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**Report Sheet for Experiment 5: Rotational Inertia**

Abstract

In this experiment, standing waves in the resonance tube, which occurred by an interference between opposite waves, are investigated to their properties, including the applying frequency, length of the tube, and what happen at various positions in the tube with standing wave. The relationship between previously mentioned parameters, wavelength, and speed of sound are determined by different strategies including plotting the resonant frequency with integers (first experiment), finding the node and antinode of the wave (second experiment), and subtracting the two tube lengths where resonances happen (third experiment). The calculated speed of sound is close to the theoretical ones leaving some rooms for error, for instance, the length measurements, obstacles for air to propagate energy(results in an energy lost), the selection of the frequency to experiment with, and the continuous compressing of the tube to vary the tube lengths.

Introduction and Theoretical Background

Wave is a way that particles oscillate and propagate energy through the medium which can be categorized by whether the oscillation parallel (longitudinal wave e.g., sound wave) or perpendicular (transverse wave e.g., electromagnetic wave) to the propagation direction. To elaborate more on sound wave, when a source like a speaker vibrates at a certain frequency, the surrounding air transmits the energy by compressing and expanding. Therefore, the particles are moving outward the source. Any waves’ propagation can be described by the wave equation below:

…(1)

By solving above differential equation, the wave function of x-distance and time can be achieved as:

…(2)

where A is the amplitude of the peak, is wave number, is angular frequency, and is phase of the wave. is wavelength of the wave where the position repeats itself and T is the time (period) between those two points. Moreover, the velocity of the wave can be expressed as:

…(3)

<http://electron6.phys.utk.edu/optics421/modules/m1/mechwaves.htm>

When two opposite waves interfere, standing wave can be generated when the reflected wave is perfectly in or out of phase whether the product of them is completely constructive or destructive. The frequency of sound that creates completely constructive waves is called ‘resonant frequency’, that is, the resulting wave has the maxima amplitude(energy).This phenomenon can occur in a tube where waves have a change to interfere, making the condition diverge into two cases: opened tube and closed where the latter case wave can reflect back and constructively interfere.

Therefore, one of the factors governing the occurrence is the length of the tube which its relationship with the resonant frequency, which in a closed tube situation, is

where L is the tube’s length, is the wavelength, and n is 1,2,3,4,…

On the other hand, in an opened tube (open at both ends), resonance can happen only when the wavelengths are in the following relationship:

where n is 1,2,3,4,…

A picture containing graphical user interface

Description automatically generatedcombining above equation with the velocity-frequency-wavelength relationship, the resonant frequency, wave velocity, and tube’s length can be derived as:

…(4)

Figure 1 displays standing wave in opened and closed tubes[2]

Lastly, since sound is the propagation of gas molecules in the air, there is one more variable, affecting the experiment which is temperature of the atmosphere. It directly affects the kinetic energy of the molecules and thus the speed of the wave as follows[3]:

vair = 331.5 +0.6T [m/s] …(5)

Methods

1. Set the resonance tube, oscilloscope, function generator, and microphone

Part A – Resonant Frequency of a Tube

1. Increase the frequency gradually and record the frequency when the sound noise is the highest
2. Repeat with closed-end tube

Part B – Standing wave in a Tube

1. Set the frequency to be 559 Hz (the frequency should be one of the resonant ones found in the prior experiment) and use microphone to detect the noise at different positions in the open-ended tube
2. Record the maximum noise and minimum noise positions of the tube
3. Repeat with closed-end tube and change the frequency to 677 Hz

Part C – Tube lengths and resonant nodes

1. Set the frequency to 800 Hz and start moving the pistol so that the length of closed-end tube is getting larger
2. Record the tube lengths when resonance is happening
3. Repeat with changing frequency to 850, 900, and 950 Hz.

Results

The temperature in the laboratory room is 16, therefore, the theoretical sound’s speed is 331/5 + 0.6(16) = 341.1 m/s

**Part A – Resonant Frequency of a Tube**

From the experiment, when the resonant frequency and n as integer is plotted together, a linear relationship can be achieved. This confirms the equations above.

Chart, line chart

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Figure 2 displays linear relationship of resonant frequency and number

Since fn = (v/2L)n for opened tube and fn = (v/4L)n for closed tube, the slopes of the fitted line above refer to the value in the parenthesis. Therefore, the speed of sound can be calculated and summarized in the Table1 below. An example for such calculation is done as follows.

Fitted line: fn = (187)n - 0.6 🡪 slope = 187 1/s (another line: fn = (245)n + 0.2 )

Speed of sound = 2\*0.9\*187 = 336.6 m/s

%Error = (336.6-341.1)/341.1\*100 = -1.32%

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Experiment | Slope (1/s) | Tube Length (m) | Sound speed (m/s) | %Error |
| Opened tube | 187 | 0.9 | 336.6 | -1.32% |
| Closed tube | 245 | 0.7 | 343 | 0.56% |

Table 1 summarizes the slope from Figure1, tube lengths, sound speed and their error

**Part B – Standing wave in a Tube**

|  |  |  |
| --- | --- | --- |
| Experiment | Maxima positions (cm) | Minima positions (cm) |
| Opened tube | 15.5, 46, 76.5 | -1, 29.5, 60, 91 |
| Closed tube | 10.5,37.2, 62 | -1, 24.7, 49,7 |

Table 2 shows the maxima and minima results from the experiment

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Experiment | # Nodes | #  Antinodes | Average distance (m) | Wavelength (m) | Wavelength from v(T) (m) | Frequency (Hz) | Sound speed (m/s) | Speed %Error |
| Opened tube | 3 | 4 | 0.151 | 0.604 | 0.610 | 559 | 337.636 | 0.29% |
| Closed tube | 3 | 3 | 0.12875 | 0.515 | 0.504 | 677 | 348.655 | 0.30% |

Table 3 summarizes the average distance between node and adjacent antinode, calculated wavelength, sound speed, and their error

By counting the maxima and minima positions and infer to Figure1, the opened and closed tube experiments are 3rd and 5th harmonic, respectively. Furthermore, the distance between node and antinode equals to one fourth of the wavelength. So, the distances are averaged out and multiplied by four to get the wavelength. Then the sound speed and %error are calculated the same way as Part A. An example for such calculation is done as follows.

Average distance = [(29.5-15.5)+(46-29.5)+(60-46)+(76.5-60)+(91-76.5)]/5/100

= (91-29.5)/5/100 = 0.151 m

Wavelength = 0.151\*4 = 0.604 m

Speed of sound = 559\*0.604 = 337.636 m/s

%Error = (337.636-341.1)/341.1\*100 = -1.32%

**Part C – Tube lengths and resonant node**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Frequency (Hz)** | **Tube lengths to make resonance (m)** | | | | **Average wavelength (m)** | **Wavelength from v(T) (m)** | **Sound Speed (m/s)** | **Speed %Error** |
| 800 Hz | 0.585 | 0.36 | 0.15 |  | 0.435 | 0.426 | 348 | 2.02% |
| 850 Hz | 0.525 | 0.32 | 0.115 |  | 0.410 | 0.401 | 348.5 | 2.17% |
| 900 Hz | 0.673 | 0.48 | 0.29 | 0.098 | 0.383 | 0.379 | 345 | 1.14% |
| 950 Hz | 0.63 | 0.45 | 0.268 | 0.095 | 0.357 | 0.359 | 338.83 | -0.66% |

Table 4 summarizes the tube length that make resonance, calculated wavelength, sound speed, and their error

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Frequency (Hz)** | **Wavelength from v(T) (m)** | **Ratio between tube length and wavelength** | | | |
| 800 Hz | 0.426 | 1.49 | 0.92 | 0.38 |  |
| 850 Hz | 0.401 | 1.34 | 0.82 | 0.29 |  |
| 900 Hz | 0.379 | 1.72 | 1.23 | 0.74 | 0.25 |
| 950 Hz | 0.359 | 1.61 | 1.15 | 0.68 | 0.24 |

Table 5 summarizes the ratio between tube lengths and theoretical wavelengths

The distance between the positions where resonance is happening is half of the frequency of the sound, since there are more than just one couple of points, so, the distances are averaged out and summarized. The speed of the sound is then calculated with the multiplication of the frequency used and the acquired wavelength. The example of 800 Hz experiment calculation is as follows.

Have of wavelength = (0.585-0.36 ), (0.36-0.15)

Wavelength = 2\*(0.585-0.36 ), 2\*(0.36-0.15)

Average wavelength = (0.585-0.36 )+(0.36-0.15) = 0.435

Speed of sound = 800\*0.435 = 348 m/s

%error = (348-341.1)/341.1\*100 = 2.02%

Discussion

In the first experiment, closed opened and closed tube are used when applying sound with varying frequency and the frequency where the resulting amplitude of the sound is locally high is recorded, naming resonant frequency. When there are antinodes at the opening end (1 for closed and 2 for opened), that resonance is called the first harmonic as depicted in Figure 1. The different resonant frequencies happen when the constructive interference of the sound waves happen at higher harmonics. From the derivation in the Introduction leaving the equation 4 which describes the relationship between the resonant frequency and the integers(1,2,3,4) as a linear one as expected. The slope of such lines can be further used to calculate the velocity of the sound by multiplying it by 2 times the length of the tube. The calculated speed has only -1.32% and 0.56% in an opened and closed tube set, respectively. This small deviation might come from the length measurement that is not accurate enough, the close-ness of the tube that the lit does not cover/fit the tube’s diameter completely, or the open-ness that there still be some obstacles at the opening end of the tube.

Furthermore, the second experiment the position dependence of the standing wave by measuring where the peaks (maxima) and the node (minima) occur. The fact that the distance between the amplitude is zero to when it is at either peak is one-fourth of the whole wavelength enables us to find the speed of sound from that particular frequency. The obtained sound speeds are 337.6 and 348.6 m/s, a 0.29% and 0.30% error, for opened and closed tube respectively. The error except the ones listed in the first experiment can be caused in the opened tube when the resonant frequency is not used, therefore, the wavelength can be varied, so the phase changes, and the positions where waves interfere shift.

Finally, different lengths of closed tube are varied to find at which length and frequency of sound, resonance will occur. Wavelengths are calculated as twice the difference between each length. The speeds of sound are then calculated and compared with the theoretical value. The result yields a slightly higher error compared to the first two experiments at -0.66% to 2.17%. Subsequently, the proportion between the length of the tube and the wavelength (both from previous calculation and from experiment one calculation results in the same trend) are calculated and are not in integers or halves of those as expected. This might come from the selection of the frequencies(800 to 950 Hz), which from the experiment 1, will create resonance in a higher harmonic, making the distance between resonances becomes shorter, hence, the error from length measurements might be amplified. One other possible cause is the continuous measurement which the tube cover is continually move closer to the other end, making the reflection of waves not happen consistently, the phase and therefore distance might be shifted from this procedure.

Conclusion

In conclusion, the wavelength and speed of the sound can be determined by both opened and closed tube experiment. With the changing parameter, for example, sound frequency and tube lengths, the resulting sound wave differs and at one local maximum where the amplitude is high, resonance is investigated. First, standing wave in an opened and closed tube is used to find and compare speed of sound and results 336 and 343 m/s. The error could come from the length measurements, how covered the tube is closed and how open the tube is opened, otherwise the energy dissipation of the standing wave will happen at lower efficiency than it would be expected. Secondly, the amplitude of standing wave versus distance is explored by measuring nodes and antinodes of the wave. Wavelengths are calculated by multiplying the distance between node and antinode by four. This results in an accurate and precise speed of sound with error of 0.3% and 0.29%. Finally, different lengths of closed tube are varied to find at which length and frequency of sound, resonance will occur. This supposed to find the ratio between the tube’s length and the calculated wavelength as integers and halves of those, however, the experiments do not get along well with that. The higher harmonics might lead to this. Moreover, the continuous measurement which the tube cover is continually move closer to the other end, making the reflection of waves not happen consistently, the phase and therefore distance might be shifted from this procedure.

Reference

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