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Development and Utilization of a Modified Resonator Tube Apparatus for Sound Wave Experiments

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ABSTRACT

Acoustic resonance is a physical phenomenon in which in-phase sound waves combine together to produce maximum amplitude; on the other hand, out-of-phase sound waves cancel each other to produce minimum amplitude. The purpose of this study is to investigate and demonstrate this phenomenon with the use of a reliable device. This study requires a modified resonator tube apparatus to be developed and fabricated from locally-available materials for the purpose of demonstrating resonance and normal modes of sound waves. Air column length versus harmonic number (L vs n) and frequency versus harmonic number (f vs n) experiments were performed together with open-pipe and stopped-pipe procedures. For L vs n experiments, deduced value of speed of sound is 337.79±0.94 m/s at 760 Hz for open-pipe taken at 29°C; and 357.72±9.34 m/s at 412 Hz for stopped-pipe taken at 25°C. For f vs n experiments, deduced value of speed of sound is 337.09±5.98 m/s at 2.30 m for open-pipe taken at 25°C; and 345.92±5.55 m/s at 1.60 m for stopped-pipe taken at 30°C. Results had shown that the modified resonator tube apparatus is accurate and precise within 5% margin of error. Therefore, the apparatus is a reliable device in demonstrating acoustic resonance phenomenon in the physics classroom setting.

Keywords - Physics, Sound Waves, Resonance, Normal Modes, Experimental Method, Philippines

INTRODUCTION

There are several classroom demonstrations and laboratory activities concerning wave motion in general and sound waves in particular. Inman (2006) performed a standing-wave experiment with a guitar; in which, standing waves could be produced on a vibrating string by plucking a guitar string which is fixed at both ends. LoPresto (2005) introduced a correction factor for resonance experiments involving a quarter-wave tube. Froehle (2006) utilized the resonance of sound waves being produced by a tuning fork and extending tube in order to deduce the outdoor temperature.

Glass-tube resonance apparatus has been widely used as the conventional apparatus in demonstrating and performing resonance and normal modes experiments. However, we can only perform and obtain stopped-pipe results by using this type of resonance apparatus. The experimenter needs to secure himself a complete set of expensive tuning forks to perform the experiments. Water spillage due to leaky rubber tubes, poor tube fittings and cracked glass tubes are commonly experienced by students who repeatedly use this kind of resonance apparatus in the laboratory. Moreover, a teacher who wishes to bring the entire setup with him has to give extra caution to avoid breakage during transportation.

Pasco Scientific, Inc. came up with the Economy Resonance Tube model WA-9495 (Pasco Scientific, 2005). Acoustic resonance could be demonstrated inside the resonance tube without the need for water. Even though the resonance tube is made up of cardboard material, the necessary accessory devices such as sine-wave generator and open-type speaker are to be bought separately and are very much expensive compared to the resonance tube itself. The entire resonance tube setup would not function without the necessary accessory devices.

OBJECTIVES OF THE STUDY

The main objective of this study is to construct a modified resonator tube apparatus in order to demonstrate and perform experiments in wave propagation and normal modes for open and stopped pipes. The specific objectives are the following:

a. To verify the relationship between air column length and harmonic number of normal modes produced by a discrete frequency;
b. To verify the relationship between frequency and harmonic number of normal modes produced by a selected discrete frequency; and
c. To compare the deduced speed of sound waves to the standard speed of sound waves obtained at room temperature.

METHODOLOGY

The procedures of construction and experimentation using the modified resonator tube apparatus are discussed in this chapter. We designed the apparatus with the use of locally available materials through innovative improvisations.

Experimental Design

Figure 1 shows the block diagram of experimental set-up. Portable music player stores and plays discrete sound frequencies in mp3 format. This signal is amplified by a power amplifier and passes the amplified signal to three open-type speakers. Each speaker delivers sound signal through its corresponding PVC tube set-up, which is made up of an inner and outer tube. An acrylic cap is placed to cover either edge of the inner tube when performing stopped-pipe experiments.

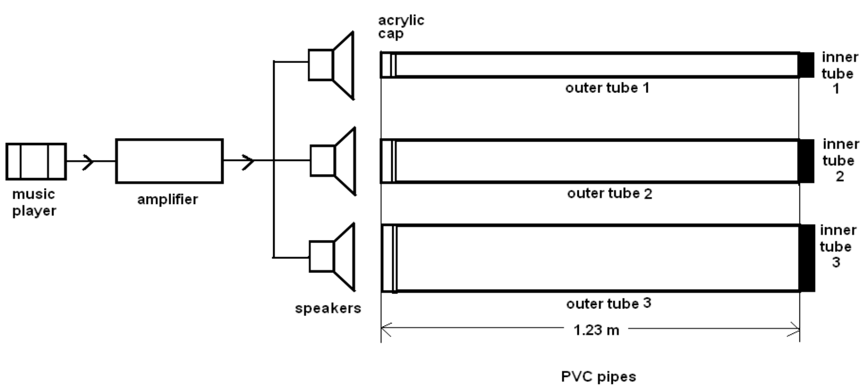

Figure 1. Block diagram of the modified resonator tube apparatus.

Frequency Signals

Frequency signals are discretely generated, pre-recorded and stored to a music player device. Room temperature is measured using a digital thermometer. Table 1 shows the frequencies that were predicted for a tube length of 240 cm.

Table 1. Number of harmonics and corresponding frequencies of sound for both open-pipe and stopped-pipe experiments as taken at room temperature of 300K and air column length of 240 cm.

Number of Harmonics	Frequency (Hz)	
	Open-pipe	Stopped-pipe
1	72.6	36.3
2	145.2	72.6
3	217.7	108.85
4	290.3	145.15
5	362.8	181.4
6	435.4	217.7
7	507.9	253.95
8	580.5	290.25
9	653.1	326.55
10	725.6	362.8

Table 1 shows the following normal modes and corresponding frequencies. Taking the speed of sound at 300K as 348.3 m/s, the first harmonic for the full-length of 240 cm occurs at 72.6 Hz. To observe ten harmonics for both open-pipe and stopped-pipe of length 240 cm, the frequency to be used must be in the range of 35 Hz to 750 Hz.

Music Player Device

An MP3 player is designated as store-and-play device for discrete frequencies of sound which are recorded in mp3 format. This is only an accessory to the project and the experimenters do not manufacture one but just purchase it commercially.

Power Amplifier

A 750mW power amplifier served as an accessory device to boost the sound signal coming from the mp4 unit. The output volume of sound can be adjusted using the volume control of the power amplifier.

Speaker Setups

We used three pieces of 3-inch diameter, hi-fi midrange speakers with 8Ω impedance and 30W maximum power output to drive sound frequencies into the PVC pipes. Each of the speakers is mounted to a 14 cm x 14 cm plyboard square so that the speaker can stand vertically opposite to the edge of the PVC pipe. The plyboard square is mounted to a support base on the wooden platform to guarantee firm footing. Since there is no plyboard covering around the back of the speaker, therefore we call it an *open-type* speaker.

Resonator Tube Setups

The improvised apparatus is made up of three PVC tube set-ups with different diameters; namely, Tube set-up 1, Tube set-up 2 and Tube set-up 3. The inner and outer tubes are 123 cm long each.

Wooden Platform

A wooden platform is designed to support the entire setup in place. It is made of 45 cm x 150 cm, ½-inch thick marine plyboard. Each of the speakers is mounted to a wooden base while the horse clamps that will hold the PVC pipes are mounted on the board by using wood screws and washers.

Construction Procedure

The entire apparatus is practically designed in a way that the parts could be conveniently assembled and disassembled. The following steps of constructing the apparatus are described in the following procedures:

A thin-walled 10-feet long PVC pipe is purchased from a hardware store. The PVC pipe was cut into two 123c m-long segments by using a hacksaw. One tube segment was assigned as the outer tube while the other tube was assigned as the inner tube. A 3-mm wide gap was cut along one side of the inner tube by using a wood file. Epoxy was applied on the gap edges and held them together for a minute until the epoxy dried and the joined edges hardened. Epoxy residues were removed from the tube surface by using sandpaper. A tape measure was placed on the surface of the inner tube. The inner tube was slowly inserted into the outer tube. Tube set-ups were mounted on the wooden platform with the use of horse clamps and wood screws.

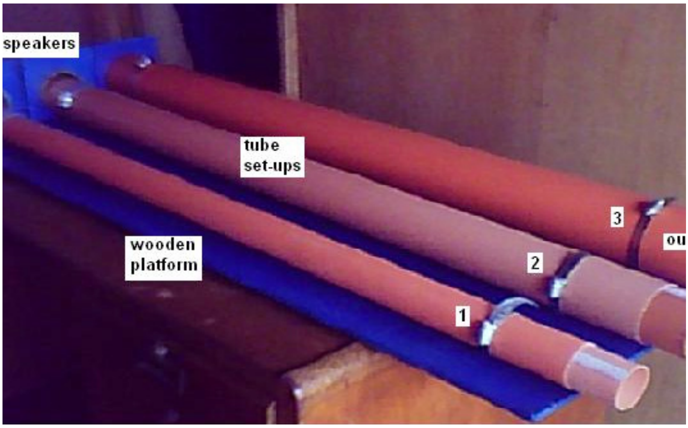

Figure 2. Fully-operational modified resonator tube apparatus.

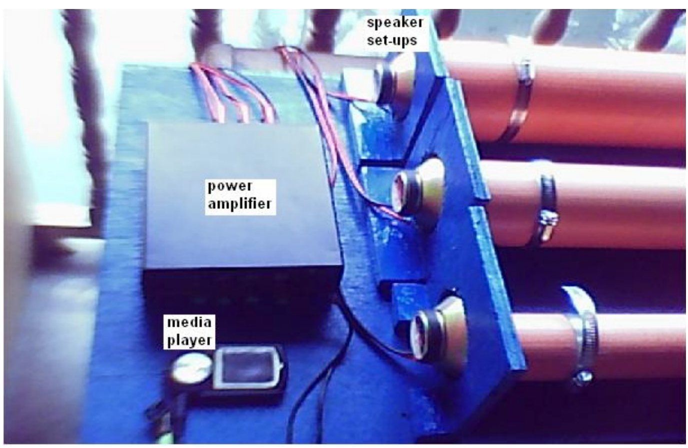

Figure 3. Project accessories: power amplifier, speaker setups and MP3 player.

Experimental Procedure

The resonator tube apparatus is useful in performing a variety of experiments on resonance and normal modes. Two sets of experimental procedures are being implemented to obtain results, namely, open-pipe and stopped-pipe experiments. Room temperature is measured at the start and end of an experiment by using a 100-°C glass thermometer.

Air Column Length vs Harmonic Number Experiment

The following steps are procedures being done in performing air column length vs harmonic number experiments:

For open-pipe procedure, room temperature was recorded first at the start of every experiment. Both inner and outer tubes were free to resonate without obstruction. A speaker set-up was placed closer to an open edge of the resonator tube. A frequency of sound was selected and played using the music player. Sound intensity was set to minimum by adjusting the volume control of the amplifier. The inner tube was slowly pulled from the outer tube edge until the loudest "hum" is produced. The gained length of inner tube was recorded as indicated by the tape measure plus the fix length of the outer tube. The inner tube was pulled continuously to obtain longer lengths that correspond to loud "hums" being produced. These lengths were recorded correspond to different harmonic numbers. Entire procedure was repeated in 5 trials.

For stopped-pipe procedure, record the room temperature at the start of every experiment. One edge of the inner tube was covered with an acrylic cap. The speaker set-up was placed closer to an open edge of the resonator tube. Frequency of sound was selected and played using the music player. Sound intensity was set to minimum by adjusting the volume control of the amplifier. The inner tube was slowly pulled from the outer tube edge until the loudest "hum" is produced. The gained length of inner tube was recorded as indicated by the tape measure plus the fix length of the outer tube. The inner tube was continuously pulled to obtain longer lengths that correspond to loud "hums" being produced. These lengths were recorded correspond to different harmonic numbers. Entire procedure was repeated in 5 trials.

Frequency vs Harmonic Number Experiment

The following steps are procedures being done in performing air frequency vs harmonic number experiments.

For open-pipe procedure, room temperature was recorded first at the start of every experiment. Both inner and outer tubes were free to resonate without obstruction. A speaker set-up was placed closer to an open edge of the resonator tube. Sound intensity was set to minimum by adjusting the volume control of the amplifier. Tube set-up was set into a fixed length. Resonant frequencies were selected by pressing the select button of the music player. Resonance occurred as a selected frequency produced loud "hum" through the tube set-up. Additional frequencies were obtained as we select further in the music player. These resonant frequencies were recorded corresponding to different harmonic numbers. Entire procedure was repeated in 5 trials.

For stopped-pipe procedure, room temperature was recorded first at the start of every experiment. One edge of the inner tube was covered with an acrylic cap. The speaker set-up was placed closer to an open edge of the resonator tube. Sound intensity was set to minimum by adjusting the volume control of the amplifier. Tube set-up was set into a fixed length by adjusting the inner tube. The acrylic cap served as rigid boundary for sound waves to bounce back toward the open edge of the outer tube. Resonant frequencies were selected by pressing the select button of the music player. Resonance occurred as a selected frequency produced loud "hum" through the tube set-up. Additional frequencies were obtained as we select further in the music player. These resonant frequencies were recorded corresponding to different harmonic numbers. Entire procedure was repeated in 5 trials.

As to critique the procedures described in this study, the procedures are developed in a trial-and-error basis until optimized results are obtained. Systematic and random errors are kept within 5% margin of error to ensure high reliability of the apparatus. Resulting data will be treated with error propagation techniques.

RESULTS AND DISCUSSION

Actual experiments are done by using the entire resonator tube apparatus. The researcher used ROOT 5.18 software to plot the data points and obtain corresponding graphs.

Air Column Length vs Harmonic Number

Figure 4 shows the superimposed open-pipe L vs n plots obtained from tube setup 1 by using frequencies f_1 = 760 Hz, f_2 = 766 Hz and f_3 = 770 Hz, respectively. Individual plots in Figure 4 represent the data shown in Tables A.1, A.2, and A.3, respectively.

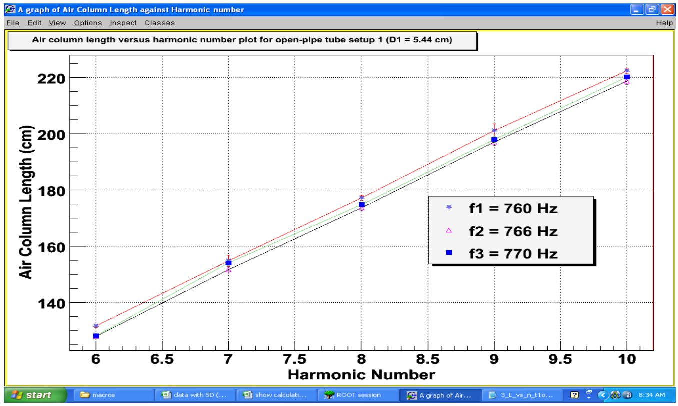

Figure 4. Air column length vs number of harmonics for open-pipe using frequencies f1 = 760 Hz, f2 = 766 Hz and f3 = 770 Hz, respectively.

The deduced speed of sound is 337.79±0.94 m/s for f_1 = 760 Hz, 332.09±1.39 m/s for f_2 = 766 Hz, and 333.53±1.52 m/s for f_3 = 770 Hz, respectively. The margins of error obtained are 3.34 % for f_1 = 760 Hz, 4.17 % for f_2 = 766 Hz, and 3.92 % for f_3 = 770 Hz, respectively.

Figure 5 shows the superimposed stopped-pipe L vs n plots obtained from tube setup 1 by using frequencies f_1 = 412 Hz, f_2 = 414 Hz and f_3 = 416 Hz, respectively.

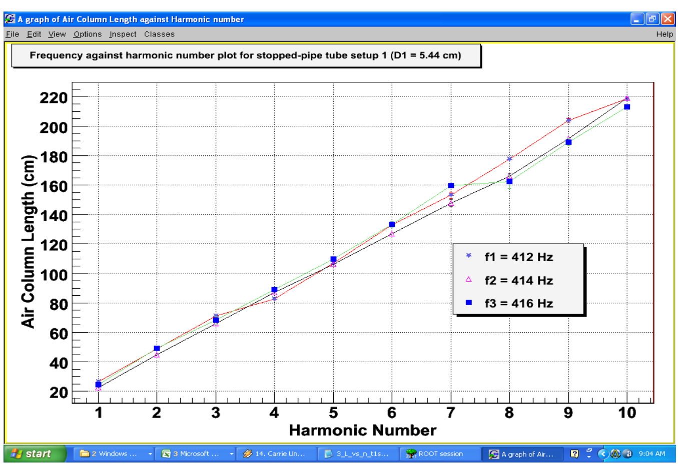

Figure 5. Air column length vs number of harmonics for stopped-pipe using frequencies f_1 = 412 Hz, f_2 = 414 Hz and f_3 = 416 Hz, respectively.

The deduced speed of sound is 357.72±9.34 m/s for f_1 = 412 Hz, 349.43±5.67 m/s for f_2 = 414 Hz, and 337.67±17.07 m/s for f_3 = 416 Hz, respectively. The % errors obtained are 3.05 % for f_1 = 412 Hz, 0.83 % for f_2 = 414 Hz, and 2.73 % for f_3 = 416 Hz, respectively.

Frequency vs Harmonic Number

Figure 6 shows the superimposed open-pipe f vs n plots obtained from tube setup 1 by using air column length L_1 = 2.3 m, L_2 = 2.35 m and L_3 = 2.4 m, respectively.

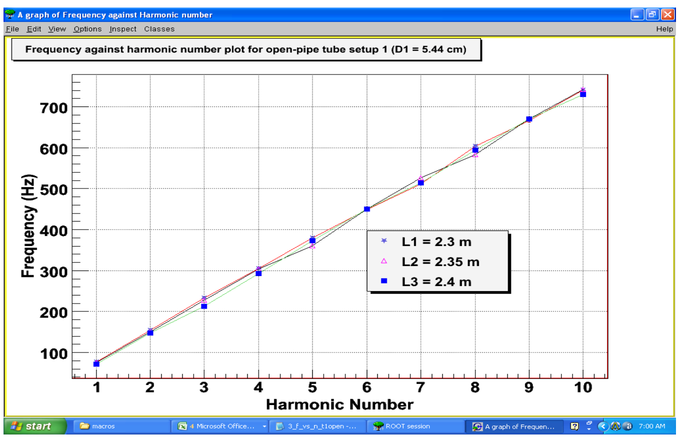

Figure 6. Frequency vs number of harmonics for open-pipe using air column lengths L_1 = 2.3 m, L_2 = 2.35 m and L_3 = 2.4 m, respectively.

The deduced speed of sound is 337.09±5.98 m/s for L_1 = 2.30 m, 339.02±3.94 m/s for L_2 = 2.35 m, and 340.80±3.09 m/s for L_3 = 2.40 m, respectively. The % errors obtained are 2.89 % for L_1 = 2.30 m, 2.50 % for L_2 = 2.35 m, and 1.98 % for L_3 = 2.40 m, respectively.

Figure 7 shows the superimposed stopped-pipe f vs n plots obtained from tube setup 1 by using air column length L_1 = 1.6 m, L_2 = 1.7 m and L_3 = 1.8 m, respectively.

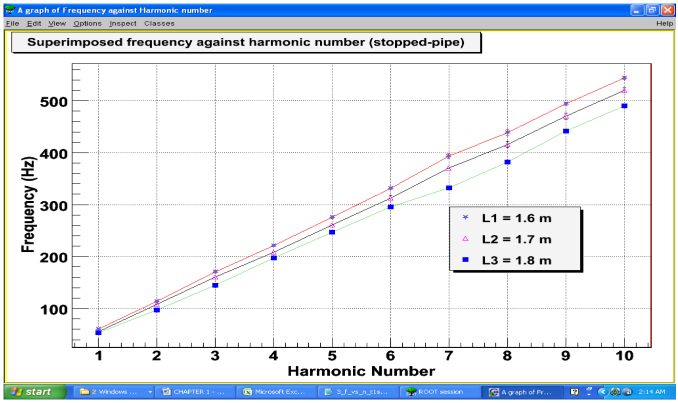

Figure 7. Frequency vs number of harmonics for stopped-pipe using air column lengths L_1 = 1.6 m, L_2 = 1.7 m and L_3 = 1.8 m, respectively.

The deduced value of speed of sound is 345.92±5.55 m/s for L_1 = 1.60 m, 351.05±3.48 m/s for L_2 = 1.70 m, and 348.35±4.40 m/s for L_3 = 1.80 m, respectively. The % errors obtained are 1.18 % for L_1 = 1.60 m, 1.13 % for L_2 = 1.70 m, and 0.35 % for L_3 = 1.80 m, respectively.

CONCLUSIONS

A resonator tube apparatus is constructed from PVC tubes and other locally available materials. This special project is intended for resonance experiments and classroom demonstrations. Experiments on the calculation of the speed of sound such as air column length vs harmonic number and frequency vs harmonic number are performed using this apparatus.

Frequencies of 760 Hz, 766 Hz and 770 Hz are used to produce five numbers of harmonics in the open-pipe experiments while frequencies of 412 Hz, 414 Hz and 416 Hz are used to produce ten numbers of harmonics. The room temperature is recorded for both open-pipe and stopped-pipe procedures.

Results of the experiments show linear relationship between air column length and harmonic number and between frequency and harmonic number. This linear relationship is shown in both open-pipe and stopped-pipe procedures.

RECOMMENDATIONS

The percent error on the calculated speed of sound obtained from any experiment did not exceed 4.17 %. Therefore the resonator tube apparatus is recommended for classroom demonstrations and laboratory activities. Since the apparatus has two more tube set-ups to spare, any interested student could continue the experiments using these tube set-ups provided that an optimized amplifier is used. Moreover, the apparatus could be modified using preformed tubes of different materials (i.e. glass, metal). Digital function generator that can produce continuous frequency signals could replace the mp3 player for optimal results.

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