Design and development of multipurpose Kundt’s tube as physics learning media

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Abstract. Research had been conducted to develop Multipurpose Kundt’s tube as a physics learning media. Research background was the absence of sound waves visualization to improve the understanding of learners. The purposes of this research were to develop Multipurpose Kundt’s tube as physics learning media and to test its feasibility. The developed tool was tested to find the speed of sound in the air, showing the double slit interference phenomenon of the sound, and show the temperature changes in the cold and heat reservoirs in the thermoacoustic process.

The development step that had been used was Preliminary Study, Development, Field Test, and Dissemination or known as PDFD Model. On the implementation, the dissemination process was not done. The test was done by the experts, peers, and college students to find out the media feasibility level.

The speed of sound in the air which was measured using Multipurpose Kundt’s tube obtained \( v \pm \Delta v = 263 \pm 24 \) m/s with the closeness value of 76.63% closer to the theoretical value. Also, it was founded a calibration factor of 1.32. The tool was able to show sound waves on the open-end tube. The value of the distance between minimum and maximum interferences between the experimental results compared to theory was almost the same, so it was concluded that the phenomenon of double-slit interference of the sound could be shown by the tool. The thermoacoustic phenomenon could be observed and gave maximum temperature 31.4°C in the hot reservoir, and minimum temperature 24°C in the cold reservoir at the frequency of 119 Hz. Temperature differences obtained 7.4°C. The result of the feasibility test obtained the average result of 88.23 in a “Very Good” category.

1. Introduction

Waves are an important phenomenon in the physics world and become basic knowledge of physics teachers. Waves become one of the most important concepts in the curriculum of Junior High School and Senior High School. Waves course in Physics Education of Universitas Ahmad Dahlan (UAD) has not used instructional media. Based on observations made in the classroom by the lecturer, it was found that the student had not yet received a clear image of the form of sound in an open-end tube. Concepts concerning the antinodes and nodes of pressure in an open-end tube cannot be fully understood by the students.

The concept of an open-end tube can be used as an experiment to find the speed of sound in the air. Kundt's tube is one tool to visually display sound by inserting fine styrofoam into its tube. Using this tool also can be used to measure the sound wavelength directly using an ordinary ruler. Then from it, the
speed of sound in the air can be calculated. Remembering the importance of the basic concept of sound waves in the open-end tube for physics education students, it is necessary to build a learning media that can provide a clear and visible image of the sound in an open-end tube. Kundt's tube is the solution and has enormous benefits in building student knowledge about waves. Tools which has been created can also be an educational tool for high school and junior high school students.

The purposes of this study are: (1) Develop Multipurpose Kundt's Tube as physics learning media on sound wave subject studies, (2) Measure the speed of sound in the air using Multipurpose Kundt's tube, (3) Knowing the temperature differences on the thermoacoustic phenomena in Multipurpose Kundt's tube, (4) Knowing the suitability of the double slit interference on sound waves with the theory, (5) Measuring the feasibility of Multipurpose Kundt's tube based on the assessment of experts, peers, and students.

2. Theoretical Background

Physics experiments and demonstrations provide the experience of working on a project with a clear purpose and ultimately will result in conclusions of principles or concepts. The instructional pattern considered to encourage students and correct misconceptions in physics is Interactive Lecture Demonstrations (ILD) [1]. Both experiments and demonstrations need learning media. The sound cannot be seen, so that only the sense of hearing plays a role in detecting sounds. It will be fascinating if the sound can be seen with the naked eye. Multipurpose Kundt's tube learning media can be used for visualizing sound in an open-end tube. Alfonso Gutiérrez & Kathleen Tyner said that newly adopted media by the community or school are trying to get into the curriculum [2]. This is because the media provide an excellent impact to foster student learning motivation.

Commonly, the tools used in resonance experiments in the air column resonance is a tube made of glass which is equipped with a plastic funnel [3]. Kundt’s Tube is a tube which speakers as the source of sound placed in one end of it. In general, this tool is closed at one end. This tool was made by Kundt's in 1866 to visualize the nodes and the antinode in an open-end tube. Dust/powder is inserted into the tube, and a single frequency sound is turned on. The result is dust/powder will be neatly produced a clear view where the location of the nodes and the antinode can be seen by naked eye.

Development of this tool can be used as a tool to show the phenomenon of sounds diffraction, double slits interference, thermoacoustic, determine the speed of sound, harmonic frequencies, etc. It also can be used to determine the sound absorption coefficient [4]. Kundt's tube with a closed at one-end will result in open-end tube pressure wave characteristics. By making a tube with an easily visible material (glass/acrylic/plastic) and giving styrofoam granules in the tube, it can be seen the waves present in it along with its node an antinode. This can provide an overview of stationary waves on an open-end tube. The thermoacoustic device consists primarily of a resonator system with a stack in it with the support of the sound source system [5]. A heat exchanger is placed on the inside of the tube to produce temperature changes due to the sound waves passing through it. This heat exchanger is named "stack". The stack is the heart of a thermoacoustic system. This stack will pump heat from a cold reservoir to a hot reservoir.

3. Methods

The development steps which were used in this research is Preliminary Study, Development, Field Test, and Dissemination which known as PDFD model [6]. The process is adapted to develop physics learning media in the form of Kundt's tube. Dissemination step was not done in this research. This research was conducted in Basic Physics Laboratory of UAD. The research time is from February to December 2016. The population in this research is physics students who follow vibrations and wave course. Students are asked to see the demonstration using the tools and then asked to provide input and suggestions for better tools. Learning media experts is physics education lecturer who had passed Master degree, had educational background and mastery of the concept vibrations, waves, and sounds. Peer also selected by its competence in making tools and concepts about vibrations, sounds, and waves.
4. Result and Discussion

4.1 Development of Multipurpose Kundt’s Tube

The difficulty making multipurpose Kundt’s tube is found in search of acrylic pipes. Acrylic pipes and acrylic sheets are used as the main material for making this tool. All parts of the tool can be seen clearly, so it is possible to learn the entire contents of the tool that had been made. The active power speakers are 25 watts. The cover is made of several parts tailored to the needs. All components of the tool can be seen in Figure 1. Multipurpose Kundt’s tube made with dimensions of 30 cm x 30 cm x 30 cm speaker box, 25-watt speaker power, 4.6 cm diameter acrylic pipe, one meeting cap, cover with two holes elongated one piece, an amplifier, and one heat exchanger. The design of Kundt’s is almost the same as redesigned Kundt’s Tube by Papacosta and Linscheid with replacing Cork dust with Styrofoam [7]. The design of the thermoacoustic engine is simple thermoacoustic engine according to [8].

![Figure 1. Multipurpose Kundt’s tube](image1.png)

4.2 Experimental result of measuring sound speed in air using developed tools

Measurement of the speed of sound is a very common procedure in many schools, and many appealing methods have been described in the literature, one of them is the time of flight method [9]. However, here, the sound velocity in the air was measured by measuring the wavelength of the first harmonic on the Multipurpose Kundt’s tube. In this experiment, we place the tube horizontally. From the data obtained, it can be done and analysis using the equation for the open-end tube in harmonic one.

\[ f_n = \frac{n \nu}{4L} \quad \text{where} \quad n : 1,3,5, \ldots \ldots \]  \hfill (1)

\( f_n \) is the resonance frequency, \( \nu \) is the speed of sound in air, \( L \) is the distance of node to the source, and \( n \) is the harmonic frequency. The sound velocity in the air based on this experiment is \( \nu \pm \Delta \nu = 263 \pm 24 \) m/s with 76.63% approaching the theory 343 m/s taken from experiment [4,1]. Also found there is a calibration factor of 1.32. The instrument is capable of showing sound waves on an open-end tube as shown in Figure 2.

![Figure 2. Node and antinode from styrofoam moving inside the pipe when the speaker is turned on.](image2.png)
4.3 Experimental result of double-slit interference of sound

Double slit cover placed in Multipurpose Kundt’s tube. Using a single source and two holes on the cover it was obtained the first interference in the left and right of the central interference. This maximum or minimum interferences was indicated by the increase and decrease in sound intensity. Using equation two can be determined the wavelength of the sound. The position of the tool can be shown in figure 3.

\[
\frac{dp}{l} = m\lambda \quad \text{with} \quad \lambda = \frac{v}{f} \quad (2)
\]

\(d\) is the distance between two slit, \(p\) is the distance from central to maximum interferences, \(l\) is the distance from slit to the wall, \(v\) is the speed of sound, \(f\) is the frequency used, \(\lambda\) is wavelength, \(m\) is order number.

The sound frequency which was used is 10000 Hz, and the speed of sound which was used in the air is 343 m/s, the distance between the gap to the screen is 0.5 meters, and the distance between the gap is 2 cm. It can be determined the value of the distance between the maximum of the center to a minimum of 1 and maximum one interference (p) by placing the sound detector in the wall (result in Figure 3).

The result of this experiment is close to the theory. From figure 3, we found that constructive interference in left and right happened on 80 cm and 85 cm from center respectively which was close to the theory that should have happened in 85.75 cm from center. Destructive interference found on 45 cm in the left and right from the center which also close to the theory that should have happened in 42.5 cm from the center.

![Figure 3. The position of the tool in the double slit interference experiment of sound (left) and graphic of sound intensity versus distance from central maximum (right)](image)

4.4 Experimental result of thermoacoustic process

Thermoacoustic instability is defined as the excitation of acoustic modes in chambers with heat sources due to the coupling between acoustic perturbations and unsteady heat addition [10]. Then, thermoacoustic involves the conversion of heat energy and acoustic energy in one another [7]. More detailed explanation on the working of thermoacoustic is given by Swift [11]. The stack or heat exchanger in this experiment made from a small drinking straw (diameter: 3.61 ± 0.05 mm) wrapped with cardboard so that it enters and closes perfectly inside of the acrylic pipe. This heat exchanger is placed at \(\frac{\lambda}{20}\) or 14 cm from the closed end. The design of the thermoacoustic experiment is shown in the figure. 4.

The highest temperature is 31.4°C in the hot reservoir and in the cold reservoir the lowest temperature is 24°C at 119 Hz. Maximum temperature difference obtained 7.4°C. The thermoacoustic phenomena can be shown through Multipurpose Kundt’s Tube. The increase and decrease of temperature in hot and cold reservoirs are shown in Figure 4.
Figure 4. Thermoacoustic data retrieval position and graph of temperature differences versus time at 119 Hz

4.5 Result of Feasibility test

Feasibility test obtained that the tool is in the category “Very good” with the average value 88.23. The scores of expert tests, peers, and student test results were 87.5, 87.5, and 89.7, respectively, in “excellent” categories. Figure 5 shows the histogram of this conclusion. Student comments are positive, quite interesting, inspiring and desirable tools used in the learning process.

Figure 5. Feasibility test results of Multipurpose Kundt’s Tube.

5. Conclusion

Based on the observation data, the researchers obtained the following conclusions: (1) Multipurpose Kundt’s tube can be made with dimensions of 30 cm x 30 cm x 30 cm speaker box, 25-watt speaker power, 4.6 cm diameter acrylic pipe, one meeting cap, cover with two holes elongated one piece, and an amplifier. (2) The sound velocity in the air based on this experiment is \[ v \pm \Delta v = 263 \pm 24 \text{ m/s} \text{ with 76.63\% approaching the theory (343 m/s).} \] Also found there a calibration factor of 1.32. The instrument is capable of showing sound waves on an open-end tube. (3) Young double slit interference can be demonstrated through this experiment. The results of the measurements in the Multipurpose Kundt’s tube obtained that the p-value almost the same as the theory. (4) The highest temperature is 31.4\degree C in the hot reservoir and in the cold reservoir the lowest temperature is 24\degree C at 119 Hz. Maximum temperature difference obtained 7.4\degree C. The thermoacoustic event can be shown through Multipurpose Kundt’s Tube. (5) Feasibility test obtained that the tool is in the category “Very good” with the value 88.23. The scores of expert tests, peers, and student test results were 87.5, 87.5, and 89.7, respectively, in “excellent” categories.

Multipurpose Kundt's tubes that had been developed did not yet produce good data for the learning process. Further research is needed to improve the performance of the tool. Finer styrofoam is required to
produce a better waveform in the pipe to be observed. The length of the pipe is excellent for the thermoacoustic experiment but not for the experiment of determining the speed of sound in the air. The length of the pipe can be shortened with the frequency in the higher set is likely needed to produce better data. This short pipe will also generate greater intensity in the double-slit interference experiments of sound waves so that constructive and destructive interference will be more visible. Speaker power can also be upgraded to 60 watts so that the increasing temperature in the thermoacoustic process can be more visible. This will be done in further research.

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