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Research Article

Construction of Resonance Tube Apparatus to Investigate the Speed of Sound

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Abstract

Resonance is a phenomenon when a system undergoes a forced vibration such that the natural frequency of the system matches the frequency of the forced vibration thereby making the system to vibrate with the maximum amplitude. With a focus resonance on an acoustic system such as a column of air, resonance will result in amplification of sound waves. Based on this principle, a resonance tube apparatus was designed and constructed to investigate the speed of sound in air. The apparatus consists of sound generator and glass tube of length 1 meter. Sound wave of different frequencies from 304 Hz to 765.4 Hz was used in an experiment to determine the velocity of sound in air at room temperature. The speed was found to be 343.9 m/s within the limit of experimental error.

Keywords: Resonance; Acoustic; Sound; Sound Generator

Introduction

Natural frequency is the rate at which an object or system vibrates when it is disturbed. All objects have different natural frequencies of vibration. These natural frequencies of vibration depend on certain properties of these objects such as tension, linear density, temperature and length which affects either the wavelength or speed of the object (the Physics Classroom, 2022). According to Singh and Graf (2003), when forces are applied to these objects at their natural frequencies of vibration (i.e. when the forced frequency equals the natural frequency), they vibrate with maximum amplitude. This phenomenon is termed resonance.

Resonance has been observed in mechanical system, acoustic system, electromagnetic system, and a nuclear-magnetic system. Acoustic resonance finds application in musical instruments where it is used to produce or amplify sound waves. Hearing in mammals has been attributed to acoustic resonance [1].

A common laboratory experience encountered by students of physics is an experiment which utilizes the concept of acoustic resonance to compute the speed of sound in air. Commonly, the experiment involves setting up of a standing wave pattern in a tube that is closed at one end, by striking a tuning fork just above the tube and changing the effective length of the tube until a loud hum emanating from the top of the tube or within the tube is heard. The effective length of the tube can be changed by raising the tuning fork and a tube partially submerged in water or by withdrawing a plunger from the tube.

When hum is heard, a standing wave pattern is set up inside of the tube, with an antinode at the open end and a node at closed end. This makes the distance between the open end and the closed end approximately three-quarter of wavelength of the standing wave. With the knowledge of the length of the tube which causes this phenomenon and the frequency of sound used, the speed of sound can be easily computed. The major drawback of this method is the difficulty in moving the tuning fork and the tube simultaneously and the need to repeatedly tap the tuning fork as its oscillation dampens [2].

In this paper, we describe the design and construction of a resonance tube apparatus which was then used to investigate the speed of sound in air. The apparatus consists of a sound generator based on Wien Bridge oscillator and an audio amplifier in place of a tuning fork. This eliminates human error and also allows the student or user to obtain much more accurate results.

Methods

The Resonance tube apparatus consists of a wooden box that houses the electronic board. A glass tube of length 1.0 m and inner diameter 400 mm, with a plunger is mounted on the box as shown in Figure 1. A metre rule is mounted alongside the tube.

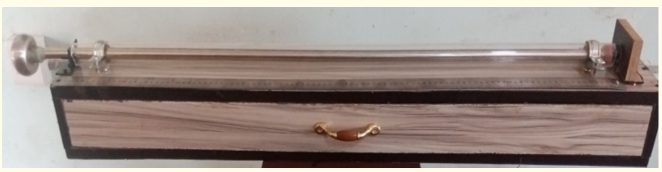

Figure 1: Resonance Tube.

A loudspeaker that is connected to the sound generator is mounted at a distance of 1.0 cm from one end of the tube. Figures 2 and 3 show the circuit of the Wien bridge oscillator and the audio amplifier respectively. The apparatus can be described by the block diagram (Figure 4).

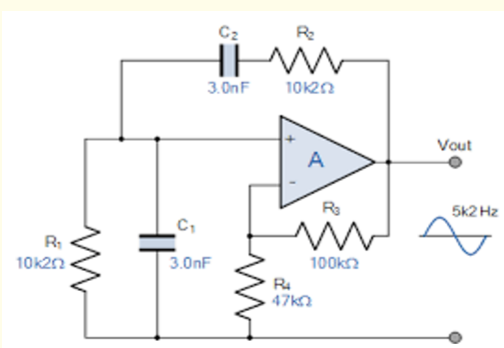

Figure 2: Circuit of Wien Bridge Oscillator.

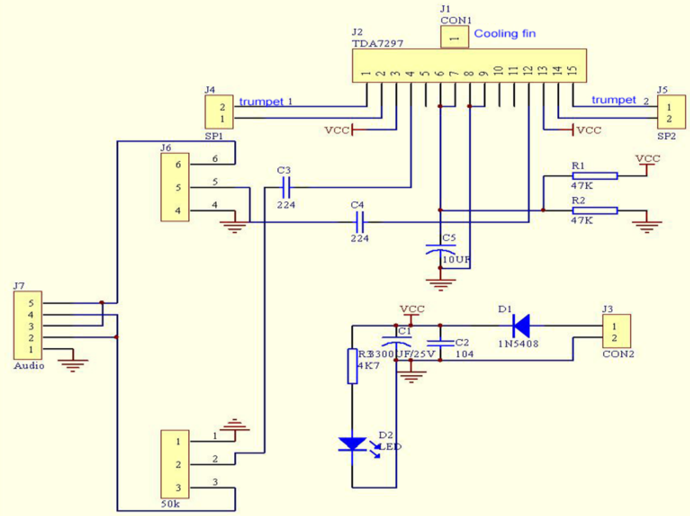

Figure 3: Audio Amplifier Circuit.

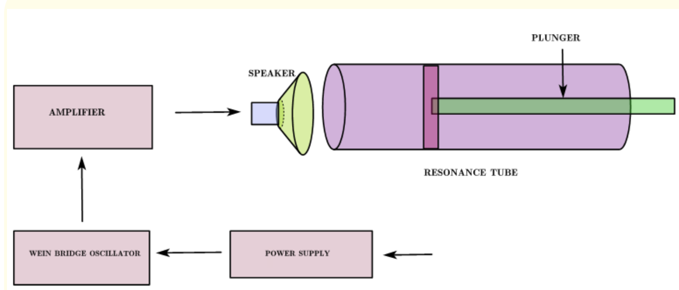

Figure 4: Block Diagram of Resonance Tube Apparatus.

Operation of the apparatus

The Wien bridge oscillator generated a sine wave signal of a particular frequency which was amplified by the audio amplifier. The loudspeaker which was placed at one end of the tube produced the sound waves. The speaker sets up a standing wave pattern in the tube. The antinode of the wave was at the open end of the tube near the speaker and the node is established somewhere in the tube. As the plunger was slowly drawn away from the speaker, the effective length of the tube increased. When the length of the tube is one-quarter of the wavelength of the emitted sound, resonance occurred and the loud sound was heard. Then the length of the tube was measured as L_1. As the plunger moved further, a second resonance point at which the effective length of the tube was three-quarter of the wavelength of the sound was obtained. The standing wave pattern in the tube at the first and second resonance points, (FRP and SRP respectively) is shown in figure 5.

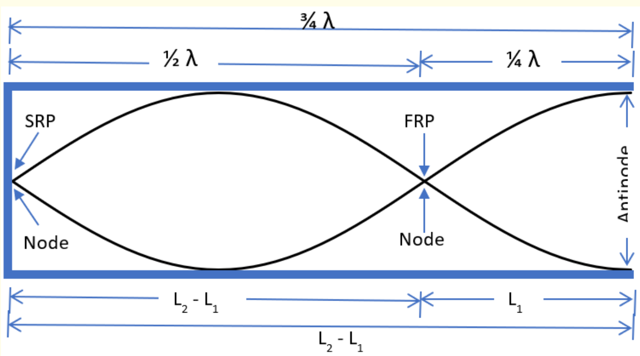

Figure 5: Standing Wave in a Tube with One-closed End.

In theory, $L_2 - L_1 = \frac{1}{2}\lambda$,

$$2(L_2 - L_1) = \lambda$$

The relationship between the speed of sound wave (V) with frequency (f) and wavelength (λ) is given by $V = f\lambda$

Therefore, $V = f.2(L_2 - L_1)$

$$f = V.\frac{1}{2(L_2 - L_1)} \text{ i.e., } f = V.\frac{1}{\lambda}$$

The gradient of a graph of 'f' against λ will give a constant, which is the velocity of the wave (V). The speed of sound varies with temperature. It increases with increase in temperature. On average, for every 1° C change in temperature, the speed of sound increases by 0.61 m/s [3].

Result and Discussion

Table 1 shows the effective lengths obtained at first and second resonance at any given frequency of oscillation. A graph showing the dependence of frequency on inverse wavelength is shown in

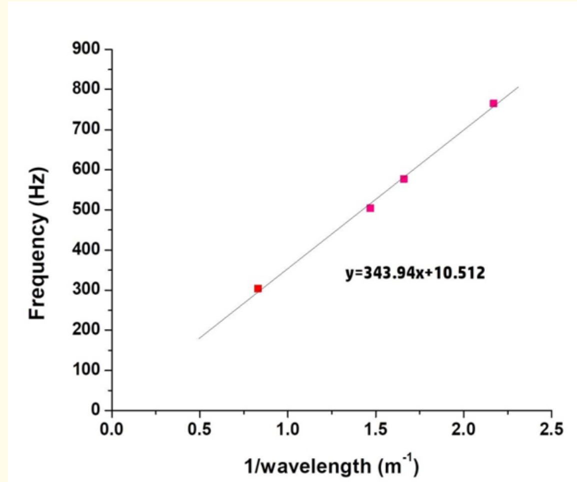

Figure 6: Graph of Frequency Against Inverse Wavelength.

figure 6. The value of the speed of sound in air at normal temperature and pressure 0° C is given as 332 m/s [3].

The result from the graph shows that the speed of sound in air at the time of the experiment is 343.9 m/s. The increase by 11.9 m/s from the standard could be attributed to the room temperature at the time of the experiment. According to [3], the relationship between temperature and speed of sound in air is

$$\frac{V_{NTP}}{V_\theta} = \sqrt{\frac{273}{273+\theta}}$$

Where,

V_{NTP} is speed of sound in air at Normal temperature and pressure 0° C = 332 m/s,

V_Θ is speed of sound in air at given temperature Θ

With the above relation, imputing V_Θ = 343.9 m/s, the value of Θ is 20.5° C which is the room temperature at the time of the experiment. According to William (2004) [4], the speed of sound in dry air at 20° C is 343.2 m/s

Frequency (Hz)	L_1 (m)	L_2 (m)	$\lambda = 2(L_2 - L_1)$ (m)	$1/\lambda$ (m^{-1})
304.0	0.285	0.890	1.210	0.83
504.0	0.175	0.515	0.680	1.47
577.0	0.150	0.452	0.604	1.66
765.4	0.120	0.350	0.46	2.17

Table 1: The Effective Lengths at Resonance for Different Frequencies.

Conclusion

The apparatus was found to be easy to use for determining the speed of sound in air since it does not involve moving the sound source and the tube during the experiment as in the case of the use of tuning fork and the tube partially submerged in water. The amplitude of the sound can be adjusted to the desired level. The speed of sound in air at the prevailing temperature and the time of the experiment were found to be 343.9 m/s.

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