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DESIGN AND ANALYSIS OF IMPEDANCE TUBE FOR SOUND ABSORPTION MEASUREMENT

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ABSTRACT

Acoustic materials play a very important role in design of automobile interior, factories, workshops etc., Acoustic materials are most commonly used now a day in passive noise control to prevent unwanted noise Many new acoustic materials are discovered day by day for this application. Finding out the characteristic of those acoustic materials before using it in the application is so mandatory. Absorption coefficient of a material at various frequency ranges has to be known since absorption coefficient varies at various frequencies. This paper elaborately describes how to measure the absorption coefficient of the material from the proposed design. Both electrical and mechanical components are getting fabricated in the aim of reducing the price and also modification has been made in the conventional impedance tube. This paper gives the selection of tube diameter, length, tube material, sample size, amplification circuit, microphone, pre amplification, filters, microphone position and Data acquisition using sound card and LABVIEW. Using the standard calibrated specimen absorption coefficient of the material is calculated and it is compared to find the accuracy of the setup. Experimental setup is fabricated as per the ASTM c384 standard. Sound absorption coefficient (α) of any acoustic material can be calculated by using this setup. In order to find out the accuracy of the setup standard materials is kept and tested.

Keywords: impedance tubes, sound absorption coefficient, data acquisition, transfer function.

1. INTRODUCTION

Noise is undesirable sound which causes both physical and psychological problems of human and reduces productivity. So, only most of the company wall is covered with acoustic materials to reduce the noise. Noise varies from frequency 200Hz to 6.5 KHz finding out a single material which can work well throughout all frequency range is so difficult. Hence the selections of materials for the acoustic application play a vital role. Similarly, in automobile also number of new innovation has been performed to increase the performance of the vehicle. This increase the sound produced by various mechanical part inside the vehicle. So a perfect shielding has to be there to reduce the noise of the vehicle. Cabin of the automobile is provided with acoustic material covering to provide noise proof comfort to the passenger inside vehicle.

Now a day new acoustic materials are discovered by various researchers for acoustic application. Some of the materials have better porous nature, some having good absorption and some having good reflecting nature are discovered. Apart from this there are wide ranges of acoustic materials already under usage. Finding out the nature of the acoustic materials is so mandatory before using it in the application. Nature of the acoustic materials at various frequencies is to be found out. Depending upon the frequency of the noise particular materials can be chosen.

Sound absorption is defined as the process by which a material takes in sound energy when sound waves encountered. When sound waves are passed through the acoustic material there are three processes

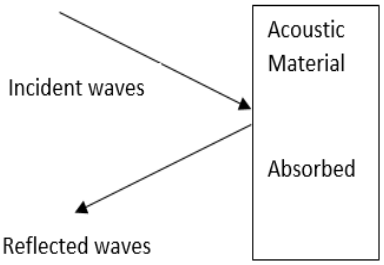

Figure-1. Sound absorption nature.

occur in the material. 1. Sound reflection 2. Sound absorption 3. Sound transmission. Amount of sound energy absorbed/reflected by the material depend on the sound absorption coefficient (α). It is a dimensionless number whose value differs from 0 equal to 1. Sound absorption coefficient (α) of a material indicated how much of the sound get absorbed by that material. In simple word it is the sound intensity by material per unit area to the incident sound intensity per unit area.

$$\propto = \frac{Ia}{Ii}$$

Ia = sound intensity absorbed in w/m^2
Ii= incident sound intensity in w/m^2

The value of α=0 indicates the entire sound incident on the material get absorbed. Similarly, the value α=1 indicates the entire sound waves incident on the material get absorbed. For any material to be a good sound absorption material the value of α should be greater than 0.75. Similarly, sound reflecting material have α<0.25. So Finding the value of the α value of any material is so mandatory to utilize them in proper application. Value of

the sound absorption coefficient of the material various at various frequencies so the noise reduction coefficient is calculated. NRC is the arithmetic average of the value of the sound absorption coefficient of the material at 250Hz, 500Hz, 1000Hz and 2000Hz. SAA (Sound absorption average) also get calculated from the sound absorption coefficient.

3 commonly used methodologies for finding out the absorption coefficient are Reverberation chamber, Reflection Method and Impedance tube. Reverberation camber [11] is oldest method and used now a day even, but it requires more space and costlier. RC is not suitable for research purpose since the sample size in this method is bigger so only impedance tube method [7] [8] is preferred by researchers. Reverberation and Wave tube method are not suited for finding out the absorption coefficient of the material on the realistic condition. Reflection method is an in situ method (Realistic) [3] [4] which can be carried out in the normal room condition along with background noise. This method is highly sensitive, even a minor error will produce in accurate results. So it is rarely preferred.

2. EXPERIMENTAL SETUP

Impedance tube method [7] [8] has more advantage when compared to other method because of its compact, low cost and fast result. In this method sound is created inside the impedance tube and made to incident on the acoustic material. From the reflected waves some of the characteristic of the acoustic materials can be calculated. Impedance tube method is well suitable for the small sample size where as in case of the reverberation camber larger sample are used (say $8m^2$). Standing wave method [6] and transfer function method [7] [8] are two commonly used method of impedance tube. It is the direct method which involves calculation of the standing wave ratio (SWR). In this method microphone is moved along the length of the microphone by means of the carrier assembly. This most common and simple method to calculated the absorption coefficient (α) of the materials only. Here the sound of particular frequency is produced by means signal generator or android application in the mobile.

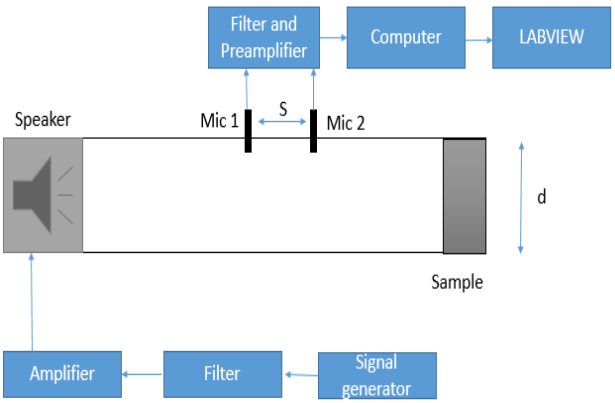

Figure-2. Two microphone setup.

Loud speaker is kept at the one end of the impedance tube while the sample is kept at the other end of the impedance tube. 2 microphones are kept at the particular interval inside the impedance tube. This microphone converts the sound pressure inside the tube to respective voltage signal from that signal absorption coefficient can be calculated. 3 microphones and 2 sources are some other techniques proposed by Olivier Doutres [10] and Z. Tao [9].

3. SOUND GENERATION

By means of the signal generator or any equivalent circuit sound signal is produced. Signal generator should be cable of producing sine wave of frequency varying from 200 Hz to 3000Hz.

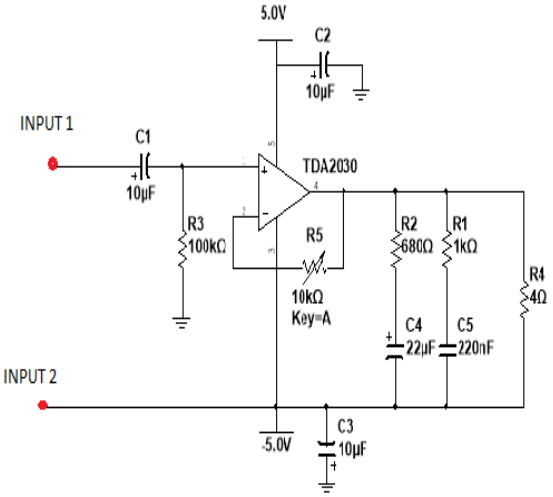

Figure-3. Power amplification circuit diagram.

In this studies signal generator android application is used as the signal source which is found to be more accurate with commercially used signal generator. Signal produced by the signal generator will have a desired voltage difference but it does not have the required current to run the speaker so an amplification circuit is required. Based on the compactness, flexibility and availability TDA 2030 IC is chosen for the work. It can give the output of maximum 14W. AC source is converted into regulated 5V by means of transformer and bridge rectifier. It is given as the power source for the IC. By using the desired feedback resistor, amplitude of the output signal can be changed. Circuit diagram of power amplification for speaker with filter and regulated linear output segment is shown in the Figure-3.

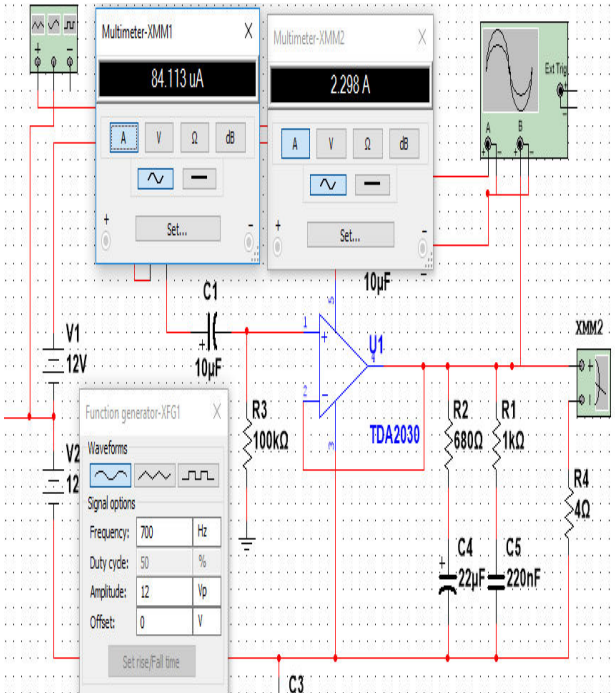

Figure-4. Simulation of power amplifier.

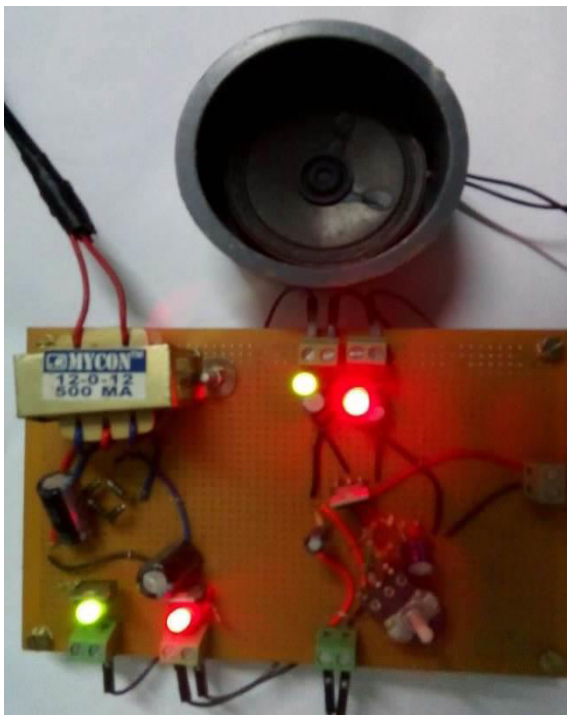

Figure-5. Power amplification kit.

4. IMPEDANCE TUBE

The interior section of the tube can be circular or rectangular but should be constant dimension from one end to another. The tube should be straight and its inside surface should be smooth, nonporous, and free from dust to maintain low sound attenuation [1] [2]. The tube length shall be large so sound transmission through the tube wall can be made to negligible. Cement, wood or plastic can be used as the material for the tube. In order to maintain low sound attenuation for plane wave's necessary sealing has done to the interior wall. For this research [7] [8] in order to reduce the cost of the setup commercially available PVC had been chosen. 2-inch pipe (D_i=57mm, D_o=60mm, t=3mm). Upper most working frequency of the system can be found out by the means of the formula

$$f_u < \frac{KC}{d}$$

K=0.586 c=speed of the sound =340*10^3mm/s
2-inch impedance tube can have the upper most working frequency of 3495.5Hz.

$$f_l < f < f_u$$

Length of the tube should be greater than the thrice the diameter of the tube (L>3d). Here 1-meter length pipe is used based on the literature review [1, 2, 7&8]. Two holes are drilled in the PVC tube in order to make it fit the microphone. The distance between the sample and first microphone is x_1 should be greater than the half of the tube diameter for the flat sample surface. Spacing between the mic can be calculated by the formula

$$S << \frac{C}{2f}$$

C=speed of sound f= upper most working frequency.

Spacing is maintained less than 70mm. lowest frequency response of the system is found out by the formula

$$f_l = \frac{0.1C}{2S}$$

By using this 2-inch impedance tube, acoustic material can be analyzed at the frequency range of 250 Hz to 3000Hz. commercially available end cap is used as the sample holder. Reflective material (foil paper) was glued inside it in order to increase the reflexive characteristic of the material.

5. MICROPHONE AND DAQ

In order to reduce the cost of the setup, Electret capacitor microphone (ECM) is used in this research. It is a type of pre-polarized microphone which has overcome all the inconveniences of traditional capacitor microphone like need for polarization. It is a condenser microphone which can be operated on 5V supply voltage. It is Omni-directional microphone which of very inexpensive and smaller in size. But the only disadvantage is that it needs an integrated pre-amplifier circuit. In order to reduce the cost of the entire setup amplification circuit is fabricated. LM386 IC is used because of its compactness and low single supply source. Simulation of the circuit is made by using the Multisim. Microphone is getting sealed to the holed drilled in the PVC Pipe. Preamplifier circuit is connected to the output of the microphone and it's connected to a 3.5 mm jack connector. Both the signal from the microphone can be acquired and can be written in the spreadsheet with the help of LABVIEW. Data

acquisition program is shown in the fig. Microphone signal can be acquired using the DAQ card or sound card or any other equivalent equipment. Since we are dealing with sound, now a day all the commercially available laptop is inbuilt with a sound card. Microphone jack of the laptop can be used to acquire the signal. But it has some disadvantage of only one signal can be acquired at a time. So two laptops are used to acquire signal. Diode and resistor are used to make a simple safety circuit to prevent any damage to laptop. For the next trial Ni DAQ (4432) card is connected to the output of the microphone. By using two channel, signal can be acquired in the same ways and saved in a single excel sheet.

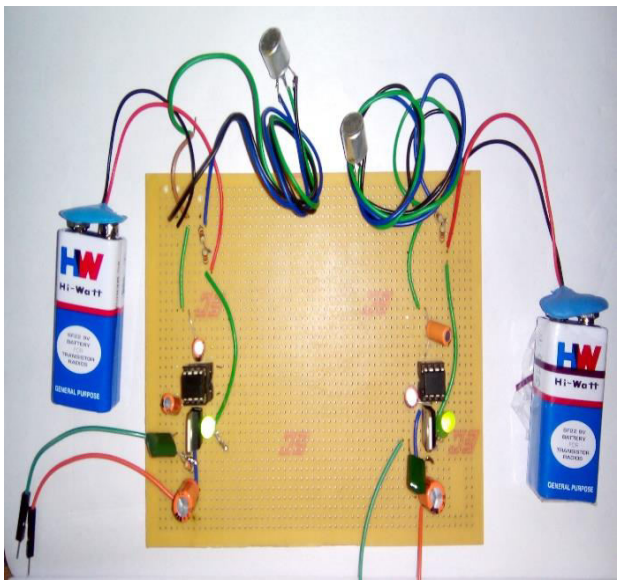

Figure-6. Microphone with preamplifier.

6. ABSORPTION COEFFICIENT CALCULATION

All the equipment is placed in a stable frame so that there should not be any oscillation in impedance tube. Power supply is given to the speaker amplification circuit. Signal generator is connected to the amplification circuit. Output from the amplification circuit runs the speaker which is attached to the one side of the impedance tube. Sample to be tested is kept on the other side of the impedance tube. First the test is done without any sample. Highly reflecting aluminium foil is kept at the other end of the sample so that the absorption coefficient should be nearly to 0. First the speaker is made to run for certain period of time for stabilization. Temperature of the surrounding has to be maintained throughout the experiment. Amplitude and frequency of the input signal can be adjusted. LABVIEW acquire the signal depending upon the sampling rate. According to Nyquist equation sampling rate should be greater than twice the working frequency. Now the value of the frequency is changed and the signals are acquired for each trial. Sample is made with diameter same as that of the tube diameter, thickness 15mm. There should not be any gap between the sample and the tube. Using write to spread sheet command, the values can be imported to excel. Mean of the value is found out in both the laptop. Absorption coefficient is calculated using the following equation.

Absorption coefficient

$\alpha = 1-|r|^2$

Reflection coefficient:

$$r = \frac{H_{12} - Hi}{Hr - H_{12}}$$

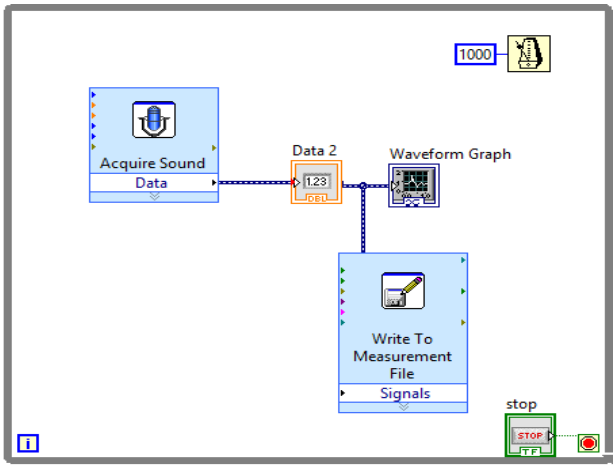

Figure-7. LABVIEW coding to acquire signal.

$H_r = e^{jks}$ $H_i = e^{-jks}$ $H_{12}=S_{12}/S_{11}$

S_{12}= Cross spectrum b/w two mic= $P_2 P_1$

S_{11}= Auto spectrum of mic 1 =$P_1 P_1$

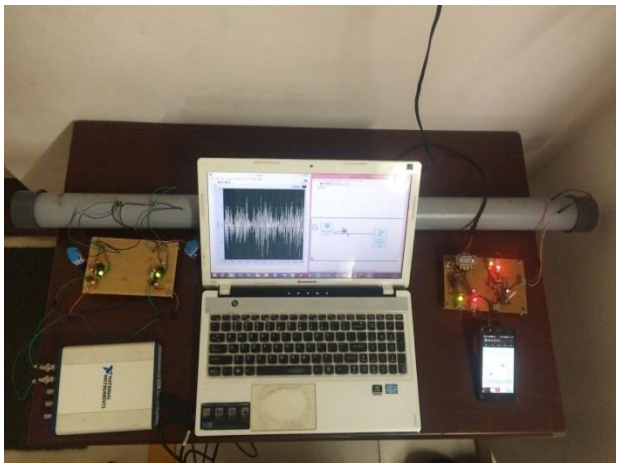

Figure-8. Impedance tube setup.

7. RESULT AND DISCUSSIONS

Experiment is conducted for empty tube with only aluminum foil. Output voltage of both the microphone for various frequencies is found out. Absorption coefficient of empty tube is calculated from the above formula.

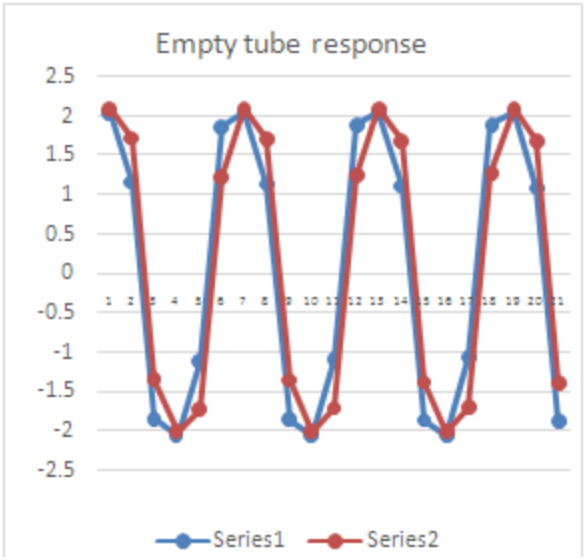

Figure-9. Time vs amplitude for empty.

Graph is plotted in between the time and the output voltage to find the response of the system. In Figure-9 both the signal overlap together which shows output from both the microphone is same. Similarly, Figure-10 & Figure-11show the amplitude response for the wooden sample and with some acoustic sample. From the blue curve it is found out for acoustic materials absorption coefficient is higher so the amplitude is lower when compared to that of the wooden sample. Now the Graph is plotted between frequency and absorption coefficient. Figure-12 shows variation of absorption coefficient of empty tube for various frequencies with sound card setup. Values should be closer to zero for 100% accuracy. It is found that the system responds in the same way as done Deshpande [8] and the graph acquired is more or less similar that. Which conclude the accuracy of the system is far better at this cost. Figure-13 shows the output for empty tube with DAQ card. From the graph we can conclude the system response far better since most of the value is near to zero. This concludes the system with DAQ response far better than system with sound card.

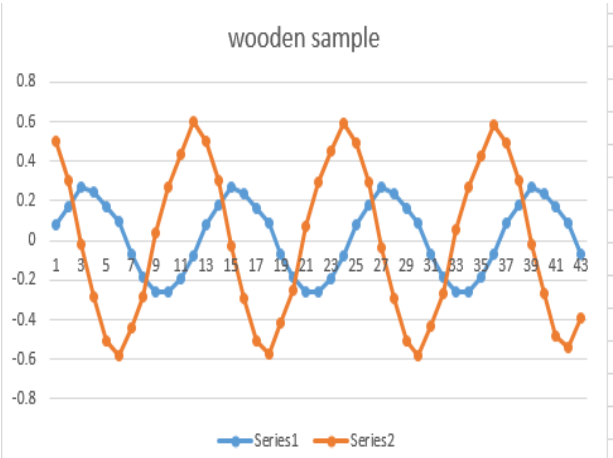

Figure-10. Time vs amplitude for empty.

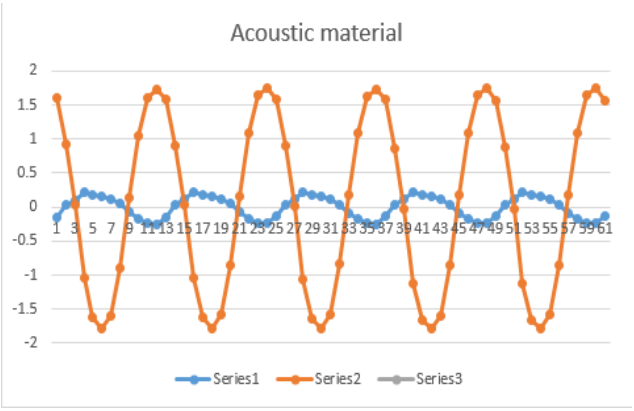

Figure-11. Time vs amplitude cure for wooden.

Figure-12. Absorption coefficient vs frequency for empty tube with sound card.

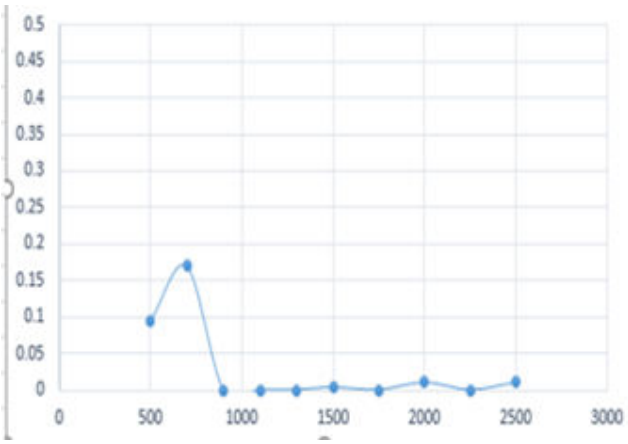

Figure-13. Absorption coefficient vs frequency for empty tube with DAQ card.

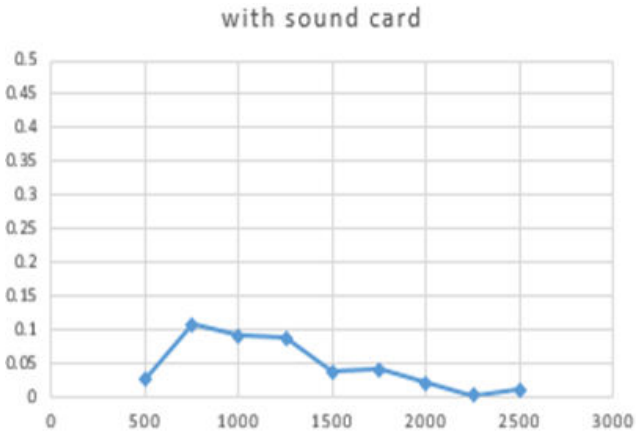

Figure-14. Absorption coefficient vs frequency for wooden sample with sound card.

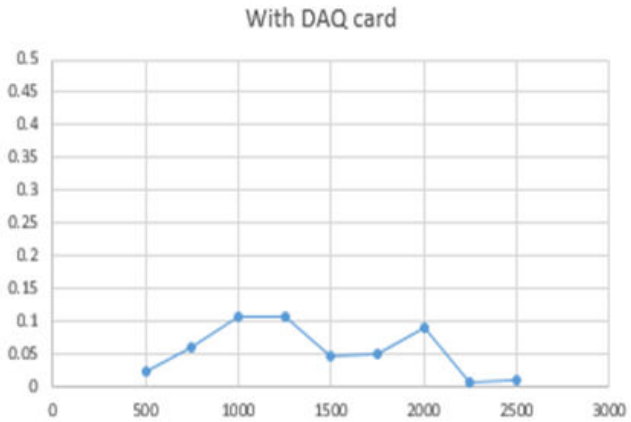

Figure-15. Absorption coefficient vs frequency for empty tube with sound card.

Now the graph is drawn for the frequency Vs amplitude for impedance tube with wooden sample for both trials (with sound card and with DAQ card). For the standard wooden sample absorption coefficient at the frequency range should be more or less equal to 0.1. From the graph we can conclude the accuracy of the setup. For the frequency range from the 1500 to 2000Hz the system give value lesser then the 0.1 but the system with DAQ card gives all value near to 0.1 so it is find out the system responds in better way with high accuracy at this low cost.

8. CONCLUSION AND FUTURE WORK

Experimental setup is constructed to calculate the absorption coefficient of any acoustic material at low cost as possible. Initial testing of the setup is made with aluminium foil and then with wooden sample it is found that the system responds better at this low cost. Analyses of the system are done with changing the DAQ system (with Ni DAQ card & with sound card). So, that Accuracy of the system is found out. Some more validation test is to be conducted by placing the standard samples. From the absorption coefficient, some other variables like reflection coefficient, transmission loss and complex acoustic impedance can also be calculated.

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