Comparison of Sound Absorption Coefficients Determined by Different Methods

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Abstract –**One of the important acoustic properties of an absorbing material is the absorption coefficient. It can be measured using different methods. Some of them are classified as laboratory methods, while some others can be applied not only in laboratories, but also in other environments and in situ. The comparison of absorption coefficients obtained by four methods, impedance tube, reverberation room, intensity method, and reflection method are made in this paper. For that purpose, the absorbing material of the same type but different samples is used. The results obtained by the methods using diffuse sound field are similar, with some deviations specific for a particular method. The values of absorption coefficient for reflection method are closest to the values for impedance tube method since both methods are based on normal sound incidence.**

Keywords – **Sound absorption coefficient, impedance tube, reverberation room, intensity method, reflection method.**

I. Introduction

The absorption is a property of acoustic material that allows a reduction in the amount of reflected sound energy. The introduction of an absorbent on the surfaces of a room reduces the sound pressure level in the room since the part of sound energy striking the room's surfaces is absorbed. In that, the acoustic energy is usually transformed into heat energy. Absorption of a given material is frequency dependent and it is affected by the size, shape, location, and method of mounting [1, 2].

Sound absorbing materials have been extensively used in the field of noise control engineering and architectural acoustics in order to obtain the desired characteristics of the sound field. Today's growing focus on noise control issues and the sound quality as an important aspect of product design even increases their significance. Because of that, it is important to have the values of the parameters of absorbing materials used for acoustical treatments. One of the important acoustical parameters is the frequency characteristic of absorption coefficient. It describes the efficiency of the material or the surface to absorb the sound. It is defined as the ratio of the absorbed sound energy to the incident energy. The knowledge of absorption coefficient is very valuable for all tasks related to acoustical design of a room such as prediction of reverberation time, planning model experiments or computer simulation of the sound propagation in enclosures [1].

The characterisation of an absorbing material and determination of its absorption coefficient can be done using different measurement methods. They are divided on laboratory methods and methods that can be applied in situ. The former group contains wave tube method, reverberation room method, and intensity method [1,3,4] while the latter is based on reflection method [5,6]. The results of absorption coefficient obtained by the mentioned methods are compared here. The same type of absorbing material, rock-wool, but different samples was used. In addition, the measurements were performed by different institutions, different equipment and operators, and in a long time period with more than 15 years between the first and the last measurements.

II. Measurement of Sound Absorption Using Different Methods

A. Measurement of absorption coefficient in impedance tube

The sound absorption coefficient, reflection factor as well as surface impedance of materials and objects can be determined by means of a device known as impedance or standing wave tube. The method is specified in corresponding standard [4]. For that purpose, only normal sound incidence is used and the standing wave pattern of a plane wave in the tube, which is generated by the superposition of an incident sinusoidal wave with the plane wave reflected from the test object, is evaluated.

In order to determine the absorption coefficient, it is sufficient to measure the maximum p_{max} and the minimum p_{min} values of the sound pressure, i.e. the pressures in the nodes and anti-nodes of the standing wave in the tube. Thus, the sample's sound absorption coefficient is:

$$\alpha = 1 - |R|^2 = 1 - \frac{(p_{\max} - p_{\min})^2}{(p_{\max} + p_{\min})^2}, \quad (1)$$

where R is the reflection factor.

The absorption coefficient is a function of frequency and measurement over the frequency range of interest is required. The simplicity, reliability, and accuracy of this traditional method have been proven in practice. However, the measurement procedure itself is relatively time-consuming. Because of that, several attempts have been made to replace

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this procedure such as applications of impulse response measurements [1].

B. Measurement of absorption coefficient in reverberation room

Reverberation room is a room having a long reverberation time, specially designed to make the inside sound field as diffuse as possible. For that purpose, it is designed to minimize the sound absorption of all surfaces, which are typically smooth and rigid. [1, 2, 7]

The reverberation room method (on ideal conditions) is used for determination of the sound absorption coefficient for random sound incidence. The evaluation of the sound absorption coefficient in a reverberation room is based on a number of simplifications and approximate assumptions concerning the sound field and the size of the absorber [1]. Measurements are normally carried out in a certificated laboratory where a standardized reverberation room is used in accordance with the standard [7].

The results of the measurements depend on the size and form of the area of the test sample, but also on the degree of diffusion of sound waves in the room. The results are influenced by the location of the loudspeaker and microphone in the room too. It is recommended that the loudspeaker is placed in a corner, and that the microphone is moved or rotated during the measurement. It has been confirmed that testing of the same specimen of an absorbing material in different laboratories and using only the reverberation room method lead to considerable disagreement in the results [1]. This emphasizes the uncertainty related to the accuracy and reliability of the results obtained with this method.

C. Determination of absorption coefficient by intensity method

Starting from the definition of absorption coefficient and the characteristics of sound intensity as a vector quantity, the methodical procedure for the absorption coefficient measurement for random sound incidence in the regular parallelepiped rooms, which don't satisfy the necessary condition for the application of the reverberation room method, has been developed [3]. The measurement procedure is based on the relation between the absorption coefficient and sound intensity:

$$\alpha = \frac{4 I_\alpha \rho c}{p^2}, \qquad (2)$$

where I_α is the intensity absorbed by the specimen and p is the sound pressure in the room where sound field is considered to be diffused.

The measurement procedure includes the sound intensity and the sound pressure measurements. Since the measurement precision can be influenced by the local changes of these quantities, the measurements are carried out in a number of points and the obtained values are averaged. The incident sound energy can be determined by sound pressure measurements in the middle part of the room, on the measurement surface divided into segments of the area ΔS_i, whereas the absorbed sound energy can be determined by mapping of the sound intensity right above the specimen on the measurement surface divided into segments of the area ΔS_j**.** The ratio of the absorbed sound energy to the incident sound energy defines the absorption coefficient:

$$\alpha = \sum_{j=1}^{m} I_j \Delta S_j \Bigg/ \sum_{i=1}^{n} \frac{p_i^2}{4\rho c} \Delta S_i , \qquad (3)$$

where p_i is the sound pressure measured on the i-th segment, n is the number of the segments for sound pressure measurements, I_j is the sound intensity measured on the j-th segment and m is the number of the segments for intensity measurements [3].

If the values of the sound pressure and sound intensity are respectively expressed by the sound pressure level L_p and sound intensity level L_I obtained in measured bands, the sound absorption coefficient can be determined by the following equation [3]:

$$\alpha = 10^{\frac{L_I - (L_P - 6)}{10}} . \qquad (4)$$

In this way, defined measurement procedure gives the frequency characteristic of the sound absorption coefficient.

III. Measurement of Absorption Coefficient by Reflection Method

A. Theory of the reflection method

Measurements of absorption coefficient in situ are based on a measure of the complex pressure reflection factor determined by means of acoustic signals impinging on and reflecting from the test specimen. Because of that, they are usually designated as reflection method. There have been several approaches how to apply this method such as scheme with pure tones in an anechoic room, techniques based on impulse response measurements using spark source, blank shots, correlation technique or even cepstral analysis [5].

The sound absorption coefficient can again be obtained using reflection factor R from Eq. 1. Since the reflection factor is a complex number, its measurement is equivalent to the measurement of specific surface impedance. However, the phase information is not used for determination of absorption coefficient. According to the definition of reflection factor, it is necessary to detect incident and reflected signals from the test surface. For that purpose, the same microphone can be used. There are two approaches related to the placement of the microphone. In the first one, the microphone is placed at some distance from the test surface, usually at half of the distance between the loudspeaker and the surface, Fig. 1a). Relevant impulses are given in Fig. 2a). In the second approach, the microphone is placed relatively close to the test surface [6], which is shown in Fig. 1b), and corresponding impulses are shown in Fig. 2b).

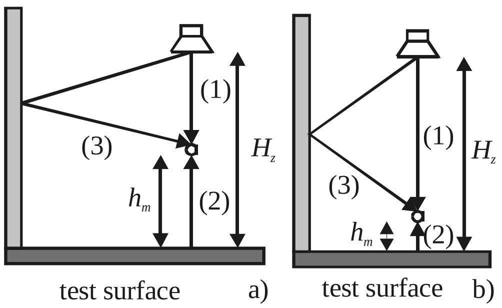

Fig. 1. Set-up for absorption coefficient measurements a) microphone at some distance from the test surface, b) microphone close to the test surface

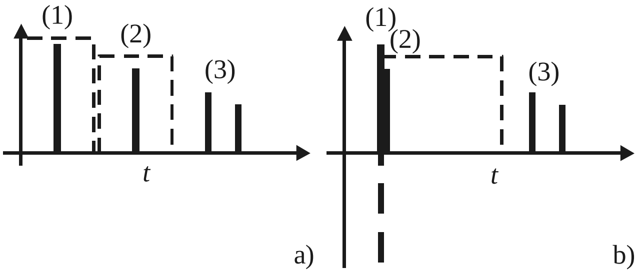

Fig. 2. Impulses obtained using the set-up from a) Fig. 1a) and b) Fig. 1b) where (1) represents the incident impulse, (2) the reflected impulse and (3) parasitic reflections

The basic difference between these approaches is related to time separation of the impulses. The first approach enables direct time separation and extraction of the incident impulse and reflected one assuming that the duration of the incident impulse is short enough, i.e. it decays to negligible values at the point where the reflected impulse starts. The impulses are extracted applying appropriate window function in time domain. It has been shown that the best results are obtained using the right-half Blackman-Harris window [5]. Opposite to the first approach, there is almost no time separation between the incident and reflected impulses in the second approach. Because of that, it is necessary to cancel incident impulse by subtraction assuming that it is exactly known [6]. In order to have the incident impulse for subtraction, it is measured in the pseudo-free-field condition where the loudspeaker-microphone arrangement is located remote from reflecting surfaces.

The spectrum of the sound reflected from the test surface P_r can be expressed as:

$$P_r = C_r R P_i e^{-2\pi i f \tau_r}, \tag{5}$$

where C_r is the correction factor ($C_r=(H_z-h_m)/(H_z+h_m)$), P_i is the spectrum of incident sound, and τ_r is the time delay due to the path difference [5]. The absorption coefficient can be now calculated as:

$$\alpha = 1 - \frac{1}{C_r^2}\frac{|P_r|^2}{|P_i|^2}. \tag{6}$$

B. Application of reflection method on developed measurement system

The described reflection method was applied on developed measurement system based on PC. The impulse responses were measured using maximum length sequence (MLS) technique. MLS of degree of 15 was used as an excitation signal. Both mentioned approaches shown in Fig. 1 were applied, but only the results obtained using the second one are presented here. The microphone was placed close to the test surface (approximately 10 cm from it), while the distance between the loudspeaker and microphone was somewhat more than 1 m. Since it was necessary to measure the pseudo-free-field incident impulse in addition to the measurement in front of the test specimen, the distance between the loudspeaker and microphone was kept constant in these measurements using a suspended construction.

Tested absorbing material was the rock-wool “Vunizol” L of density of 50 kg/m^3 manufactured in “Vunizol” A.D. The panels of dimensions 100×50×5 cm^3 were placed on the wall of one of the laboratories of Faculty of Electronic Engineering in Niš similar to the classroom. The total sample size was approximately 2.5×2 m^2.

After subtraction of incident impulse, the reflected impulse was separated from parasitic reflections applying the right-half Blackman-Harris window directly in time domain. This subtraction enabled usage of longer window and obtaining of higher resolution of the results. The window length and the resolution were only limited by parasitic reflections from other surfaces relatively close to the absorber.

IV. Analysis of Measured Results

This section compares the absorption coefficients of the same type of absorbing material mentioned before but different samples obtained by described four methods. In addition, the methods were applied by different institutions, by different operators and even with considerable time difference among the measurements. Thus, more than 15 years passed between the first measurements carried out by the reverberation room method and the last ones performed by the reflection method.

The results obtained by means of the impedance tube in the certified laboratory and given in the report [8] are used here as the reference (Fig. 3). The shape of presented curve is typical for the rock-wool absorbing material, with the values close to 100 % (or 1 in absolute units) above 1 kHz.

The frequency characteristics of absorption coefficient determined by the reverberation room and intensity method are plotted in Fig. 4 [3]. Since original data obtained by the reverberation room method according to the standard [7] have some values above 100 %, they are normalised to have maximum value of 100 %. The measurements by intensity method were carried out in two regular parallelepiped empty rooms of different volumes (8.8x6.2x3.8 m^3 and 7.6x5.2x3.8 m^3) and the results for both rooms are given here. Although there are some deviations between the presented results for two methods in the observed frequency range, they are rather similar.

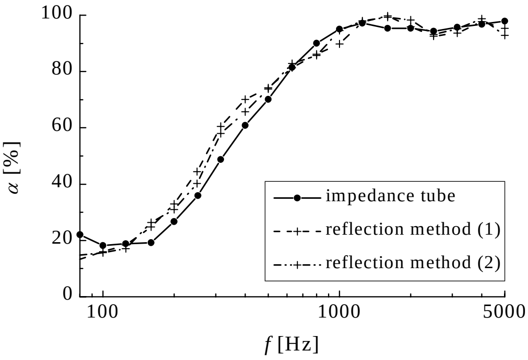

Fig. 3. The frequency characteristics of absorption coefficient of rock-wool determined by impedance tube and reflection method

The shape of the curve already seen for other methods exists for reflection method too, Fig. 3. The results from two measurements carried out by the described second approach of reflection method are shown in the figure, where the absorbing material was completely dismantled after the first one and placed again on the same wall. There is only a small deviation between the curves for these two measurements.

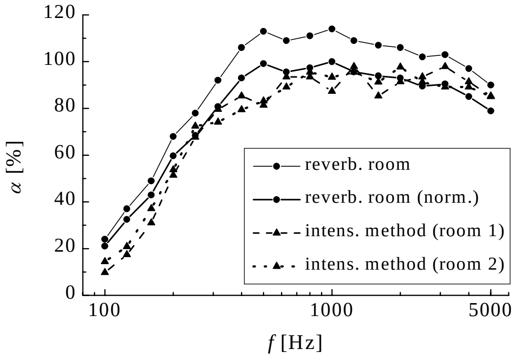

Fig. 4. The frequency characteristics of absorption coefficient of rock-wool determined by reverberation room and sound intensity method

The characteristics of absorption coefficient for all four used methods are approximately the same for frequencies above 1 kHz. However, at lower frequencies, characteristics are similar to each other for methods in which the measurements are performed in the diffuse sound field – the reverberation room method and intensity method. Also, similar characteristics at lower frequencies are obtained for methods in which the measurements are performed only for normal sound incidence – the impedance tube method and reflection method.

The statistical values of absorption coefficient calculated using both measured coefficient and law of energy density distribution in diffuse sound field as a function of incidence angle are not presented here. This calculation is not so important because the obtained values often deviate from the ones determined by the measurement in diffuse sound field. The reason could be inappropriate assumption of the mentioned dependence of sound energy distribution and incidence angle.

V. Conclusion

The results of absorption coefficients of the same absorbing material but different samples determined by different methods, different institutions, and operators, and even measured with the time distance of more than 15 years are compared here. The pattern common for the rock-wool absorbing material is seen in all the results. The values of the absorption coefficient are similar for corresponding sound field and incidence type.

The results obtained by reflection method are closest to the results obtained by impedance tube. Thus, although these two methods use specimens of completely different sizes and placed in a different way, the absorption coefficient in both of them is measured only for normal incidence.

In that way, it is shown that the reflection method, in principle, can give measurement results that are in a good agreement with impedance tube method. Thus, the advantages of this method such as characterisation of material in situ can be utilised.

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