delta V = \lambda \Delta\nu + \nu \Delta\lambda$$

Substituting the values:

$$\Delta V = 313 \times 1 + 1000 \times 2 = 313 + 2000 = 2313 \text{ mm/s} = 2.31 \text{ m/s}$$

Thus, the velocity v is:

$$\boxed{V = V_{\text{mean}} \pm \Delta V = 339 \pm 2.31 \text{ m/s}}$$

5.3 Possible Sources of Error

- **Least Count**: The least count of the scale used to measure X_1 and X_2 is 1 mm, which can introduce errors in the calculation of λ and v.
- **Temperature**: Variations in temperature can affect the speed of sound in air, leading to inaccuracies in the velocity measurements.
- **Humidity**: Changes in humidity can alter the density of air, thereby affecting the speed of sound and introducing errors.
- **Human Error**: Errors in reading the positions of X_1 and X_2 manually can introduce additional uncertainties.

6 Conclusion

The Kundt's Tube experiment determined the speed of sound in air with the following result:

$$\boxed{V = V_{\text{mean}} \pm \Delta V = 339 \pm 2.31 \text{ m/s}}$$

- The average speed of sound was calculated to be 339 m/s.
- The **maximum error** in the velocity measurement was found to be 2.31 m/s.
- The error in wavelength λ was calculated to be 2 mm for the maximum error case.
- Factors such as measurement least count, temperature, humidity, and human error contributed to the observed uncertainties.

7 Author Contributions

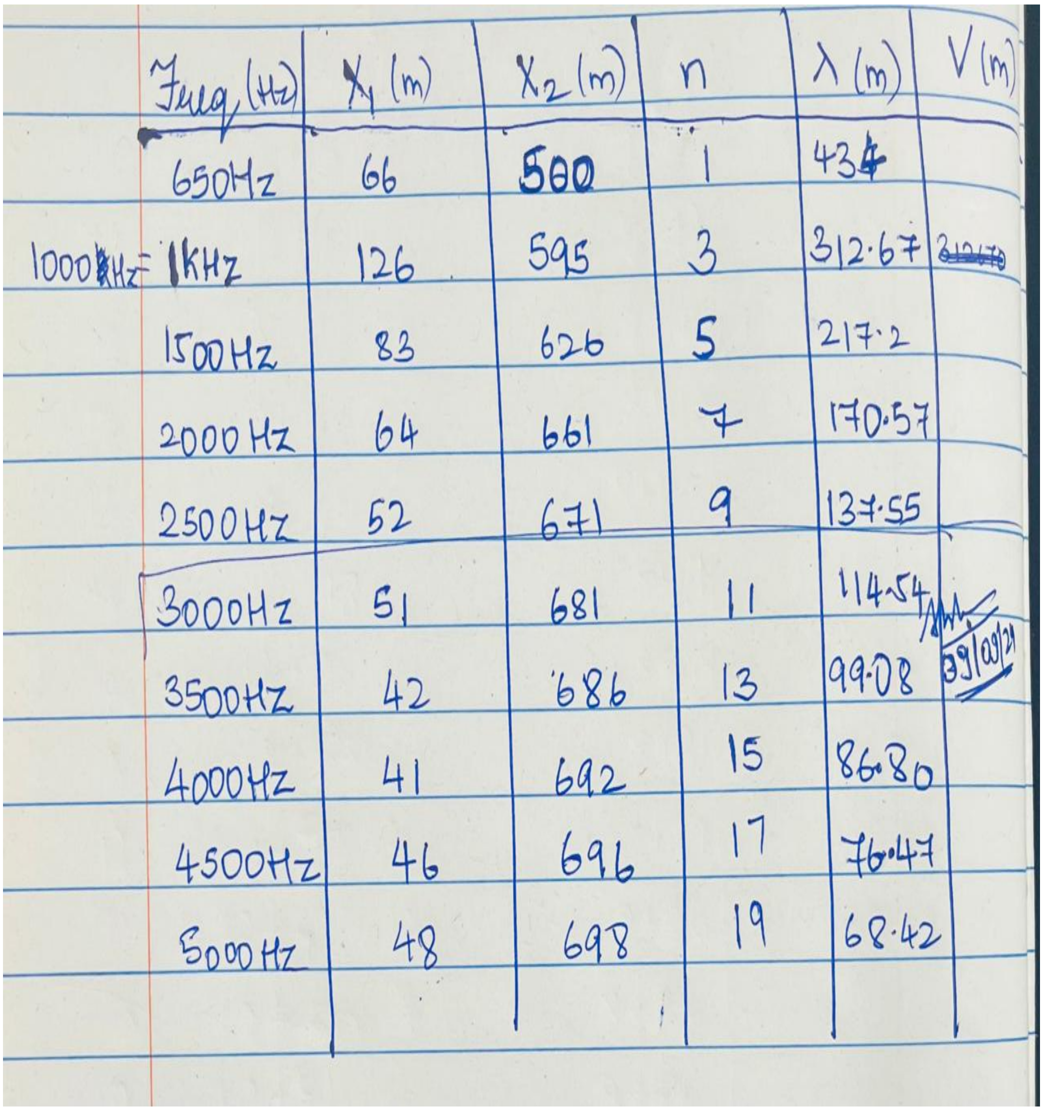
- **Birudugadda Srivibhav**
  - Collected and analyzed the experimental data for wavelength and speed of sound.
  - Created and formatted the tables and figures used in the report.
  - Calculated errors in wavelength and velocity.
- **Vubbani Bharath Chandra**
  - Collected and recorded the experimental data.
  - Formatted and finalized the report.
- **Ankeshwar Ruthesha**
  - Collected and recorded the experimental data.
  - Wrote Objective, Apparatus description, Theory and Experimental Procedure.
- **Kirtankumar Patel**
  - Reviewed and edited the final report for accuracy and consistency.

8 References

1 Holmarc. *Kundt's Tube Apparatus*. Available at: `https://holmarc.com/kundts_tube_apparatus.php`

2 "Kundt's Tube - Wikipedia," Colorado State University, Accessed: Sep. 15, 2024. [Online].

3 Taylor, J. R. (1997). *An Introduction to Error Analysis: The Study of Uncertainties in Physical Measurements*. University Science Books.



Freq (Hz)	X_1 (m)	X_2 (m)	n	λ (m)	V (m)
650Hz	66	500	1	434	
1000 Hz = 1KHz	126	595	3	312.67	~~312.670~~
1500Hz	83	626	5	217.2	
2000 Hz	64	661	7	170.57	
2500Hz	52	671	9	137.55	
3000Hz	51	681	11	114.54	
3500Hz	42	686	13	99.08	29/09/21
4000Hz	41	692	15	86.80	
4500Hz	46	696	17	76.47	
5000Hz	48	698	19	68.42	

Figure 2: Lab Recordings