



**coustics'08
Paris**
June 29-July 4, 2008
www.acoustics08-paris.org

Student project of building an impedance tube

Mia Suhanek, Kristian Jambrosic and Hrvoje Domitrovic

Faculty of EE and Computing, Unska 3, Department of Electroacoustics, HR-10000 Zagreb,
Croatia
mia.suhanek@fer.hr

This paper describes a project of building an impedance tube for measuring the absorption coefficient using the transfer-function method, in accordance with the standard ISO 10534-2. For the tube, only inexpensive materials and transducers were used. The tube was designed for the frequency range between 90 and 2000 Hz. In order to achieve this range with a single tube, three microphone positions have been used. The resulting absorption coefficient has been calculated using the one-microphone method. The goal of this paper is to compare the two methods for measuring the sound absorption coefficient, the method that uses the standing wave ratio and the transfer-function method, on several different materials using different broadband excitation signals such as MLS, pink noise and sine sweep. Various problems with the design and construction are addressed and the optimal configuration is discussed. The initial measurements were performed without the tested material in the tubes. Additional measurements were made on mineral wool and foam.

1 Introduction

There are two standardized methods used for measuring the normal incidence sound absorption coefficient for small samples: one using standing wave ratio standardized in ISO 10534-1, and the transfer-function method standardized in ISO 10534-2 [1,2]. Both methods are devised for measurements on small samples. The method using standing wave ratio is well-established, but slow, so it is substituted with transfer-function method because of its quickness and accuracy. There are also other methods for calculating the absorption coefficient using a tube [3].

The sound absorption coefficient of a material can be measured not using a tube (e.g. the reverberation room method), but this procedure requires a much bigger sample of tested material and special laboratory facilities which are not always available.

1.1 Method using standing wave ratio

This method relies on the fact that there are only plane incident and reflected waves propagating along the tube axis in the test section of the tube (the section where standing wave pattern is explored). The incident plane sinusoidal sound wave is generated by a loudspeaker placed at one end of the tube. The other end of the tube is terminated with the test sample backed with a hard reflective end. We can conduct the measurement in octave or 1/3-octave frequency bands. Using the definition of the standing wave ratio:

$$s = \frac{|p_{\max}|}{|p_{\min}|} \quad (1)$$

the reflection factor can be easily defined as:

$$|r| = \frac{s-1}{s+1} \quad (2)$$

yielding the sound absorption coefficient α for plane waves:

$$\alpha = 1 - |r|^2 \quad (3)$$

1.2 Transfer-function method

This method is implemented through generation of plane waves in the tube by a sound source emitting a random or pseudo-random sequence, and then the sound pressures are measured in two locations in close proximity of the sample.

The complex acoustic transfer function of the two microphone signals is determined and then used for calculating the normal-incidence complex reflection factor, the normal-incidence absorption coefficient and the impedance ratio of the test material. The frequency range depends on the diameter of the tube and the distance between the microphone positions.

The normal incidence reflection factor can be calculated using the formula:

$$r = |r| e^{j\phi_r} = \frac{H_{12} - H_I}{H_R - H_{12}} e^{2jk_0x_1} \quad (4)$$

where:

x_1 is the distance between the sample and the farther microphone location;

ϕ_r is the phase angle of the normal incidence reflection factor;

H_{12} is the transfer function from microphone one to two, defined by the complex ratio $p_2/p_1 = S_{12}/S_{21}$;

H_R and H_I are the real and imaginary part of H_{12} ;

The sound absorption coefficient can be calculated as:

$$\alpha = 1 - |r|^2 = 1 - r_r^2 - r_i^2 \quad (5)$$

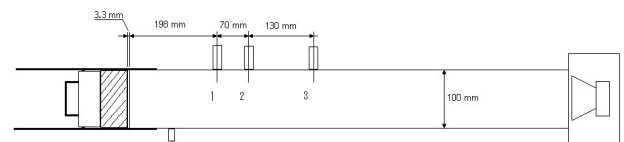


Fig.1 The impedance tube schematics

2 The tube construction for transfer-function method

The tube was designed and constructed as a part of a student project [4]. The goal was to use inexpensive materials and still obtain reliable and accurate measurement results.

The tube was made of stainless steel using a lathe machine and the holes for microphones were drilled with a milling machine due to the required tolerance of only ± 0.2 millimetres, Fig. 1. Rubber seals were inserted in the holes for microphones, following the demand that the microphones have to be hermetically sealed. The hard reflective piston was also sealed and it is acting as a backing to the sample material. It slides against the inner wall of the extension tube, which is mounted in continuation of the transfer-function tube. Once inserted,

the sample of the material to be measured stays firmly in its referent position, pressed against a grill located on a fixed calculated distance from the microphones.

2.1 The tube calculation for transfer-function method

The tube has to be plane, maintaining a constant diameter along its length (within the tolerance of $\pm 0.2\%$) with smooth, nonporous tube walls without holes and tears (except at intended microphone positions). The tube wall has to be strong and thick enough to prevent the vibrations generated during the emission of the sound signal and to prevent resonance at frequencies within the operating frequency range. The recommended thickness of the metal tube wall for the impedance tube with a circular cross-section is roughly 5% of the tube diameter. The tube has to be isolated from exterior noise and vibrations.

The tube has to be long enough to ensure the development of plane sound waves between the sound source and the sample. The microphones have to be positioned in the plane wave field. Non-plane waves will disappear at a distance from the source approximately three tube diameters. It is recommended that the microphone is placed at a distance of at least one tube diameter from the sound source.

The upper limiting frequency f_u can be calculated from the following condition:

$$d < 0.58\lambda_u \quad (6)$$

The selected diameter is $d = 100$ mm and therefore the upper limiting frequency is $f_u = 2$ kHz.

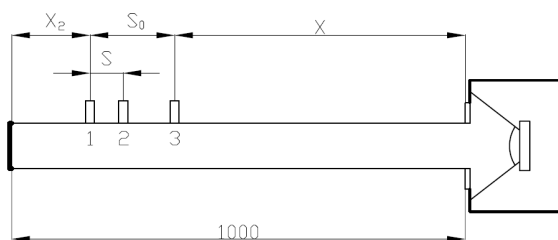


Fig.2 Calculation of tube dimensions

The lower limiting frequency depends on the distance between the microphones s_0 , Fig. 2, which should be larger than 5% of the wavelength for the specified lower limiting frequency. Therefore, s_0 determines the lower limiting frequency f_l using the following condition:

$$s_0 > 0.05 \cdot \lambda_l \quad (7)$$

Additionally, the following condition has to be satisfied:

$$f_u \cdot s_0 < 0.45c_0 \quad (8)$$

For the selected distance $s_0 = 20$ cm, the lower limiting frequency is $f_l = 86$ Hz. We also have to take into consideration that larger distance between microphones increases the measurement accuracy.

The spacing between the sound source and the microphone x according to ISO 10534-2 should be:

$$x > 3 \cdot d > 300\text{mm} \quad (9)$$

For this particular tube, the selected spacing between the sound source and the microphone is equal to $x = 60$ cm.

The distance x_2 between the test sample and the microphone nearest to it depends on the type of sample. We have chosen to meet the condition given for the highly asymmetrical type:

$$x_2 \geq 2 \cdot d = 200\text{mm} \quad (10)$$

Finally, the total tube length is given with:

$$l = x_2 + x + s_0 = 1000\text{mm} \quad (11)$$

2.2 The calculation of microphone positions

Three openings were drilled in the tube wall for positioning the measuring microphones. This particular tube utilizes 1/2" microphones. The characteristics of the two microphones have to be as similar as possible. When the microphones are inserted into the test openings, their membranes have to be aligned with the inner tube surface (because the position of the microphones in the vertical axis is not fixed). The microphones have to be well sealed in the test opening. The position of the microphones has to be specified within the maximum tolerance of 0.2 millimetres. While using two microphones, the third opening has to be sealed in order to avoid air leakage and to preserve the smoothness of the inner tube wall.

In order to increase measurement accuracy at higher frequencies, a smaller microphone distance s is also used. The microphone diameter has to be small in comparison with the ratio c_0/f . It is advised that the microphone diameter has to be smaller than 20% of the distance between them, hence:

$$d_{mic} < 0.2 \cdot s \quad (12)$$

As a consequence, the smallest possible distance is $s = 60$ mm. The value $s = 70$ mm was selected.

Taking into account equations (7) and (8), for the distance $s = 70$ mm the following limiting frequencies can be calculated:

$$f_u < 2192\text{Hz} \quad (13)$$

$$f_l > 244\text{Hz} \quad (14)$$

Consequently, for $s_0 = 200$ mm, the following limiting frequencies can be calculated:

$$f_u < 767\text{Hz} \quad (15)$$

$$f_l > 85\text{Hz} \quad (16)$$

We can conclude that the constructed impedance tube with three test openings has a usable frequency range from 85 Hz to 2 kHz, in compliance with the requirements stated in ISO 10534-2.

3 Measurements

First of all, the two measurement methods (the standing wave ratio method and the transfer-function method) were compared using the same sample material. The first

material was felt, a non-woven cloth produced by matting, condensing and pressing fibres of 12.5 mm thickness. The second material was foam of 20 mm, 30 mm and 40 mm thickness.

The results were compared for the frequency range of the constructed impedance tube, e.g. from 80 Hz to 2000 Hz. Since the first method uses two tubes of different diameters to cover this frequency range, the results obtained using both of these tubes were combined and plotted on the same figures. The discrete results obtained using the first method are plotted in red diamonds, and the continuous absorption curves obtained using the second method are represented with blue lines. They were measured using sine sweep as excitation signal.

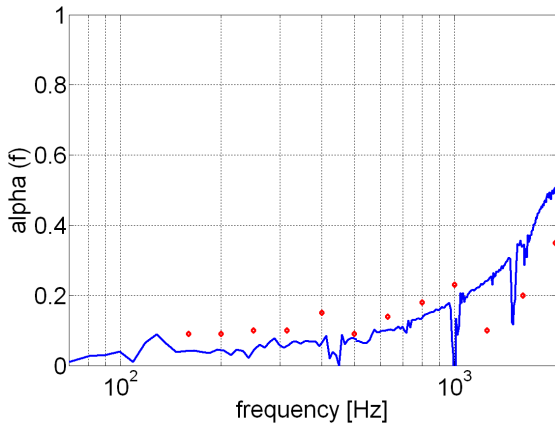


Fig. 3 Absorption coefficient for one layer of 12.5 mm thick felt

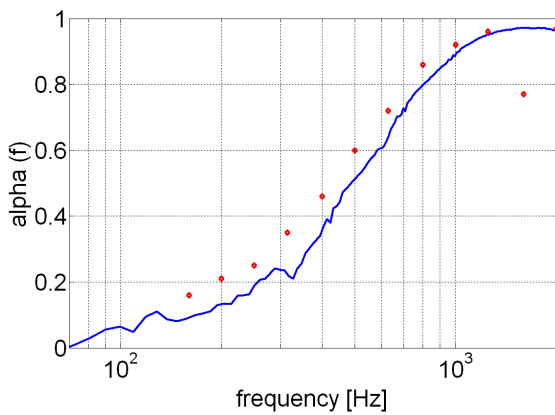


Fig. 4 Absorption coefficient for four layers of 12.5 mm thick felt

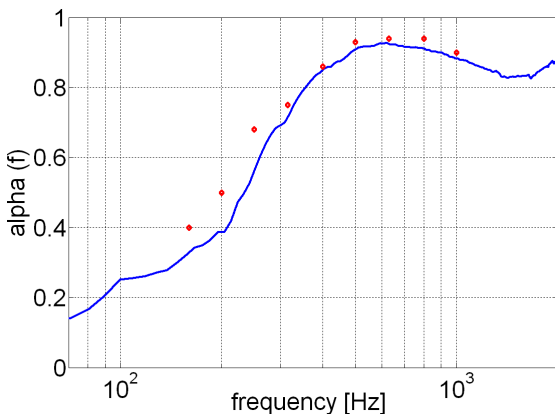


Fig. 5 Absorption coefficient for four layers of 12.5 mm thick felt backed with 50 mm of air

First, one layer of felt material with hard backing was measured, Fig. 3. There are some drops in the absorption coefficient curve (blue) compared to the discrete results, but they are much less pronounced when measuring four layers of felt, Fig. 4. If these four layers of felt are backed with 50 mm of air, the maximum absorption shifts toward lower frequencies, Fig. 5. The sound absorption coefficient curve measured for foam of 20 mm thickness also shows drops, Fig. 6. However, these drops are reduced if the thickness of the foam increases, thus increasing the absorption, Fig. 7.

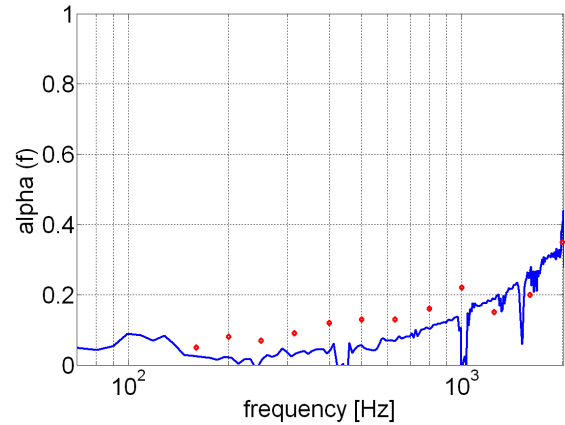


Fig. 6 Absorption coefficient for 20 mm thick foam

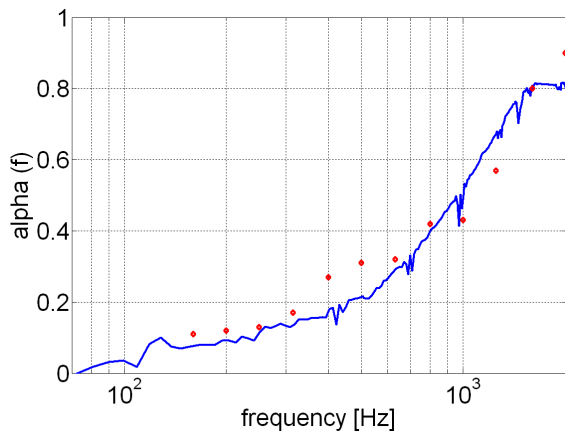


Fig. 7 Absorption coefficient for 30 mm thick foam

Second, the sound absorption coefficient for foam 40 mm thick was measured, but with various distances from a hard backing surface, using the same sine sweep as excitation signal. Fig. 8 shows the results for hard backing (without an air space). There are still visible some drops in the curve. The sound absorption coefficient was also measured for the 40 mm thick foam, but with 50 mm (Fig. 9) and 100 mm (Fig. 10) of air backing. These curves are very smooth, without any visible drops. All results are again presented for the frequency range of the constructed impedance tube, e.g. from 80 Hz to 2000 Hz.

The next measurement was made again on one layer of 12.5 mm thick felt using the sine sweep excitation signal, but calculating an average of 10 consequent measurements, Fig. 11. The drops are still visible on same frequencies (compared to Fig. 3), pointing to a conclusion that the drops are obvious not a consequence of random errors in each measurement, but they have to be connected with resonances in the tube, which is design conditioned.

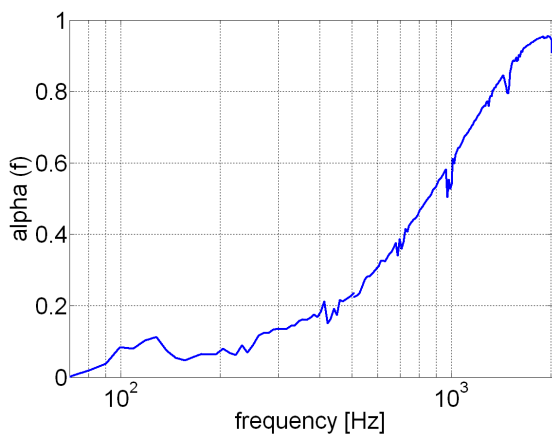


Fig. 8 Absorption coefficient for 40 mm thick foam with hard surface

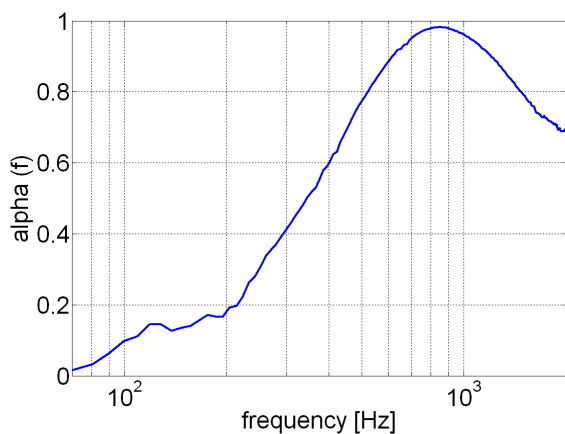


Fig. 9 Absorption coefficient for 40 mm thick foam backed with 50 mm of air

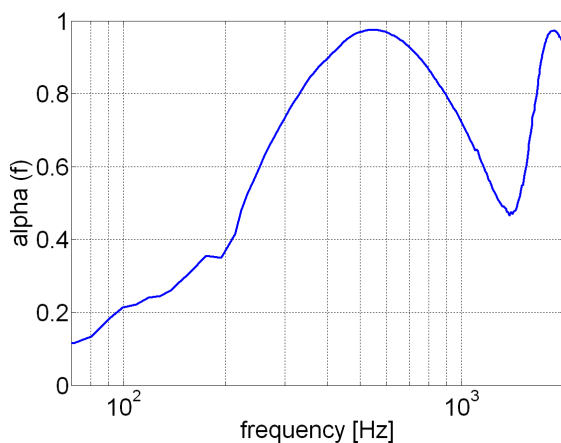


Fig. 10 Absorption coefficient for 40 mm thick foam backed with 100 mm of air

Beside the comparison of two methods, we also measured the absorption coefficient using the transfer-function method with different broadband excitation signals, such as MLS, pink noise and sine sweep. The comparison was made using the same length of the excitation signals, namely 0,2 seconds. The sample material was foam of 40 mm thickness.

The results are shown in Fig. 12 for MLS excitation signal, Fig. 13 for pink noise excitation signal, and Fig. 14 for sine sweep excitation signal. Although all signals fulfil the demands on broadband frequency spectra and repeatability,

there are obvious differences in the obtained absorption coefficients.

It seems that the MLS and pink noise signals with their random frequencies and phases are better for absorption coefficient measurements in an impedance tube as they do not excite the tube itself on certain resonant frequencies as the sine sweep signal does. The results obtained with MLS and pink noise signals are very comparable.

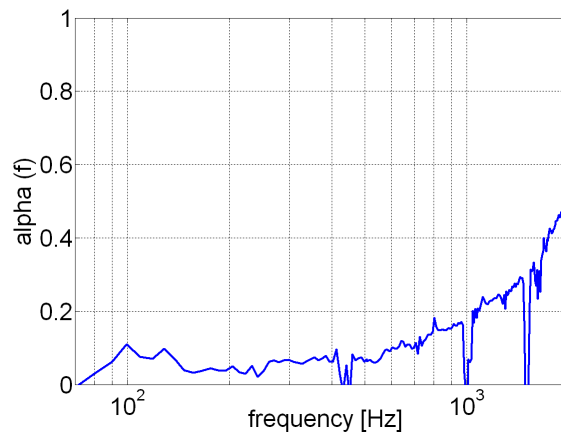


Fig. 11 Absorption coefficient for one layer of 12.5 mm thick felt, average of 10 measurements

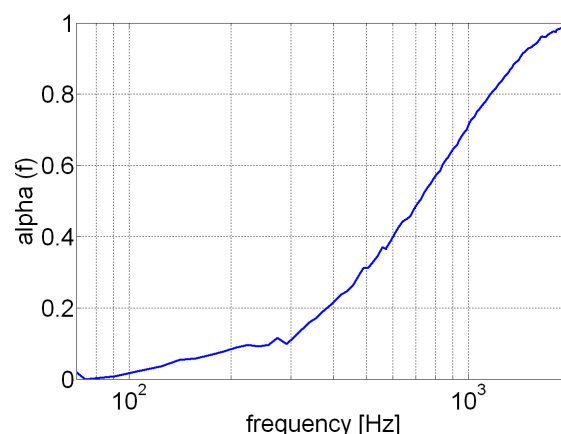


Fig. 12 Absorption coefficient for 40 mm thick foam on hard surface, MLS

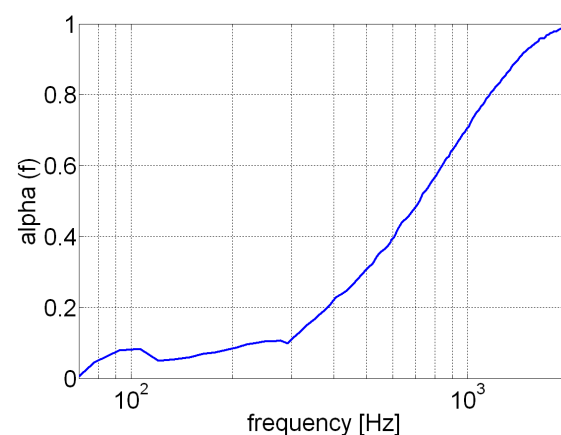


Fig. 13 Absorption coefficient for 40 mm thick foam on hard surface, pink noise

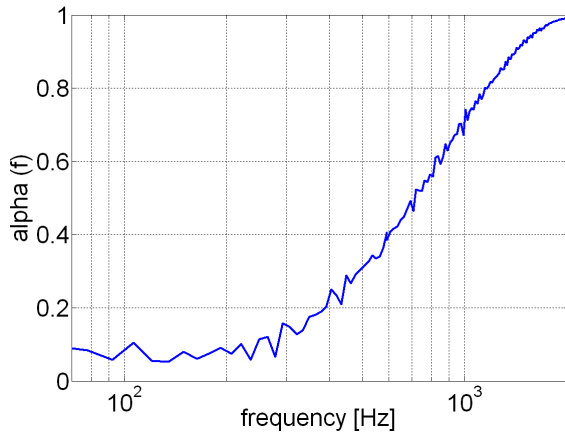


Fig. 14 Absorption coefficient for 40 mm thick foam on hard surface, sine sweep

4 Conclusion

An impedance tube for measurement of the material absorption coefficients according to ISO 10534-1 was designed and produced. It was tested with various materials of different type and thickness, with and without an air gap between the sample and the rigid surface, and using various broadband excitation signals.

It can be concluded that the transfer-function method for measuring the normal incidence sound absorption coefficient for small samples is much quicker than the method using standing wave ratio, and it gives an absorption coefficient curve rather than single values

obtained just for discrete sinusoidal frequencies. On the other hand, the constructed tube shows certain drops if the samples are of lower absorption coefficient (up to 0.2) when using sine sweeps as the broadband excitation signal. A more rigid tube, smaller microphones (1/4") and a second smaller tube for higher frequencies would most likely improve the measurement accuracy. The drops in the absorption coefficient curve cannot be significantly lowered even if doing an average of a series of consequent measurements. Nevertheless, this effect is less pronounced if using MLS or pink noise sequences as excitation signals, rather than sine sweeps.

References

- [1] Acoustics - Determination of sound absorption coefficient and impedance in impedance tubes - Part 1: Method using standing wave ratio, *ISO 10534-1*
- [2] Acoustics - Determination of sound absorption coefficient and impedance in impedance tubes - Part 2: Transfer-function method, *ISO 10534-2*
- [3] A. Farina, P. Fausti, "Standing Wave Tube Techniques for Measuring the Normal Incidence Absorption Coefficient: Comparison of Different Experimental Setups", *11th FASE Conference*, Valencia, Spain, (1994)
- [4] M. Suhanek, K. Jambrosic, M. Horvat, "A comparison of two methods for measuring the sound absorption coefficient using impedance tubes", *50th Elmar Conference*, Zadar, Croatia (2008)