Determining Speed of Sound, Frequency, and Beat Patterns

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Abstract

Sound waves can travel through any media, and exhibit interesting properties. In this experiment, using Vernier LabQuest and a microphone, the speed of sound was measured. Also the frequency of two tuning forks was obtained, and the beat pattern due to the combination of these two tuning forks was plotted. After analysis, it was found that the speed of sound was 349.932 62 m/s, that the plot of pressure amplitude of tuning forks is sinusoidal with time, and that the amplitude of a beat pattern changes periodically with its beat frequency equal to the difference in frequency of the tuning forks.

Keywords: speed of sound, harmonic waves, beat pattern

1. Introduction

Sound is a type of mechanical longitudinal wave which can travel through any media except through vacuum. It is caused by the vibration of a source which, in turn, pushes the surrounding air molecules. It is perceived if sound waves reach one's eardrum.

Like any other mechanical wave, the speed at which sound propagates depends on the media's elastic and inertial properties [1]. This implies that sound travels at different speeds in solids, liquids, and gases. When sound travels through a solid or liquid, the fluid's bulk modulus, or solid's elastic modulus, and the media's density can affect the speed at which it propagates.

However, the speed of sound in a gas depend on different factors. Gas is a fluid, and hence, the speed at which sound propagates depend on the gas' bulk modulus and density. The gas' bulk density is dependent on its pressure and adiabatic constant γ. This, and using the ideal gas law, one can express the speed at which sound propagates in gas as:

$$v_{s,\text{theo}} = \sqrt{\frac{\gamma k T}{m}} \tag{1}$$

where k is Boltzmann's Constant, having value of 1.3806×10^{-23} J/K, T is the gas' temperature in Kelvin, and m is the mass of one molecule in kilograms. In dry air, $\gamma k/m = 401.880$ m^2 s^{-2} K^{-1}. This shows that the speed of sound in a gas is entirely dependent on the gas' temperature.

As sound waves propagate, a small volume of molecules compress and expand. Since there is compression and expansion, one can say that the pressure in that volume of molecules changes through time. This pressure changes sinusoidally with time because molecules oscillate in the same behavior. Furthermore, the maximum amount at which these molecules expand and compress is known as the pressure amplitude [2].

Since pressure changes in a sinusoidal manner, one can speak of the wave's period T and frequency f. The time in which a volume of molecules expands and compresses once is the wave's period, and the number of waves that passes through a period of time is known as the waves' frequency. Given this, one can say that the wave's period is the reciprocal of its frequency.

When sound waves interfere one another, the interference can either be destructive or constructive. Consider two waves of slightly different frequencies interfering with one another. One notices that these waves are periodically out of phase, therefore when one hears these frequencies combine, one perceives sound that changes amplitude periodically [3]. This phenomenon is known as a beat. As with sound waves, one can say that a beat's frequency is equal to the reciprocal of its period. However, given that the beat is a combination of two frequencies f_1 and f_2, the corresponding frequency of the beat, or beat frequency f_b, is given as:

$$f_{b,\text{theo}} = |f_1 - f_2| \tag{2}$$

In this experiment, the speed of sound, the frequencies of two individual tuning forks, and the beat frequency produced when both tuning forks were struck simultaneously were measured and compared with their corresponding theoretical values by calculating the percent deviation between the measured and calculated values.

2. Methodology

The length l of a PVC Pipe and the temperature of the room was measured using a meter stick and the internal thermal sensor of the Vernier LabQuest respectively. Then a microphone was attached to the Vernier LabQuest, which was preset to gather data only when the air pressure reached some threshold pressure.

The microphone was then placed near the open end of the PVC pipe, and using Vernier LabQuest, the time Δt between the snapping of fingers and the first echo was measured three times, after which the speed of sound was calculated using the following expression:

$$v_s = \frac{2l}{\Delta t} \tag{3}$$

The theoretical speed of sound was calculated using the measured temperature and equation (1), and the percent deviation between the measured and theoretical values were calculated.

The frequency of two tuning forks were then measured. Hitting the rubber with one tuning fork close to the microphone, the pressure variations due to the vibrating tuning fork was measured over a span of three hundredths of a second. From the resulting plot, five nearly similar cycles was chosen and fitted with a sine function of the form:

$$y(x) = A \sin(Bx + C) + D \tag{4}$$

The resulting frequency f was then calculated using the B value from the fit using the expression:

$$f = \frac{B}{2\pi} \tag{5}$$

This was done three times with each tuning fork, after which all values were averaged and compared with the theoretical frequency engraved on the tuning forks themselves by calculating the percent deviation.

Lastly, the beat frequency was measured. The rubber was struck with the two tuning forks simultaneously and the pressure variations due to the vibrating forks was measured over the same time period. The period of one cycle was then measured with the plot. This was done three times after which the average period was calculated, and the corresponding frequency was measured. The theoretical beat frequency was then calculated using equation (2) and compared with the measured frequency by calculating the percent deviation.

3. Results and Discussion

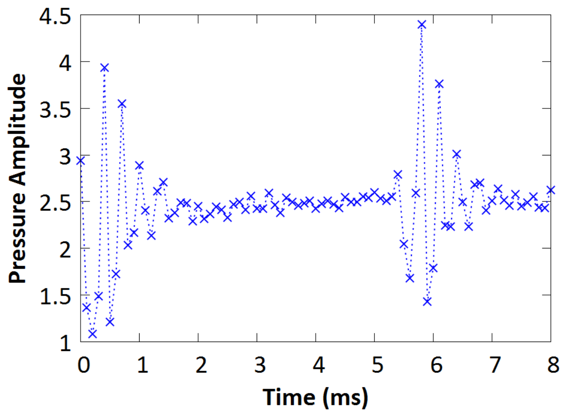

Figure 1: Pressure Amplitude vs. Time Plot for the Second Trial during the Measurement of the Speed of Sound. The speed of sound was measured by snapping one's fingers by the open end of a PVC Pipe. The plot shows the change in air pressure when the snap was done and the first echo. The first peak is the time at which the snap occured, and the second peak the time at which the echo reached the microphone. As observed, sound waves does propagate at some speed, which can be calculated using the length of the PVC pipe and the difference in time between the two peaks.

Figure (1) and table (1) show and summarize the data acquired during the measurement of the speed of sound in the room. It is observed in figure (1) that there are two distinct peaks. These peaks were formed due to the snapping of the fingers and the echo produced by the reflection of sound waves on the

Table 1: Speed of Sound Calculation

$\langle v_s \rangle$ (m/s)	349.62963
Temp. (K)	304.7
$v_{s,\text{theo}}$	349.93262
% Deviation	0.08658

other end of the PVC pipe. From the graph, since there is a time gap between the peaks, then one can say that indeed sound propagates through the air at some definite speed. Table (1) shows the calculated values for the speed of sound for the three trials, including the measured temperature of the room at the time of the measurement, and the theoretical speed of sound. As shown in the table, one can say that the theoretical expression for the speed of sound traveling through the air is valid, and indeed the speed of sound through the air is dependent entirely on its temperature.

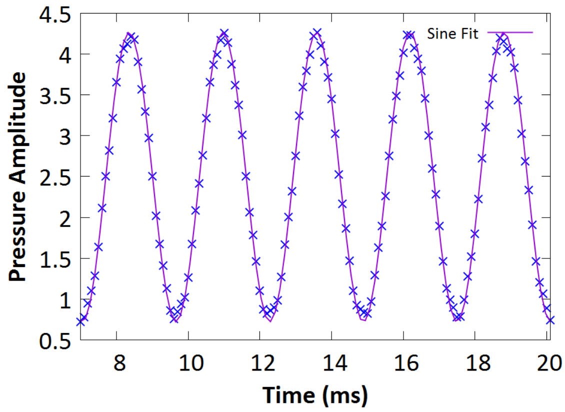

Figure 2: Pressure Amplitude vs. Time Plot for the Second Trial during the Measurement of the Frequency of the G Tuning Fork. As shown in the figure, the pressure amplitude changes in a sinusoidal manner in time, as expected. Furthermore, the pressure amplitude stays approximately the same if only one frequency is being sensed. The equation for the sine fit in the figure is $y = 1.7736 \sin(2404.3x + 0.34132) + 2.4947$ given that the time is in seconds. In this case $B = 2404.3$

Table 2: Tuning Forks Frequency Calculation

Tuning Fork Tone	$\langle T_{\text{expt}} \rangle$ (ms)	$\langle f_{\text{expt}} \rangle$ (Hz)	% Deviation
C (512 Hz)	1.94916	513.04064	0.20320
G (384 Hz)	2.61248	382.77854	0.31809

Figure (2) and table (2) on the other hand shows and summarize the data obtained while measuring the experimental frequencies of the two tuning forks used in the experiment. It is seen in Figure (2) that the pressure amplitude of a sound wave consisting of one frequency changes sinusoidally with time, as it can be fitted with a sine function. Fitting the sine function, one gets a function $y = 1.7736 \sin(2404.3x + 0.34132) + 2.4947$, so $B = 2404.3$ and hence the frequency of the graph can be calculated with equation (5) to be:

$$f = \frac{B}{2\pi} = \frac{2404.3}{2\pi} \approx 382.65623 \tag{6}$$

Hence the frequency of the sine function in figure (2) is 382.656 Hz, which is close to the supposed 384 Hz of the G tuning fork.

Table 3: Tuning Forks Frequency Calculation

$\langle T_{\text{beat}} \rangle$ (ms)	$\langle f_{\text{beat,expt}} \rangle$ (Hz)	$\langle f_{\text{beat,theo}} \rangle$ (Hz)	% Deviation
7.800	128.20513	128.00	0.16026

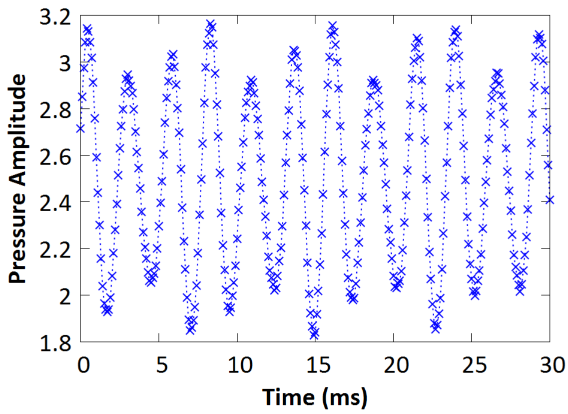

Figure 3: Beat Pattern of Two Tuning Forks for the First Trial of this Part of the Experiment. The Amplitude of the Beat Pattern changes periodically, as expected, due to the two frequencies being out of phase periodically, hence the points where they constructively and deconstructively interfere are periodic as well, and is shown here in this plot. One period of the beat pattern is equal to the time difference between two peaks or two low points.

Finally, figure (3) and table (3) summarizes the obtained data for determining the beat patterns when the rubber hit both the C and G tuning forks simultaneously. An immediate observation would be that figure (3) is very different compared to figure (2). Figure (2) has uniform amplitude, while the amplitude in figure (3) varies periodically. One explanation to this difference is due to the fact that the pattern is due to the combination of two frequencies. However, a more substantial way to account for this difference is due to the two frequencies not being in phase periodically, which results to the combination of the individual waves to constructively and deconstructively interfere at the same time intervals. Therefore there are points where there is total constructive and total destructive interference.

The obtained data however, as shown in Figure (3) does not really highlight what the beat pattern should really look like. As there is background noise, the tuning forks not vibrating at the same amplitude could have affected the data in such a way that interference was not maximized. Nevertheless, as shown in table (3), there is only a 0.16026% deviation between the experimental frequency with the theoretical frequency, which is very small.

4. Conclusion

As obtained in the experiment, the speed of sound is 349.629 63 m/s, with a 0.086 58% deviation from the theoretical speed of sound as calculated by measuring the temperature of the room. Furthermore the pressure amplitude of the air around the tuning forks, while it is vibrating, behaves in a sinusoidal manner with respect to time, with its frequency equal to the reciprocal of the waves period. Lastly the pressure amplitude of the air while two tuning forks are vibrating does change periodically with its frequency equal to the difference of the frequencies of the individual tuning forks.

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