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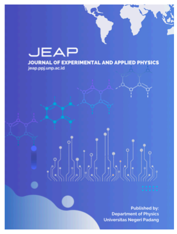

Impedance Tube Method Based On Arduino For Material Acoustic Measurement

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Abstract: Acoustics play a crucial role in technology and industry by minimizing noise, an unintended consequence of various devices. However, existing tools for acoustic properties testing often lack automation and calibration, which limits their reliability and usability. This study introduces the development of a test device designed to measure the sound absorption coefficient of materials using the two-microphone impedance tube method. The device incorporates a PVC tube, an Arduino Nano Microcontroller, and an OLED display for real-time data analysis and visualization. The proposed device offers simplicity, portability, and improved measurement accuracy compared to existing solutions. The method involves measuring sound intensity and absorption coefficients using direct and indirect techniques. Experimental results demonstrate that the device achieves an average accuracy rate of 20.38%, with consistent absorption coefficient values across repeated tests. The frequency range tested aligns with the performance limits of the device, further confirming its reliability. In conclusion, the developed device provides a practical and reliable solution for testing acoustic materials, addressing the limitations of previous methods.

Keywords: Impedance Tube, Frequency, Absorption, Sound Intensity.

1. Introduction

Acoustic science plays a crucial role in technology and industrial advancements, particularly in mitigating noise pollution. Noise, an unwanted byproduct of various devices and activities, has become a significant global challenge, affecting environmental quality, human health, and workplace productivity [1]. Researchers and engineers continuously seek effective solutions to control and reduce noise levels. One of the widely adopted strategies involves utilizing sound-absorbing materials to reduce unwanted noise and improve acoustic comfort in various settings, including residential, commercial, and industrial environments [2].

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One effective approach to reducing noise is the use of sound-absorbing materials. Commonly used sound-absorbing materials are derived from natural or synthetic fibers [3]. These materials can be applied from various methods, depending on their properties. One such techniques involves the use of specialized acoustic solutions for sound absorption [4]. To evaluate the acoustic performance of materials, experiments are conducted to measure parameters such as the sound absorption coefficient, reflection factor, and transient loss (sound reduction) [5]. Sound absorption refers to the loss of acoustic energy within a materials as a sound waves pass through it [6].

To address noise-related challenges, researchers have developed various techniques to evaluate the acoustic properties of materials. The impedance tube method is one of the most established techniques for measuring the sound absorption coefficient, reflection factor, and transmission loss of materials [7]. This method uses a controlled acoustic environment within a tube, where a loudspeaker generates sound waves that interact with the test sample. Microphones strategically placed within the tube capture the sound pressure levels, enabling precise calculations of acoustic parameters. This approach has been widely adopted due its accuracy and standardized measurement procedure [8].

Despite its effectiveness, conventional impedance tube testing setups often face limitations in automation, portability, and calibration. Many existing systems require direct connections to computers and lack integrated real-time data processing capabilities, making them less practical for field applications [9]. Previous studies have attempted to enhance impedance tube measurements by incorporating microcontrollers and digital interfaces. For instance, some researchers have developed prototypes using PVC tubes with multiple microphones connected to a computer for data processing. However, these setups often lacked automated calibration and relied on external oscilloscopes for visualization, reducing their practicality and usability [10].

To overcome these limitations, this study introduces an improved impedance tube system based on an Arduino Nano microcontroller, equipped with an OLED display for real-time data visualization. The proposed system integrates a PVC tube, a sound generator, two strategically positioned microphones, and a Sound Level Meter (SLM) to ensure accurate measurement of sound intensity and absorption coefficients. The implementation of the transfer function method enables the precise determination of acoustic properties by analyzing the Fourier transformation of acoustic pressure at different microphone locations [11].

The advantages of this two-microphone impedance tube method are that it is relatively easy to implement and easy to calculate because it only uses one configuration [12]. The primary improvement of this study lies in the development of a cost-effective, portable, and automated impedance tube system capable of performing reliable acoustic measurements with improved usability. By addressing the limitations of previous impedance tube designs, this research provides an accessible and practical solution for researchers and industries, involved in acoustic material testing. The findings of this study contribute to the ongoing efforts to enhance noise control technologies and facilitate the development of more efficient sound-absorbing materials.

2. Materials and Method

This research is classified as engineering research, integrating scientific principles into the design and testing of an acoustic material measurement device. The experimental setup follows a systematic process to ensure accurate and replicable results. The research workflow is divided into three main stages: system design, prototype fabrication, and experimental testing and validation. The main procedures of engineering research are shown flow in Figure 1.

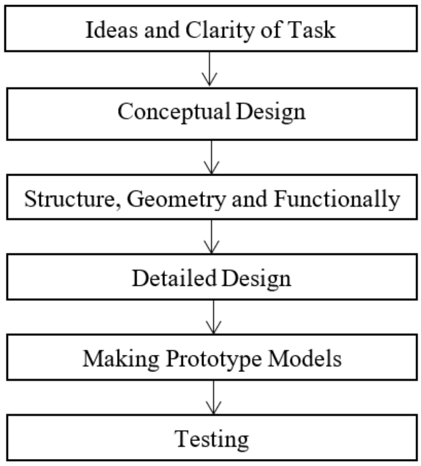

Figure 1. Research Procedure

Figure 1 is the steps in conducting engineering research are describing the tool created to meet specified specification, designing a model of the tool, and testing the tools [13]. The primary components and materials used in the construction of the impedance tube testing system include a PVC pipe that serves as the impedance tube, measuring 50 cm in length, with an inner diameter of 40 mm (≈1.5 inches) and a thickness of 3 mm. Two GY-MAX4466 microphones are positioned at different points inside the tube to capture sound pressure levels. A sound generator is used to produce controlled sound waves, which are then transmitted into the impedance tube via a loudspeaker. The system is controlled by an Arduino Nano microcontroller, which processes signals and manages the output displayed on a 128 x 64 OLED LCD screen. A Sound Level Meter (SLM) is used for calibration and measurement verification. Experimental validation is conducted using a standard sample material, specifically 3/8” plywood to test the accuracy of the system.

This study uses data collection by measuring the physical quantities contained in the system. Measurement techniques carried out include methods, namely direct and indirect measurements. Direct measurement is a measurement that does not depend on other quantities. Indirect is the measurement of a measure that is measured by another quantity and its value cannot be obtained directly from the results of the measurement. The data obtained directly include the value of the amplitude of the voltage, the value of the intensity of the sound, and the characteristics of the microphone. While the data obtained indirectly include the value of sound pressure on the microphone, reflection factor value, and absorption coefficient.

The design of the material acoustic properties test equipment system consists of hardware design and software design. Software design serves as instructions for hardware to do its job. Hardware design to describe the physical part of the acoustic properties test equipment design system. The hardware design of the material acoustic properties test equipment system using the 2 microphone impedance tube method can be seen in Figure 2.

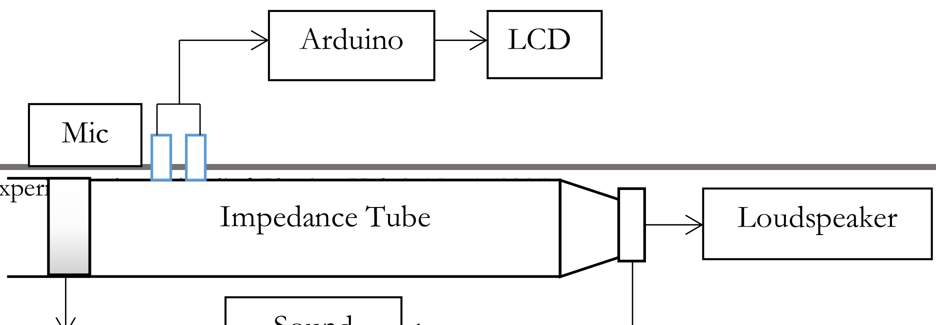

Figure 2. System Arrangement of Acoustic Properties Testing Equipment
Using Impedance Tube Method 2 Microphones

Figure 2 is an arrangement of the acoustic properties test equipment system using the 2 microphone impedance tube method consisting of a PVC pipe tube, microphone, sound generator, Arduino, LCD, and loudspeaker. For the detailed design of the impedance tube, it can be seen in Figure 3.

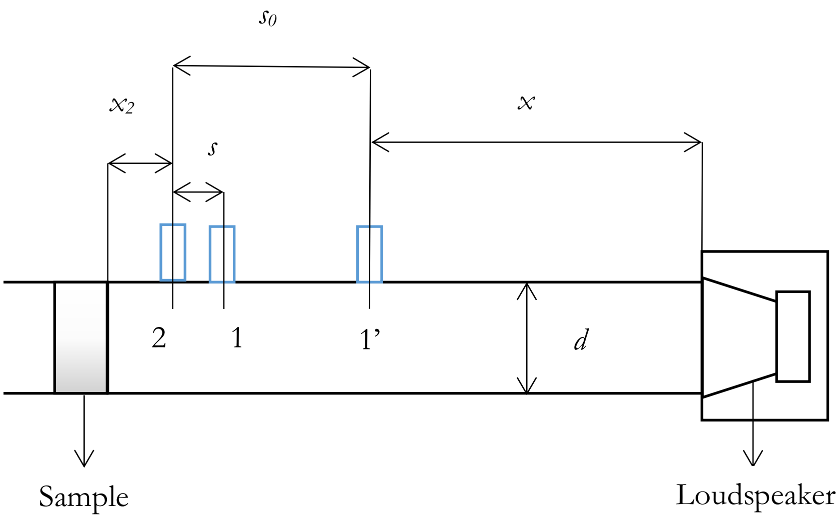

Figure 3. Impedance Tube Design

The experimental procedure consists of three main stages: system assembly and calibration, measurement process, and data analysis. In the system assembly and calibration stage, the PVC pipe is cut to precise dimensions and fitted with mounting holes for the microphones to ensure sound wave reflections and another near the sound source to capture the incident sound waves. A loudspeaker is installed at one end of the tube and connected to the sound generator, which produces controlled frequency sweeps. A Sound Level Meter is used to calibrate the microphones sensitivity, ensuring accurate measurement of sound intensity.

During the measurement process, the sample material is securely placed at the closed end of the impedance tube. The sound generator produces sinusoidal sound waves at controlled frequencies ranging from 250 Hz to 1000 Hz. The microphones record the pressure differences at their respective positions, and the Arduino Nano processes the signals to calculate the sound absorption coefficient. The test results are displayed on the OLED LCD screen in real-time. To ensure repeatability and reliability, each frequency is tested ten times.

In the data analysis stage, the absorption coefficient (α) is calculated using the transfer function method, comparing the Fourier transformation of sound pressures at both microphone locations. The measured absorption coefficients are compared to theoretical values from reference materials to determine accuracy. Additionally, error analysis is performed by calculating the percentage error to evaluate measurement reliability, with an acceptable error threshold of ≤20%.

The two-microphone impedance tube method is widely recognized as a reliable technique for measuring the sound absorption coefficient of materials. This method is chosen due to its high measurement precision, as the transfer function approach minimizes direct measurement errors. The experimental setup complies with ISO 10534-2 and ASTM E-2611 standards, ensuring that the results align with established measurement protocols. Furthermore, the integration of Arduino and an OLED display enhances efficiency and usability by providing real-time data analysis and visualization. The device is designed to be lightweight and modular, making it suitable for both field and laboratory applications. By incorporating these detailed descriptions, the methodology ensures that the experiment can be accurately replicated, reinforcing the validity of the research findings.

3. Results and Discussion

The result of the design that has been carried out is a test instrument for the acoustic properties of the material using the 2 microphone impedance tube method. This tool is able to measure the value of the absorption coefficient of a material. The results of the measurement of this tool are in the form of a sine wave which will later be displayed on the LCD. The mechanical form of the test equipment made can be seen in Figure 4.

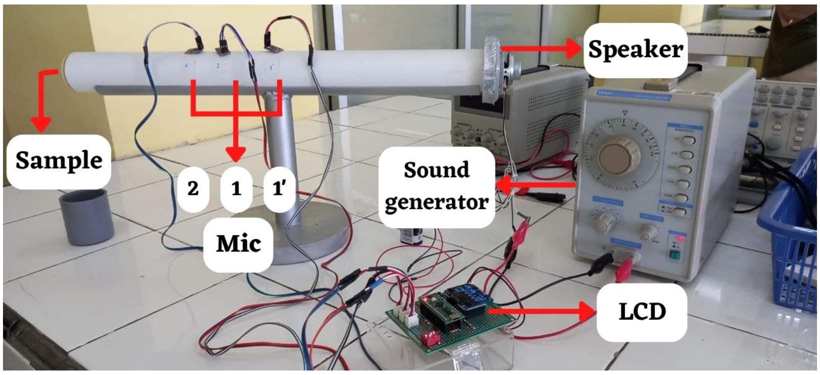

Figure 4. Materials Acoustic Properties Test Equipment Using Impedance Tube Method 2 Microphones

Figure 4 is the result of the mechanical design of the material acoustic properties test equipment made using PVC pipes. This tool consists of an impedance tube with a length of 50 cm with a diameter of 1.5 inches ≈ 40 mm and a thickness of 3 mm. The distance between microphones 1' and 2 (s_0) is 10 cm, the distance between microphones 1 and 2 (s) is 3.5 cm, for the distance between the sound source and the closest microphone (x) is 25 cm, and for the distance between the sample and the microphone closest is 15 cm. It can be concluded that the impedance tube construction for measuring the sound absorption coefficient has a frequency limit based on ISO 10534-2 and ASTM E-2611, which is from 173 Hz to 5 kHz. This test equipment is composed of several components consisting of a sound generator as a sound source or regulating the sound source that is issued, a loudspeaker as a sound output device that is set on a sound generator, and a microphone as a sound receiver. When the system has been designed according to the mechanical design, the display of the test tool will be displayed on the LCD programmed by Arduino. The form of display of test results can be seen in Figure 5.

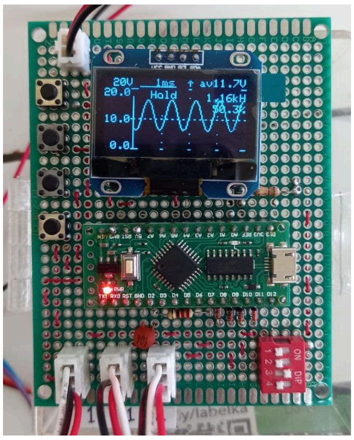

Figure 5. Waveform Display on LCD

In testing the sound intensity value, the test equipment used consisted of a PVC pipe that functions as a tube with a length of 50 cm, a diameter of 1.5 inches ≈ 40 mm, and a thickness of 3 mm. This tube consists of two pipes with a length of 55.5 which are connected by a socket. There are two holes in the pipe, each hole is located in front and behind where the sample is placed. The mechanical design of the tool can be seen in Figure 6.

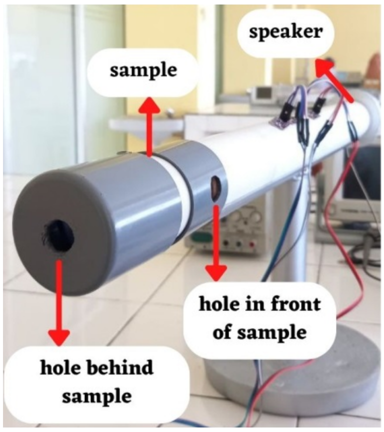

Figure 6. Sound Intensity Value Testig Mechanical System

Figure 6 shows the mechanical shape of the overall acoustic properties of the material using the 2 microphone impedance tube method for testing the sound intensity value. This test equipment is also composed of several other components consisting of speakers, Sound Level Meters, pipe manhole covers, and pipe caps. The speaker functions to produce sound that is set on the sound generator. Sound Level Meter is inserted in the hole that has been designed on the tube which serves to get data on the value of sound intensity.

The process of recognizing sound waves in the manufacture of this material's acoustic property test equipment uses the GY-MAX4466 microphone. The working principle of this microphone is to convert the volume of sound into a quantity with the output data in the form of an analog voltage [14]. The sound sensor output voltage data is needed to identify how well the sensor is being used. Data retrieval of the sensor output voltage is done by varying the frequency value at the sound source obtained from the sound generator. The test was carried out on 3 microphones by positioning each microphone facing the speaker at the same distance. The test results of the GY-MAX4466 microphone are shown in the graph in Figure 7.

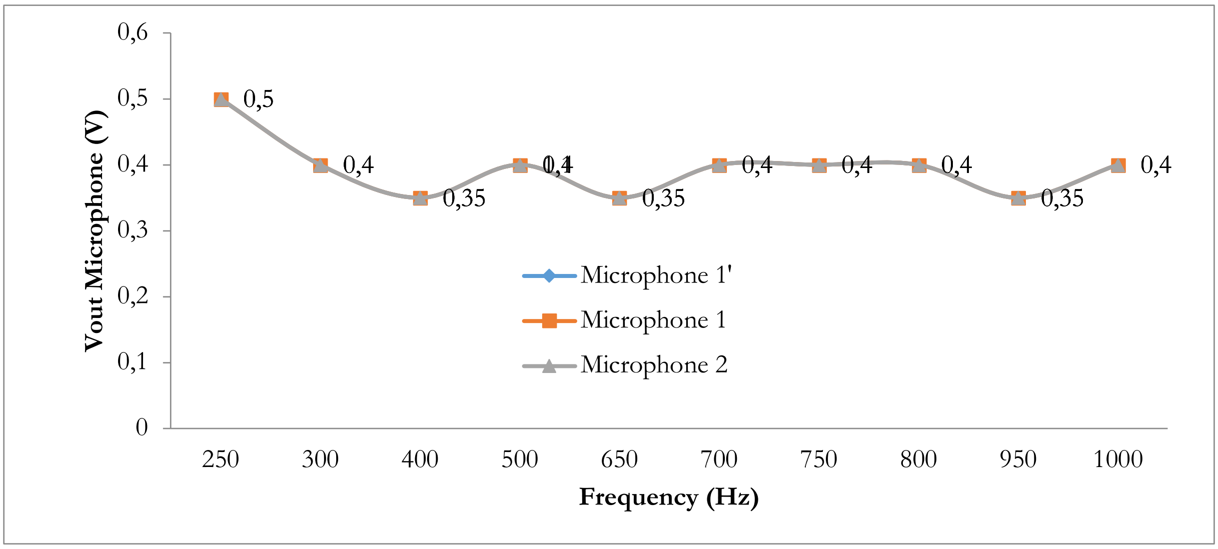

Figure 7. Graph of Frequency Relationship with Microphone Output Voltage GY-MAX4466

Based on the graph in Figure 7, it can be seen that the microphone output voltage value (Vo microphone) obtained at each frequency variation (Hz) is not much different. The graph shows that at a frequency of 250 Hz, the microphone output voltage value is high because the vibration produced is strong. The factor that affects the magnitude of the output voltage value is the strength of the vibration produced. The sound sensor works based on the intensity of the sound waves hitting the sensor membrane which causes the sensor membrane to move. The speed of the moving coil determines the strength of the electric wave generated [15]. The value of the voltage produced by the microphone depends on the received sound vibrations [16]. The difference in sound vibrations received is influenced by the results of speaker amplification, at different frequencies the amplitude of the resulting output voltage is different [17]. The results of testing the microphone output voltage value obtained at each frequency variation are not much different. The factor that affects the magnitude of the output voltage value is the strength of the vibration produced. The test results show that the microphone works well.

To see the performance of the tool, that is by testing and analyzing the tool, so that it can be seen whether the system is working properly. the accuracy of the data and the accuracy of the tool work to see how accurate the tool and the accuracy of the tool can be used. The data is obtained from the comparison of the absorption coefficient of the standard sample shown in the reference book with the absorption coefficient of the standard sample which is measured using a research instrument designed. Accuracy data obtained from test data repeatedly 10 times.

The accuracy of this test instrument was obtained from testing 10 variations of the frequency value with each frequency value carried out 10 times. The accuracy of the tool is seen from the comparison of the absorption coefficient values in the reference with the absorption coefficient values obtained from the test equipment using a standard sample of 3/8" plywood. The standard sample data reference used is the absorption coefficient value data at a frequency of 250 Hz, 500 Hz, and 1000 Hz. The plot of the absorption coefficient values from the three reference data was then searched for the linear equation using the trendline menu in Microsoft Excel as comparison data for the absorption coefficient. This comparison data is used to see the accuracy of the absorption coefficient data obtained from the test results using test equipment designed by the researcher. The graph of the test results is shown in Figure 8.

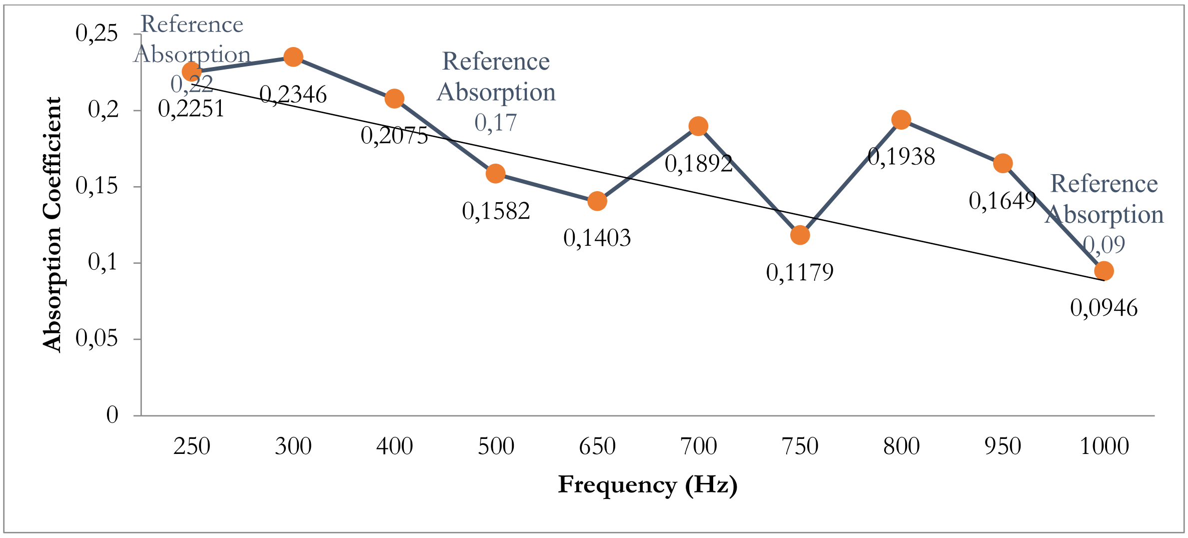

Figure 8. Testing Chart For Accuracy of Test Equipment

From the graph in Figure 8, it can be seen that the absorption coefficient data obtained using the test equipment is close to the reference absorption coefficient data. Data on the accuracy of the test equipment can be seen in Table 1.

Table 1. Absorption Coefficient Accuracy Data

Frequency (Hz)	∝ Test Equipment	∝ Theory	% Error	Accuracy
250	0.2251	0.2250	0.04%	0.99
300	0.2346	0.203	15.57%	0.84
400	0.2075	0.1816	14.26%	0.85
500	0.1582	0.16	1.13%	0.98
650	0.1403	0.492	5.97%	0.94
700	0.1892	0.1382	36.80%	0.63
750	0.1179	0,1275	7.53%	0.92
800	0.1938	0.1166	66.21%	0.33
950	0.1649	0.1058	55.86%	0.33
1000	0.0946	0.095	0.42%	0.99
Average			20.38%	0.79

Table 1 is the data on the accuracy of the test equipment at 10 frequency variations. Based on Table 1, it can be seen that the absorption coefficient obtained using the test equipment is not much different from the theoretical absorption coefficient. Accuracy data obtained with an average of 0.79 and an average percent error of 20.38%.

The accuracy of the test equipment was obtained from repeated testing 10 times to obtain the absorption coefficient value for each variation of the frequency value. Data on the accuracy of absorption coefficient values can be seen in Table 2.

Table 2. Accuracy of Sound Absorption Coefficient Test Equipment

	Frequency (Hz)									
Try to-	250	300	400	500	650	700	750	800	950	1000
1	0.2251	0.2346	0.2075	0.1582	0.1403	0.1892	0.1179	0.1938	0.1649	0.0946
2	0.2251	0.2346	0.2075	0.1582	0.1403	0.1892	0.1179	0.1938	0.1649	0.0946
3	0.2251	0.2346	0.2075	0.1582	0.1403	0.1892	0.1179	0.1938	0.1649	0.0946
4	0.2251	0.2346	0.2075	0.1582	0.1403	0.1892	0.1179	0.1938	0.1649	0.0946
5	0.2251	0.2346	0.2075	0.1582	0.1403	0.1892	0.1179	0.1938	0.1649	0.0946
6	0.2251	0.2346	0.2075	0.1582	0.1403	0.1892	0.1179	0.1938	0.1649	0.0946
7	0.2251	0.2346	0.2075	0.1582	0.1403	0.1892	0.1179	0.1938	0.1649	0.0946
8	0.2251	0.2346	0.2075	0.1582	0.1403	0.1892	0.1179	0.1938	0.1649	0.0946
9	0.2251	0.2346	0.2075	0.1582	0.1403	0.1892	0.1179	0.1938	0.1649	0.0946
10	0.2251	0.2346	0.2075	0.1582	0.1403	0.1892	0.1179	0.1938	0.1649	0.0946
Average	0.2251	0.2346	0.2075	0.1582	0.1403	0.1892	0.1179	0.1938	0.1649	0.0946

Table 2 is the data resulting from the accuracy of the absorption coefficient. Accuracy data retrieval by taking 10 variations of frequency values. Based on the data, it can be concluded that the accuracy is good because the value obtained for each repetition of the test is the same. Tool This frequency value variation is taken based on the limit of tool performance conditions. The next result is the effect of frequency variation on the value of the absorption coefficient and the value of sound intensity. The effect of the frequency variation on the absorption coefficient value can be seen by looking at the changes in the absorption coefficient value at each frequency test. To see the effect of frequency variations on the absorption coefficient value, it can be seen in Figure 9.

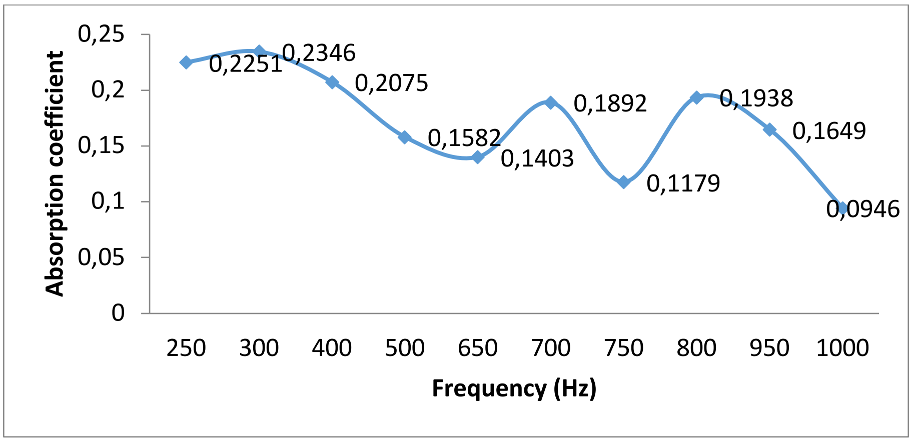

Figure 9. Effect of Frequency Relationship with Absorption Coefficient

Based on the graph in Figure 9, it can be concluded that for the standard sample (plywood 3/8") it is good for absorbing sound at a frequency of 300 Hz with an absorption coefficient value of 0.2346, while at a frequency of 1000 Hz the sound absorption is not good with an absorption coefficient value of 0.0925. The absorption coefficient (α) is expressed as a number from 0 to 1. If the absorption coefficient value is 0 it means that sound energy is not absorbed at all, and if the absorption coefficient value is 1 it means ideal absorption [18]. The sound intensity value is obtained by measuring using a Sound Level Meter at each frequency variation. Measurement of the intensity value is carried out on the back and front of the sample to see changes in the resulting value. The data from the measurement of the sound intensity value can be seen in Table 3.

Table 3. Sound Intensity Value Data

Frequency (Hz)	In Front of Sample (dB)	Behind Sample (dB)
250	92.16	72.45
300	88.06	71.75
400	87.66	67.57
500	103.26	70.07
650	89.33	63.76
700	88.55	61.36
750	92.23	60.06
800	98.04	65.14
950	93.67	57.45
1000	88.35	54.76

The effect of the frequency variation on the sound intensity value can be seen by looking at the change in the sound intensity value at each frequency test. To see the effect of frequency variations on the absorption coefficient value can be seen in Figure 10.

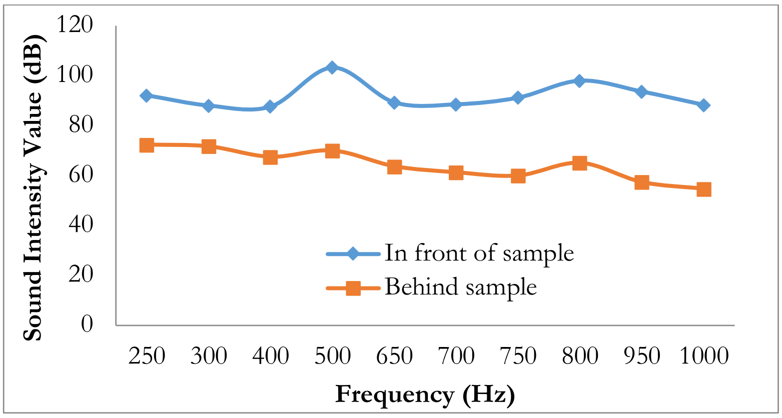

Figure 10. Effect of Frequency Relationship with Sound Intensity Value

Based on the graph in Figure 10, it can be concluded that the effect of frequency variations on the sound intensity value obtained when testing in front of a standard sample (plywood 3/8"), namely the sound will get bigger as it gets bigger along with the variation of the given frequency value. For the test on the back of the standard sample (plywood 3/8"), the value of the obtained sound intensity is reduced because the sound is transmitted through the absorbent material. The decrease in the value of sound intensity occurs quickly due to the maximum value of the vibration amplitude of the particles that make up the absorbent chip that is traversed by the sound wave so that the transmission sound wave will experience destructive interference when it leaves the absorber chip [19].

The result of this study demonstrates the effectiveness of the two-microphone impedance tube method in measuring the sound absorption coefficients of materials. The developed test device successfully captures sound intensity data and absorption coefficients, providing a reliable and portable solution for acoustic material testing. The accuracy assessment, with an average error rate of 20.38%, confirms the reliability of the measurement system. However, to critically analyze these results, it is essential to compare them with previous studies and discuss their implications for future research and applications

For the manufacture of this test instrument, the surface of the tube used must be flat, free of pores, and free of holes (except for the location of the microphone). The tube wall must be thick enough to dampen the vibrations caused by the transmission of sound signals. The recommended impedance tube thickness is at least 5% of the tube diameter. The microphone is placed in the sound wave area with a minimum distance of the diameter of the tube from the sound source [20].

The experimental data indicate that the device provides consistent absorption coefficient values across different test frequencies. The highest absorption coefficient was observed at 300 Hz, with a gradual decline at higher frequencies. This pattern aligns with established acoustic material properties, where absorption tends to be more effective at mid-range frequencies. The sound intensity measurements further validate this trend, demonstrating a noticeable reduction in intensity behind the sample compared to the front.

The manufacture of a material acoustic property test using the 2-microphone impedance tube method has advantages and disadvantages. The advantages of this test tool are that it is practical and easy to carry everywhere because this tool consists of several components that can be removed quickly, and this tool also uses an output in the form of an LCD which functions as a simple oscilloscope. This test equipment also has a drawback that in this study only compares the standard sample data tested with the standard sample data that already exists in the reference to get the value of accuracy and accuracy. Also, this designed tool is not validated to the original factory-made tool. One limitation observed in the study is the restricted frequency range of the device. While the impedance tube is theoretically capable of measuring absorption coefficients within the range of 173 Hz to 5 kHz, the practical testing was limited to 250 Hz–1000 Hz due to noise interference at higher frequencies. Future research should focus on refining the tube design and implementing noise-filtering algorithms to extend the measurable frequency range.

The findings of this study have several important implications for future research and industry applications. First, the development of a portable and automated impedance tube system enables broader accessibility for researchers and engineers working on acoustic materials. The integration of real-time data visualization simplifies the measurement process, making it more user-friendly for field applications.

Additionally, the modular design of the device allows for customization and integration with advanced signal-processing techniques. Future studies could explore the implementation of machine learning algorithms to enhance measurement accuracy and identify material properties more efficiently. Moreover, expanding the range of test materials and conducting comparative studies with industrial-grade impedance tube systems will further validate the effectiveness of the developed device.

In conclusion, this study presents a significant advancement in acoustic material testing by addressing the limitations of previous impedance tube methods. By enhancing automation, portability, and data accuracy, the proposed system provides a valuable tool for both academic research and industrial applications. Future work should focus on refining the system to accommodate a wider frequency range and exploring its potential in non-destructive acoustic material evaluation.

4. Conclusion

Based on the results of the research and the results of data analysis on the material acoustic properties test system using the 2 microphone impedance tube method, it was found that the results of the mechanical design in the form of an impedance tube according to the ISO 10534-2:1998 standard with a tube inner diameter of 40 mm ≈ 1.5 inches, 3 mm thick, and 50 cm long tube. The limit of measurement that can be done with the designed tube is 173 Hz to 5 kHz. The system design is controlled using an Arduino microcontroller whose measurement results will be displayed on the LCD. For testing the accuracy of getting results with an average of 0.79 and an average percent error of 20.38%. The data for the accuracy of the test equipment obtained from repeated testing is 10 times to obtain the absorption coefficient for each variation of the frequency value. Based on the data, it can be said that the accuracy is good because the scores obtained from each test are the same. Tool This frequency value variation is taken based on the limit of tool performance conditions.

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