ISSN 2176-5480

22nd International Congress of Mechanical Engineering (COBEM 2013)
November 3-7, 2013, Ribeirão Preto, SP, Brazil

DESIGN AND CONSTRUCTION OF A LOW COST IMPEDANCE TUBE FOR SOUND ABSORPTION COEFFICIENTS MEASUREMENTS

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Abstract. *Currently the active techniques for acoustic noise control have received considerable interest in the scientific area. However the requirement of highly precise control, stability and reliability make the passive techniques still be the traditional approach to noise control. The passive techniques such as enclosures, barriers and silencers are widely used and they use the sound-absorbing material as the basis to provide the silencing. Thus the acoustic characterization of this kind of materials is sorely needed in order to use these data in acoustic projects, even in the analytical or numerical step. In this context, this work presents the design of an impedance tube (IT) which is commonly used for determine the normal incidence absorption coefficient and the specific acoustic surface impedance of acoustic materials. This equipment proves viable when compared to others methods like the reverberant chamber, such as ease of construction, low cost, its portability and fast results providing. In this paper is described all the design steps of an IT, since its conception until the final product. Firstly the theoretical background of the transfer function method is discussed according to ISO 10534-2. The analytical formulation is presented as an important step in the design of this apparatus mainly in the working frequency range determination. The construction details of the IT (materials and dimensions) and the design of the electric devices are reported too. Previous experimental results are shown.*

Keywords: *Acoustic, impedance tube, absorption coefficients, ISO 10534-2.*

1. INTRODUCTION

Noise is characterized as undesired sound without harmony which can actually cause physical harm leading to both psychological and physiological symptoms, such as hearing loss, increased blood pressure and reduce productivity at work (Alves, 2011). So, the classical manner to reduce the annoyance caused by the noise is to do a properly acoustic treatment where can be in the industry, offices or residential environment. Mainly for architectural acoustic or high frequency noise control the absorbing materials are a good alternative. This kind of noise control is defined like passive technique and it is encountered in many applications like enclosures, barriers and silencers witch use the sound-absorbing material as the basis to provide the silencing. Several types of sound absorbing materials are currently available for noise control applications and plenty of examples can be found in fields of building and acoustics room ans transportation industry (Lanoye, 2007).

From an acoustic engineer's point of view, the absorption coefficient is the most important information about an acoustic material. According to it, materials are usually classified as absorptive or reflective. Measure methods have been developed and standardized in order to enable the study of the acoustic properties of different materials in order to use these data in acoustic projects, making possible to optimize the noise control and the acoustic quality of the environment (Jaatinen, 2011). The three standardized measurement methods best known are: reverberation chamber method described in the standards ISO 354, and two impedance tube methods that are described in standards ISO 10534-1 and ISO 10534-2.

Also, there is a fourth method for measuring the absorption curves of the material, called, by some authors, by reflection method witch measurements are made at the specific site (*in situ* methods). The samples are subjected to incidence of waves in free field at a certain angle. This method has been discussed in literature by many authors (Garai,1993; Mommertz,1995; Stevens, 2003; Mallais, 2009; Carneiro, 2011) and has growing up with the development of electronic systems, making viable the measurements outside the laboratory. The sound absorption curve is measured by a portable device that is brought to the object/location to be tested. Using the *in situ* methodology the ISO 13472-1 standard was published reporting the method for measuring *in situ* the absorbing of roads surfaces.

If a comparison is made about the four methods cited above, advantages and disadvantages of each one can be listed. The *in situ* method has the advantage of it don't destroy the sample (in the other methods the sample needs to be prepared previously) and it is not necessary a physical space to mount the apparatus measurement. Although the mathematical approach involved in the method is complex, once the acoustic waves are not planes and mathematical simplifications are not applicable (Carneiro, 2011).

The reverberation chamber measurement described by ISO 354 is an accurate method for estimating the acoustic absorption for all sounds incident angles while the impedance tube only considers normal incident angles. So the reverberation chamber requires a special installation and a considerable spare to locate it, once the related standard regulates it as a room with a volume of 200 m³, at least (Jaatinen, 2011). In order to guarantee an uniform distribution of natural frequencies, especially in low frequencies bands, the camera should not have two dimensions equal or multiple to each other. The method is performed as a comparison measurement between the reverberation times of an empty chamber and with absorptive material arranged on the floor. The sample area most have from 10m² to 12m² (Oliveira, 2005).

Unlike the reverberation chamber, the acoustic absorbing measurements using the impedance tube method are accurate for normal incident sounds waves only (Beranek and Ver, 1992). So with the methods described by ISO-10534-1 or ISO- 10534-2 it is possible to determine the normal incidence absorption coefficient and the specific acoustic surface impedance. Although for low frequencies the impedance tube method may not give accurate results because an airtight fit of the sample is needed and at the same time the sample has to be able to vibrate freely (Vissamraju, 2005). The advantage of the IT is its portability once the apparatus consists of a rigid walled tube with a sound source at one end and the sample of absorbing material to be tested at the other end. All the experimental system can be placed at a laboratory stand.

As cited above there are two methods which are employed for acoustical impedance measurements using an impedance tube: the method using standing wave ratio (ISO 10534-1) and the transfer-function method (ISO 10534-2). The first one uses transient sound excitation to excite a single microphone that can be move lengthwise inside the tube and the second uses continuous white noise to excite one or two-microphones. The classical acoustics theory must be used to derive the equations for the two methods. The transfer function (TF) method was presented by Chung and Blazer (1980) which consists in to obtain the TF between two fixed microphones located at two different positions in the tube wall. The incident and reflected waves can be recovered mathematically in an easily form. From these the reflection coefficient of the sample can be calculated for the same frequency band as the broadband exciting signal. The impedance and absorption coefficient can be calculated as well. The transfer function method has proven to be reliable and it is widely used in researches and practical applications (Vissamraju, 2005).

Over the years the impedance tube has been proved to be viable when compared to others methods cited above, such as it is relatively easily constructed, it has low cost, it is portable and it provides fast results. Although the reverberation chamber requires tests specimens which are rather large, it is not convenient for researches and development work where only samples of specimens are available. Due to these advantages, this equipment and methodology has been extensively used in the acoustic characterization of many kinds of materials, even in the analytical or numerical step (Vissamraju, 2005; Massarane, 2008).

Recently researches and published papers (Good *et al*, 2013; Dupont *et al*, 2013) show that even this methodology been well-known it possibilities many applications and configurations for studies of subjects as characterization of a wide variety of acoustic media, modeling of sound propagation in porous materials, mastery of computer based data acquisition and processing, practical problems such as cutting and positioning of the sample in the IT, design of a multilayer porous medium with desired acoustic properties, etc.

In order to contribute with details description in the IT design this paper describes all steps involved in the IT construction, since its conception until the final product. The goal was to obtain a low cost experimental setup which be capable to determinate the acoustic absorption coefficients of different materials in a precise manner using both techniques, one and two microphones. This one was constructed and practical tests were conducted.

About this paper structure, firstly the theoretical background of the transfer function method is described according to ISO 10534-2. The analytical formulation is presented as an important step in the design of this apparatus mainly in the working frequency range determination. The construction details of the IT (geometrical dimensions including detailed costs and materials) and the design of the electric devices are reported too. Some experimental results using the method of two microphones are shown, once this technique has ever been implemented in the system designed. The electronic devices for the one microphone method are still in development and it must be treated in future works.

2. THEORETICAL BACKGROUND

Due to the development of signal processing techniques the sound absorption coefficient can be determined faster and with good repeatability, especially when using the transfer function method described in the ISO 10534-2. This standard describes two methods: one and two-microphone. This work uses the two-microphone method, which is the most commonly used in researches and practical areas. The following mathematical formulation is based in this standard.

The theory underlying the two-microphone method involves the decomposition of a broadband stationary random signal (generated by an acoustical driver) into its incident and reflected components by the use of a simple transfer function relation between the sound pressure at two locations on the tube wall as depicted in Fig. 1. This wave decomposition is made by a determination of the complex reflection coefficient, from which acoustical properties such as the acoustical impedance and the sound absorption coefficient are evaluated.

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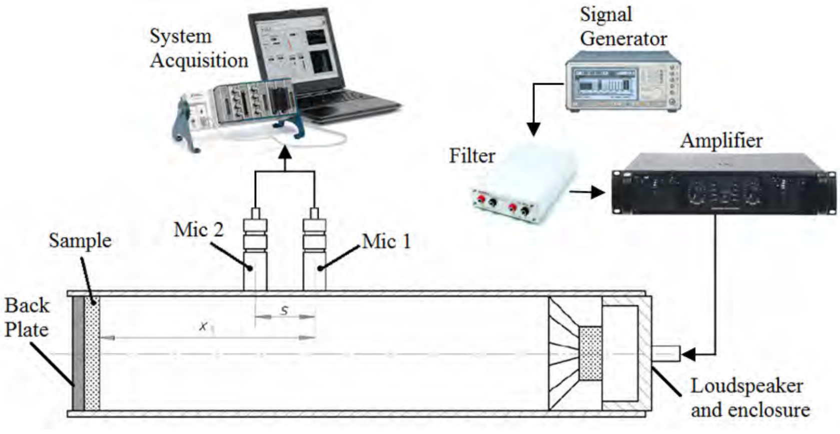

Figure 1. Impedance tube setup.

The first aspect of the instrumentation setup (Fig. 1) is to guarantee propagation of only plane waves once the formulation described in ISO 10534-2 is valid for this condition. This is achieved with the filter indicated in Fig. 1 which its cut frequency is given by Eq. (1).

$$f_c = \frac{1.84c}{\pi d} \tag{1}$$

where c is speed of the sound [m/s] and d is the duct diameter [m].

The usable frequency range depends on the duct internal diameter and the spacing between the microphones. An extended frequency range may be obtained from the combination of measurements with varying internal diameters and spacing between the two microphones.

The measurement method is based on the fact that the sound reflection factor, at normal incidence, r, can be determined from the measured transfer function H_{12} between two microphone positions in front of the material tested.

The transfer function between the two microphones shown in Fig. 1 is:

$$H_{12} = \frac{S_{12}}{S_{11}} \tag{2}$$

where $S_{12}=p_2.p_1^*$ is the cross spectrum between the two microphones; $S_{11}=p_1.p_1^*$ is the auto-spectrum of the Microphone 1.

The reflection factor can be calculated from the measured transfer function:

$$r = \frac{H_{12} - H_I}{H_R - H_{12}} e^{2jk_o x_1} \tag{3}$$

where H_I is the transfer function for the incident wave alone (Eq. 5) and H_R is the transfer function for the reflected wave alone (Eq. 6); x_1 is the distance between the test sample and the first microphone; k_o is the wave number defined as:

$$k_o = \frac{2\pi f}{c} \tag{4}$$

where f is the frequency in hertz.

$$H_I = e^{-jk_o(x_1 - x_2)} = e^{-jk_o s} \tag{5}$$

$$H_R = e^{jk_o(x_1 - x_2)} = e^{jk_o s} \tag{6}$$

ISSN 2176-5480

where the separation between the two microphones is $s = x_1 - x_2$.

The normal incidence sound absorption coefficient is:

$$\alpha = 1 - |r|^2 \tag{7}$$

The specific acoustical impedance ratio is:

$$\frac{z}{\rho c} = \frac{R}{\rho c} + \frac{jX}{\rho c} = \frac{1+r}{1-r} \tag{8}$$

where R is the real component of the impedance, X is the imaginary component of the impedance and ρc is the characteristic impedance.

3. DESIGN AND CONSTRUCTION OF THE MEASUREMENT SYSTEM

This section presents the main design steps and details of the construction procedure of the impedance tube and the electronic devices: amplifier and filter. The others commercial equipments as shown in Fig. 1 will be specified.

3.1 Design of the impedance tube and acoustic box

The impedance tube is constituted by five components as illustrated in Fig. 2(a) e 2(b): 1) acoustic box; 2) tube; 3) tube support; 4) microphones holder and 5) sample holder.

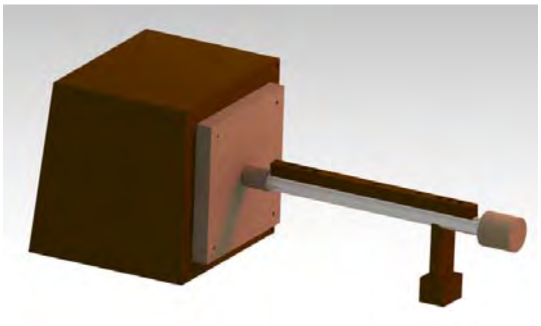

Figure 2(a). Isometric view of the IT.

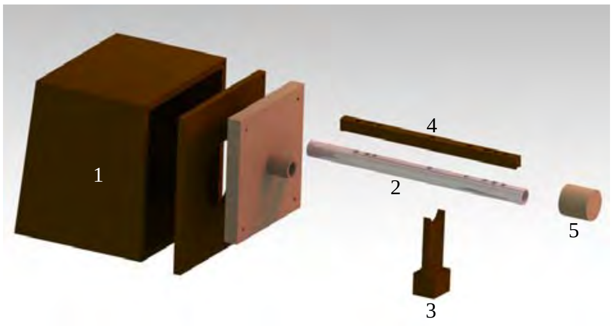

Figure 2(b). Exploded view of the IT.

According to ISO 10543-2, the loudspeaker must be stored in an insulating box in order to avoid airborne flanking transmission to the microphones. A MDF (12 mm thickness) cabinet was designed and constructed to fit the Markaudio Alpair-10 Gold 6" Full Range Gen 2 loudspeaker, which has 35 Watts RMS and frequency range of 40 to 23 kHz (manufacture specification). Figure 3(a) presents the geometrical dimensions in millimeters. As illustrated in Fig. 3(a), it is possible to note that the bottom wall of the box is lightly inclined in order to prevent the formation of standing waves. The MDF material was adopted once it was available in the institution (remainder from others applications). Although it presents to be strong, durable and it has low weight when compared with wood or steel. In order to minimize internal sound reflections and resonances, the box interior was coated with acoustic foam (Fig. 3(b)), in this case specifically, the egg crate pattern, increasing the damping factor inside the box.

In order to allow the fit between the acoustic box and the tube a connection between both was developed. This one was designed like a cover which has an internal conic shape, working like a wave guide conducting the sound from the loudspeaker to the tube in gradually reduced way. Figure 4(a) illustrates this connection with the dimensions in millimeters. It was necessary to join two MDF panels (each one of 12 mm thickness) to obtain the required cone depth. In order to connect the tube in the acoustic box cover it was used a PVC connection with 60 millimeters of internal diameter which is easily encountered in commercial stores and commonly applied for cold water system in edifications.

In the cases where the diameter of the tube is lower than the PVC connection, a PVC reducer coupler can be used as shown in Fig. 4(b). In this case, with these two kinds of PVC connection it is possible to use two impedance tubes with different diameters.

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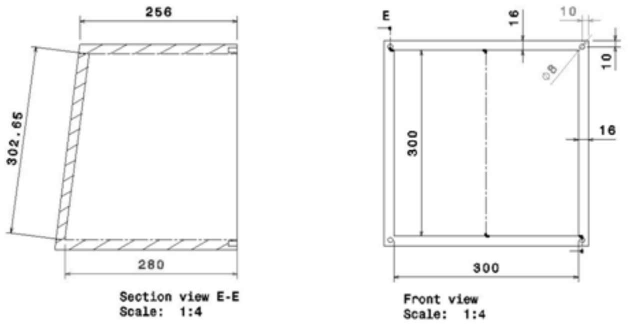

Figure 3(a). Acoustic box dimensions in mm.

Figure 3(b). Acoustic foam.

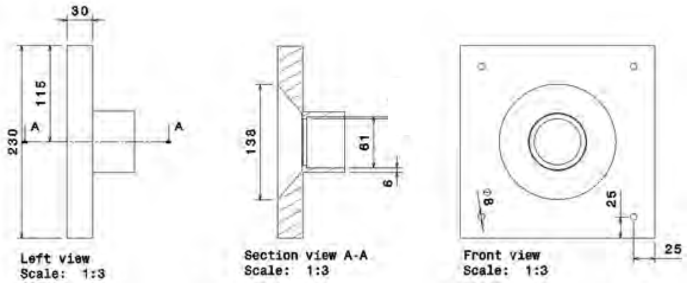

Figure 4(a). Acoustic box cover dimensions in mm.

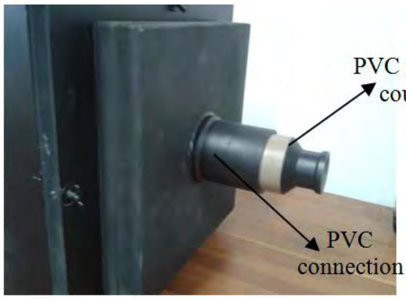

Figure 4(b). Detail of PVC reducer coupler.

The choice of the appropriate internal diameter of the impedance tube was done evaluating its cut off frequency according Eq. (1). It was selected two tubes with distinct internal diameter in order to reach different frequencies range. One has internal diameter of 53.4 mm, wall thickness of 3.3 mm and it is appropriate to evaluate frequencies until 3762 Hz. The other has internal diameter of 26.6 mm, wall thickness of 3.4 mm and it is appropriate to evaluate higher frequencies until 7552 Hz. The upper working frequency is chosen to avoid the occurrence of non-plane wave mode propagation and the lower frequency is limited by the accuracy of the signal processing equipment.

Different size of samples can be used depends on the availability. Both are commercial PVC tubes with 1 meter of length. The IS0 10543-2 recommends that the tube length should be at least 3 times the diameter.

A microphone holder was designed in order to pin the microphones to the PVC tube, as shown in Fig. 5(a). Pure wood was used for each microphone holder which was attached in each one impedance tube. The height of this microphone support should guarantee the vertical position of the sensor and the tangency of it with the inner surface of the tube. No sound leaks are permitted between the hole and the sensor. Silicone sticks were used to close the holes without microphones during the measurements. Commercial PVC termination was used as sample holder. Reflective material (foil paper) was glued inside it in order to increase the reflexive characteristic of the material, as shown in Fig. 5(b).

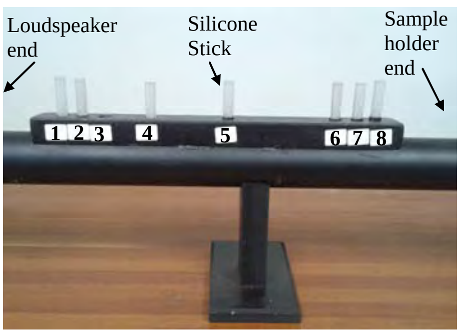

Figure 5(a). Microphone holder

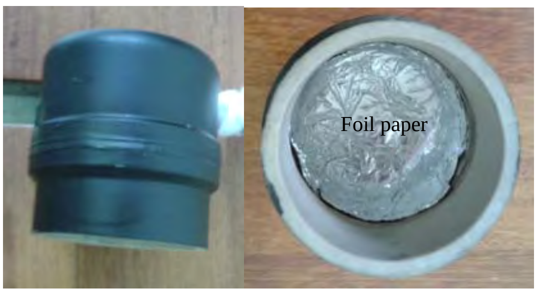

Figure 5(b). Sample holder (side view) and foil paper coating.

As shown in Fig. 5(a), in each tube was made 8 holes to place the ½” microphones. The distances (s) between them were determined according to Eq. (9). Firstly a frequency array was defined from 50Hz to 7500Hz with increment of 500 Hz. Using the Eq. (9) the microphone spacing was estimated for each frequency. Seven microphone spacing was selected in the whole considered range frequency. For this choice was considered: limiting manufacturing aspects, maximum length of the duct, dimensions recommended by ISO 10543-2, to try covering a wide range frequency as possible and to obtain a f_{ideal} nearly of the central frequency considering the octave bands. For each microphone spacing

ISSN 2176-5480

it is possible to determine the lower, upper and ideal frequency which the acoustic absorption curve presents the lowest variance (Báson, 1984). The frequency range which the measurements have acceptable accuracy can be determined using Eq. (10). Table 1 shows the microphone spacing estimated ($s_{estimated}$) from Eq. (9) and the same parameter ($s_{measured}$) measured directly in the large duct after its construction. The $s_{measured}$ shown in the Tab. 1 is narrowly different of the $s_{estimated}$ due to manufacturing error (precision error). The other columns of the Tab. 1 are estimated using Eq. (10) and $s_{measured}$. The same fact occurred with the small duct, where its microphone spacing is close to the $s_{measured}$ mentioned in the Tab. 1.

$$s = \frac{c}{2 \cdot f} \tag{9}$$

$$f_{lower} = \frac{0.1 \cdot c}{2 \cdot s} \qquad f_{upper} = \frac{0.8 \cdot c}{2 \cdot s} \qquad f_{ideal} = \frac{c}{4 \cdot s} \tag{10}$$

Table 1. Microphone spacing and recommended frequency range.

Positions	$s_{estimated}$ **[m]**	$s_{measured}$ **[m]**	f_{lower} **[Hz]**	f_{upper} **[Hz]**	f_{ideal} **[Hz]**
1-2	0,021	0,020	857	6860,0	4287,5
1-8	0,343	0,347	49	395,4	247,1
2-3	0,026	0,024	715	5716,7	3572,9
4-8	0,171	0,183	93,7	749,7	468,6
5-8	0,085	0,097	176,8	1414,4	884,0
6-8	0,043	0,046	372,8	2982,6	1864,1
7-8	0,017	0,022	779,5	6236,4	3897,7

Due to microphones spacing shown in Tab. 1 it can be defined the working frequency range of the IT setup: 50 to 6800 Hz. The lower frequency was defined mainly in function of the loudspeaker response. The small-tube setup is indicated to measure parameters in the frequency range from 50Hz to 6.8 kHz and the large-tube setup is indicated to measure parameters in the frequency range from 50 Hz to 3.8 kHz (this upper frequency is limited by non-plane wave propagation).

3.2 Design of the electronic devices

The electronics devices of the impedance tube system include the signal generator, filter, power amplifier, loudspeaker, microphones (sensors) and the data acquisition system (acquisition board and software). In order to reduce the cost of the whole IT set up the circuits of the power amplifier and the filter were design and these were constructed. The others electronics devices listed were purchased commercially and they were already available in the acoustic laboratory. In the next topic they will be specified.

Firstly the power amplifier was designed once it was necessary to supply the loudspeaker with the required electrical current. As observed in Fig. 1 the signal generator sends the desired signal to the loudspeaker, but it doesn't have the current required by the loudspeaker. So, the power amplifier can solve this trouble. The design of the power amplifier was made in order to guarantee some requirements: the relationship between the input and output signals must be as linear as possible and the frequency response must be stable throughout the working frequency range. After a bibliographic review about electronic devices applied in acoustic equipments the power amplifier circuit described in Delfino (2005) was used as an initial proposition.

For this case, the original circuit (Delfino, 2005) was adapted to work with unitary gain. The main component of the electronic project is the TDA2030A which is a monolithic integrated circuit (IC) intended for use as low frequency class AB amplifier. It provides high output current and it has very low harmonic and cross-over distortion. Others advantages are low cost and easy commercial availability. However this IC is high influenced by noise from supply voltage, so two capacitors were introduced in parallel with the supply voltage in order to avoid this problem. The power amplifier circuit design to the IT set up is shown in Fig. (6).

The next step was to design the filter which is connected between the signal generator and the power amplifier as shown in Fig. 1. This was designed in order to limit the upper frequency of the broadband signal which is sent to the loudspeaker from the signal generator. As described previous only plane waves propagating inside the duct is of interest, so the cut off frequency of the filter is defined in function of Eq. (1).

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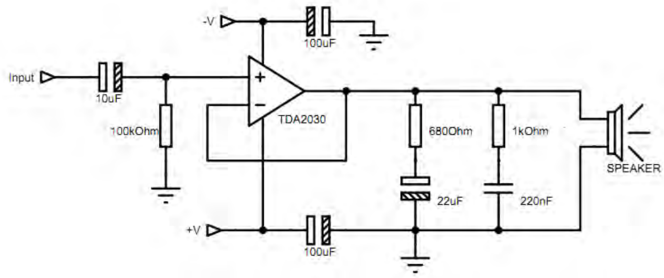

Figure 6. Power amplifier circuit.

The choice of the appropriate filter model was made after a literature analysis. It was designed an Inverse Chebyshev low-pass filter with unitary DC gain due to its flat response in the pass band and a small transition band. The main parameters are: maximum passband attenuation of 3 dB, minimum stopband attenuation of 20 dB, passband frequency of 12 kHz and stopband frequency of 15.6 kHz. The circuit of the designed filter is shown in Fig. 7.

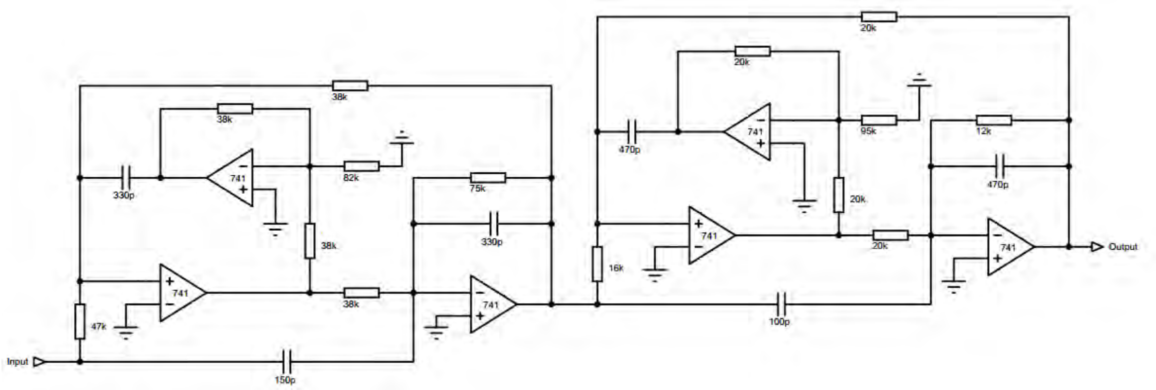

Figure 7. Filter circuit.

3.3 Specifications of sensors and equipments

The complete setup of the acoustic impedance measurement system is shown in Fig. 8. It is constituted of the follow equipments: 1) Waveform Generator *Agilent* 33220A 20MHz; 2) USB Data Acquisition System NI cDAQ-9172; 3) Four-channel signal acquisition module NI 9234; 4) Two ICP® prepolarized precision condenser 1/2" microphones (PCB Model 377B02) and preamplifiers (PCB Model 426E01) and 5) Sound level calibrator for ½” microphones Type 1251 Norsonic. The software LabVIEW® was used as interface with the computer in the data acquisition and the software MATLAB® was used to process the data (post-processing and estimative of the impedance and absorption coefficients).

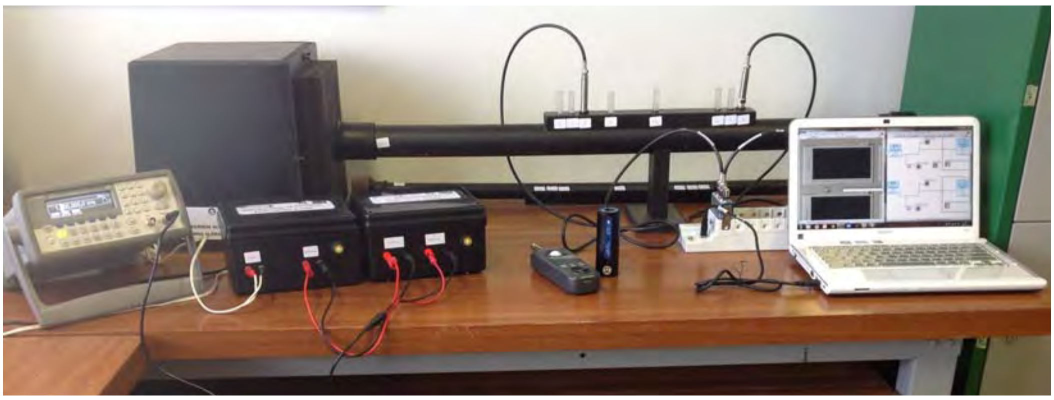

Figure 8. Acoustic impedance tube measurement setup: Two microphones technique.

As mentioned in the objectives of this work the cost of construction of this IT setup was an important design parameter which was aiming to reduce it when compared with commercial available IT (Fig. 9).

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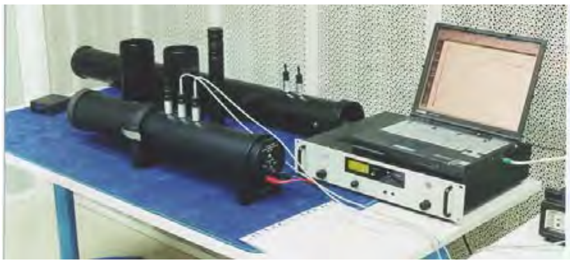


Figure 9. Commercial acoustic impedance tube measurement setup (Source: Bruel & Kjaer).

The Tab. 2 shows the cost of the IT proposed in this work considering that the materials of the acoustic box (MDF), tube support and microphone holder (wood) were recycled. The cost of the manufacturing process wasn't considered because it was accomplished in the laboratory of the institution.

Table 2. Cost of the designed equipments.

Description	Price (R$)	Price ($)*
Acoustic box and tubes	208,50	98,81
Loudspeaker	326,65	154,81
Power Amplifier	86,20	40,85
Filter	90,60	42,94
Total	711,95	337,41

*US Dollar Quote: 27/05/2013 (R$ 1,00 = $ 2,11)

In order to compare costs a commercial impedance tube costs on average R$ 8.000,00 (considering discount for academic institution), which is comprised the parts: acoustic box, tubes and the loudspeaker. The same parts from the project described in this paper cost R$ 535,15 as observed in Tab. 2 (lines 1 and 2). It was possible to achieve a saving of R$ 7.464,85.

4. ACOUSTIC MEASUREMENTS

Acoustic measurements were done with the setup shown in Fig. 8. It is important to highlight that these first measurements were done in order to check the designed setup, without to follow all regulations criteria. It was only a first check. So, the microphones were calibrated before and after the measures using the sound level calibrator specified in the previous topic and the temperature inside the duct was measured using a digital thermometer.

An acoustic foam was chosen to have its acoustic parameters (impedance and absorption coefficient) estimated using the impedance tube. This choice is justified by available of this material in the laboratory. This acoustic material is denominate of “egg crate pattern acoustic foam” with 15 mm thickness. A sample of this foam was just fit in the sample holder with care avoiding crushing it. The test samples used in both ducts was shown in Fig. 10.

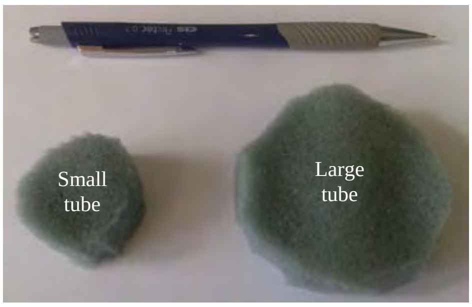


Figure 10. Test sample of egg crate pattern

The loudspeaker was turn on 10 minutes before starting the measurements (ISO 10534-2 recommendation) allowing temperature stabilization. The same regulation recommends that the temperature inside the duct keep constant during all measurement time with a tolerance of 1 K. The measured temperature was used to estimate the speed of the sound.

For the two microphones technique, the complex sound pressures p_1 and p_2 were acquired using two channels of the data acquisition system. The data were processed in Matlab® and the absorption coefficient was estimated according Eq. (7). So, firstly the transfer function between the two microphones is estimated as Eq. (2). In order to estimate the reflection factor (Eq. 3) is necessary to know the distance between the two microphones once this parameter is input to Eq. (5) and Eq. (6). Then the Eq. (7) can be used.

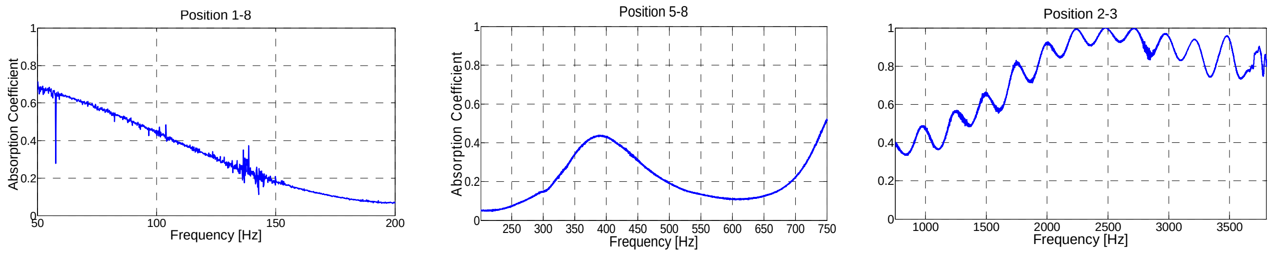
ISSN 2176-5480

The measurement procedure was accomplished for each position pair described in Tab. 1 (each line) for each tube, the small and the large. In this manner, a wide frequency range can be covered with these combinations.

In order to verify and validate the IT setup constructed, two conditions were considerate: with and without sample test. For the latter it was considered an approximation of a rigid termination.

It was acquired 10 continuous frames of data with sampling rate of 16384 Hz and number of samples of 163840. So, the total time acquired for each data is 60 s.

Using Matlab® the transfer function of each measurement was analyzed taking into account the coherence between the data from the two microphones in the frequency range specified in the Tab. 1. Then, the better position combinations which have good coherences (between 0.9 and 1) are chosen in order to cover the working frequency range for each tube. As an example Fig. 11 shows the absorption coefficient curves estimated for the large tube for the mean positions in the recommended frequency range for the acoustic foam test sample. Fig. 11(a) shows the absorption coefficient curve estimated for the position 1_8 (Fig. 5(a)) in the frequency range 50 to 200 Hz (according to Tab. 1). Fig. 11(b) shows the same parameter estimated for the position 5_8 in the frequency range 201 to 750 Hz. Finally the Fig. 11(c) shows the estimative for the position 2_3 in the frequency range 751 to 3800 Hz (this upper frequency is the cut-off frequency of the large-tube).



(a) (b) (c)

Figure 11. Absorption coefficients curves estimated for the egg crate pattern acoustic foam using the large-duct.

Figure 12 and Figure 13 presents the preliminary results obtained with the designed setup. The difference between both figures is that the Fig. 12 presents the absorption coefficient estimated by measurements with the large tube in octave band frequency and the Fig. 13 is the same parameter measured with the small duct.

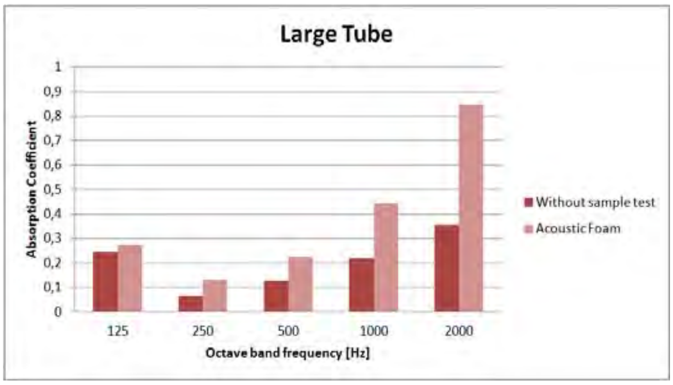


Figure 12. Absorption coefficient estimated with the large tube.

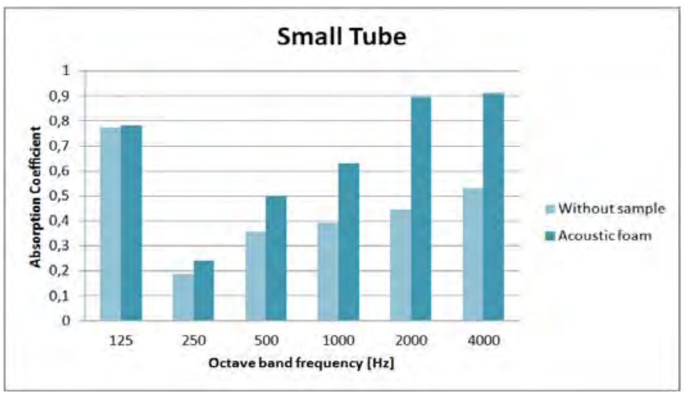


Figure 13. Absorption coefficient estimated with the small tube.

ISSN 2176-5480

Analyzing Fig. 12 and Fig. 13 we can note that the curves trend is in agreement with the acoustic theory specifically about porous acoustic material. For this kind of material the absorption coefficient has high value in the high frequencies than in the lower ones (Beranek and Ver, 1992). However we can note a high value of the absorption coefficient in the 125 Hz octave band frequency when compared with the others, which is not so common. Bellow 150 Hz the coherence between the two microphone data is not so good (there are values between 0.4 and 0.9) and it is possible to note the strong presence of noise in the transfer function (Fig. 11(a)). This fact can be explain by the electronic devices limitations including the loudspeaker once its response frequency curve is plane linear after 100 Hz despite the manufacturer specify the frequency range as 40Hz to 23kHz.

In each figure (Fig. 12 and Fig.13) is possible to see the difference between the absorption coefficient estimated with the sample and without it. In fact the absorption coefficient obtained with the “rigid termination” is small but the results reveal that it is not a perfect rigid termination.

Comparing Fig. 12 and Fig. 13 we can observe that there are differences between both results (absorption coefficient values) once each one was obtained from different tubes. Comparing the results for the same octave band frequency these should be closest if this frequency range is recommended (considered of precision) for the considered tube. However this fact is not a rule when Fig. 12 and Fig. 13 are analyzed.

Indeed the experimental results need to be better investigated. More measurements need to be accomplished, including experimental tests with more samples of the same material, in order to compute the mean absorption coefficient. There are many parameters which can influence in this estimation and needs to be studied as future working: the test specimen mounting, correction for microphone mismatch, signal-to-noise ratio, pressure-release termination of test sample, microphone mounting influence, modifications in the sample holder in order to improve its rigid and reflexive termination, like using a metal plate instead the foil paper.

As said before these are only preliminary tests only to verify the initial performance of the impedance tube setup. The aim of this work is to show the design procedure of a low cost impedance tube and the final product as well the preliminary experimental tests. In this way the research will continue in order to obtain precise results with this setup. The possible error sources listed before will be investigated. Other future work is to implement the one microphone technique.

5. CONCLUSIONS

This paper described all steps involved in a low cost impedance tube setup design, since its conception until the final product. The regulation ISO 10534-2 was used in order to implement the two microphone technique. The construction details of the IT and the design of the some electric devices were reported too. Experimental results using acoustic foam and rigid termination were presented as preliminary tests.

The IT setup constituted of acoustic box, tubes and the loudspeaker has a cost of R$ 535,15 against R$ 8.000,00 of a commercial IT (average price for academic user). A save of R$ 7.464,85 was achieved.

The absorption coefficient of an acoustic foam type “egg crate pattern” was estimated using the described setup and the two microphone technique, as well the same parameter for the rigid termination. The curves trend obtained is in agreement with the theory of porous acoustic material, in other words, the absorption coefficient has high value in the high frequencies than in the lower ones. It was possible to note that the electronic devices limitations introduce deviation at low frequencies (bellow 150 Hz). Differences between the results obtained from both tubes were encountered.

In order to continue this work the experimental results need to be better investigated and possible error sources be identified. More measurements should be accomplished and many parameters which can influence in this estimation must be studied: the test specimen mounting, selection of the number averages correction for microphone mismatch, signal-to-noise ratio, pressure-release termination of test sample, modifications in the sample holder in order to improve its rigid and reflexive termination. Other future work considered is to implement the one microphone technique.

6. ACKNOWLEDGEMENTS

The authors would like to thanks the Faculty UnB Gama for manufacturing support (materials and equipments), mainly the technical staff of the related laboratories. For financial support they thank FAPDF and DPP/UnB.

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