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Application of the Impulse Response Method in the Test of Acoustic Properties of Building Materials

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Abstract Understanding the acoustic properties of the materials used in the construction of wall surfaces, plays an important role in structural and environmental acoustics. There are many research methods for determining the acoustic parameters of building elements, such as the sound absorption coefficient, the sound reflection coefficient, or the sound insulation index determined in the laboratory or in situ. This work focuses on the determination of the sound absorption coefficient and the possibility of its measurement in "in situ" conditions by the impulse response method. The main purpose of the presented research was to check whether it is possible to use the impulse method in a small reverberant room to determine the sound absorption coefficient of a small part of the wall structure.

Keywords: impulse method, sound absorption coefficient, MLS, e-sweep

1. Introduction

In structural acoustics and environmental acoustics, an important role plays knowledge of the acoustic characteristics of materials used to construct wall surfaces. There are many test methods for determining parameters such as the sound absorption coefficient, the reflection coefficient, or sound insulation index received in laboratory conditions [1-3] or in situ conditions [4-8]. Often the parameter values obtained in the laboratories vary from the values obtained in situ [9-11]. These discrepancies have some causes related to the measurement environment with an accuracy of measurement methods, but mainly because of the way of fixing and the position of the samples tested materials.

One of the most commonly used methods in the study of sound field conditions is the impulse method. They analyze the impulse response signals reflected from the respondent surfaces. An essential advantage of the impulse method is the measurement of the installed partition in situ. Also, an important feature of these measurements is the lack of stringent requirements for the signal-to-noise ratio allowing measurements in harsh industrial environments or close to transport routes (roads, railways). An example of such research the properties of noise barriers in situ research is sound insulation [11, 12], the sound absorption coefficient or index of diffraction difference [13, 14, 18-20].

In studies on acoustic characteristics of the materials of the impulse response methods, in situ techniques are using a single microphone [5, 11, 14], two microphones [4, 15, 16], and the microphone array [10]. Many methods of measuring are accompanied by the assumption of a plane wave propagation from the source to the observation point, which then binds to the difficulties of interpretation of results, especially for the lower frequencies.

The impulse response method using the Maximum Length Sequence signal (MLS) to determine the sound reflection was of significant importance in the in situ measurement technique [17]. An interesting solution presented by Mommertz (see [Ref.5]) introducing the procedure for subtracting the signals to determine the value of the complex reflection coefficient R. This procedure allowed the use of the technique MLS without any specific requirements for measurement environmental conditions. Two measurements are required: the reference signal measurement and reflected sound, and for analyzing both recorded impulse responses are used specified time window. The measurement result of the reference is subtracted from the measurement of the sound reflected from the material. Acoustic screens are usually placed in an open space, but they are often used in industrial rooms to protect workplaces. It is worth having measurement methods that will allow you to test the acoustic parameters of screens in situ in production facilities. The paper presents the possible application of the method for determining the impulse response of the acoustic properties of materials used for construction purposes.

2. Measurement procedure

Determining the acoustic parameters of the surfaces delimiting the room is necessary for the correct reproduction of the sound field in the virtual acoustic modeling of the room. These parameters can often be obtained from the table of acoustic properties of the materials included in the textbooks. The values of sound absorption coefficients are most often acquired in laboratory tests in specific ways of mounting the test sample. The use of room tests related to the reverberation time and sound decay makes it possible to determine the average sound absorption coefficient for the room's walls. In the geometric methods of room acoustics modeling, the sound field parameters are obtained by assigning appropriate sound absorption coefficients for wall materials. In-situ measurements of the acoustic properties of materials make it possible to get the actual sound insulation index for individual elements of the structure, as this parameter depends on the material. However, it also depends on the type of surface finish, its attachment, the stiffness of the partition, the degree of material degradation, and more. In this research, the methodology presented in (see Ref. [19] "Test method for determining the acoustic performance. Intrinsic characteristics - In situ values of sound reflection and airborne sound insulation").

In the method used for the tests, the impulse responses from the tested surface, forced by the MLS signal and the e-sweep signal, are analyzed, and then the value of the sound reflection coefficient is determined. The scheme of the measurement path is shown in Figure 1. The measurements were performed with the use of Brüel & Kjær "Dirac 4.1" software which enables the recording of the impulse response using the previously mentioned two types of signal. The study compared a signal such as MLS – a pseudo-random noise and exponential sweep (e-sweep) signal, in which the frequency increases or decreases logarithmically with time.

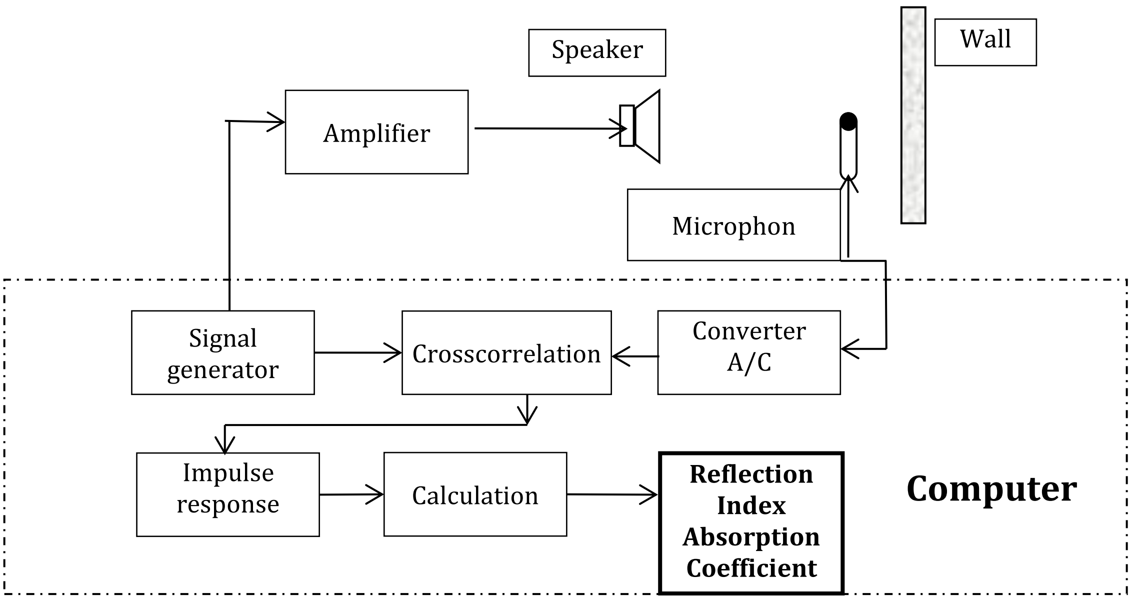

Fig. 1. Scheme of the measuring system.

The sound reflection index was determined in the frequency range from 100 Hz to 5000 Hz in 1/3 octave frequency bands. The study was carried out for two types of materials frequently used in the construction industry - the drywall (Rigips) and the chipboard (OSB - Oriented Strand Board). Both samples were lying flat on the floor. The measuring loudspeaker was placed over them. The values obtained at individual measurement points P1-P7 (see Fig. 2) were averaged, and then the sound reflection index (R) was determined [20].

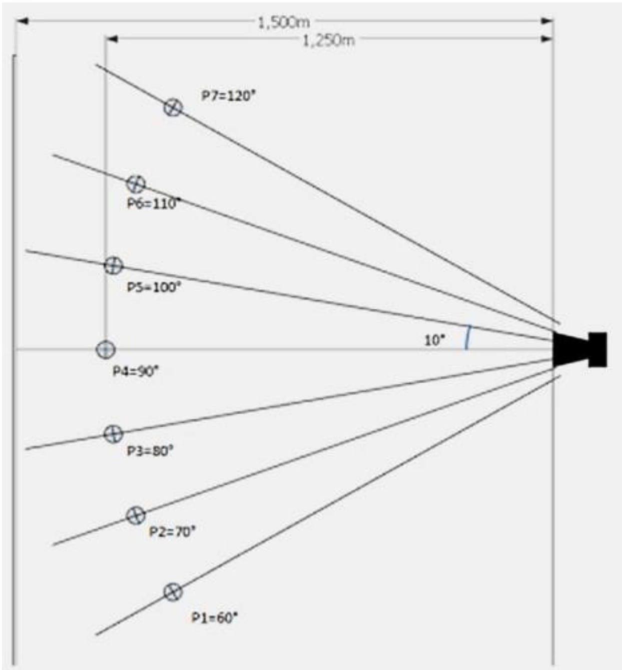

Fig. 2. Location of the sound source and measurement points P1 – P7.

The values of the impulse responses obtained at the individual measurement points P1 – P7 for individual frequencies f of the measuring range were averaged, and then the sound reflection coefficient $R(f)$ for these frequencies were determined. The sound absorption coefficients of the tested samples were calculated from the formula (1):

$$\alpha(f) = 1 - |R(f)|^2 \tag{1}$$

where a is the sound absorption coefficient, $R(f)$ *is* the sound reflection index, and f is the frequency [Hz].

However, the limitations of using this method, described in [20], are other sound-reflecting surfaces less than four meters from the vertically standing sample. In this case, define the lower frequency limit from which the calculation can be made (see Fig. 3).

In large rooms, e.g., the industrial room type, these restrictions are less restrictive, while in small rooms, many reflections make it difficult or impossible to perform measurements. Due to the dimensions of the test samples (2,3 m x 1.3m), calculations were made for the frequency range of 500 Hz - 5000 Hz (see Fig. 3).

3. Results

Figures 4 and 5 below show the results obtained for the two different materials using the MLS and e-sweep test signals. Measurements were made in a real reverberation room and a free field (anechoic chamber). The graphs show the calculated absorption coefficients for the drywall (Fig. 4) placed in an acoustic reverberation field and an acoustic free field. Similarly, Fig. 5 shows the values of the sound absorption coefficient for the OSB board. The experimental results show that in the conditions of the reverberant field occurring in small spaces, the impulse response is disturbing, and the method should be improved for use in the reverberation field conditions.

Basically, this method requires an acoustic free field or conditions close to the free field. Since the impulse responses were recorded from the frequency of 100 Hz, such a range was analyzed. Unfortunately, the obtained results in the range of 100 - 500 Hz were characterized by significant discrepancies, which is related to the test environment. The problem with the measurement of the sound reflection coefficient occurring in the free field seems to correspond to the size of the tested surface (2.3 m x 1.3 m).

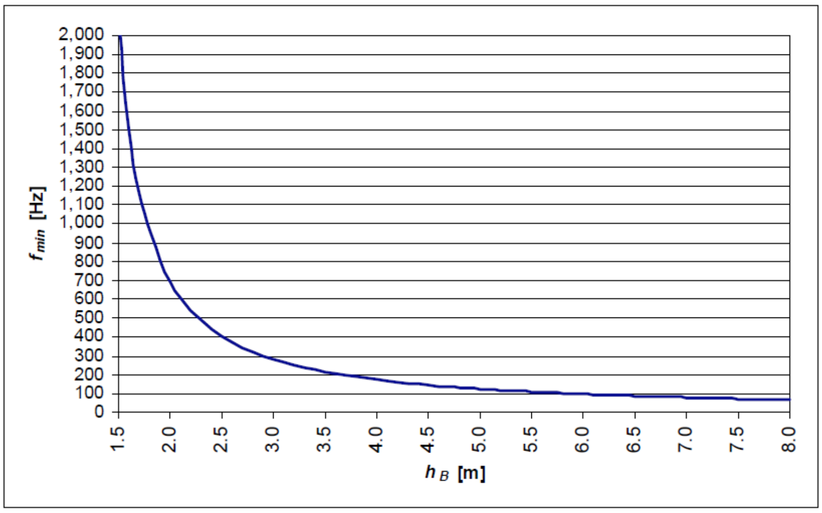

Fig. 3. Low-frequency limit of reflection index measurements as a function of the height of the wall under test for normal incidence measurements [20].

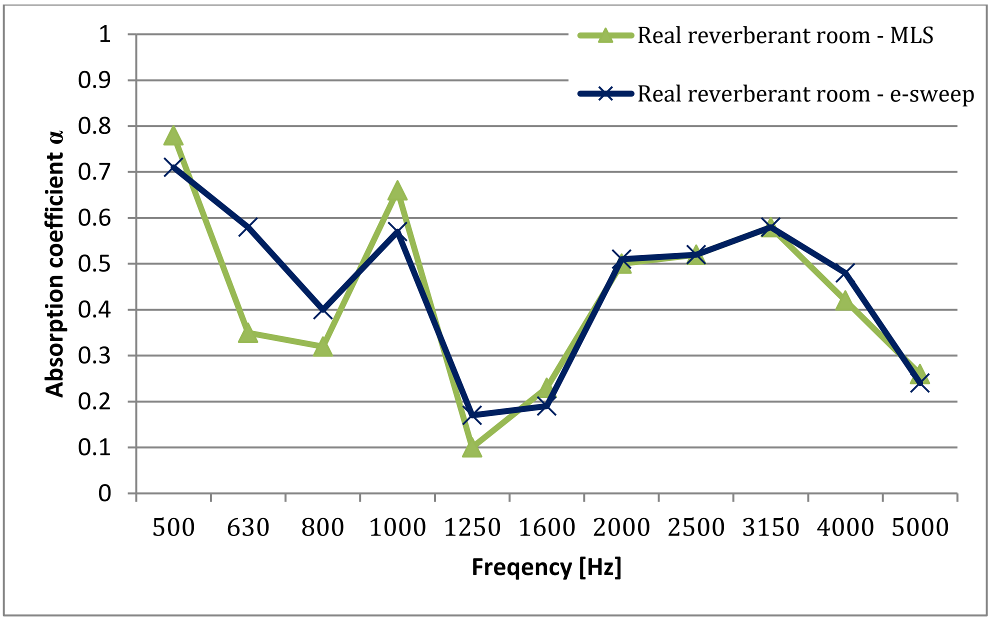

Fig. 4. Reverberant room – comparison of results for drywall – MLS and e-sweep signal.

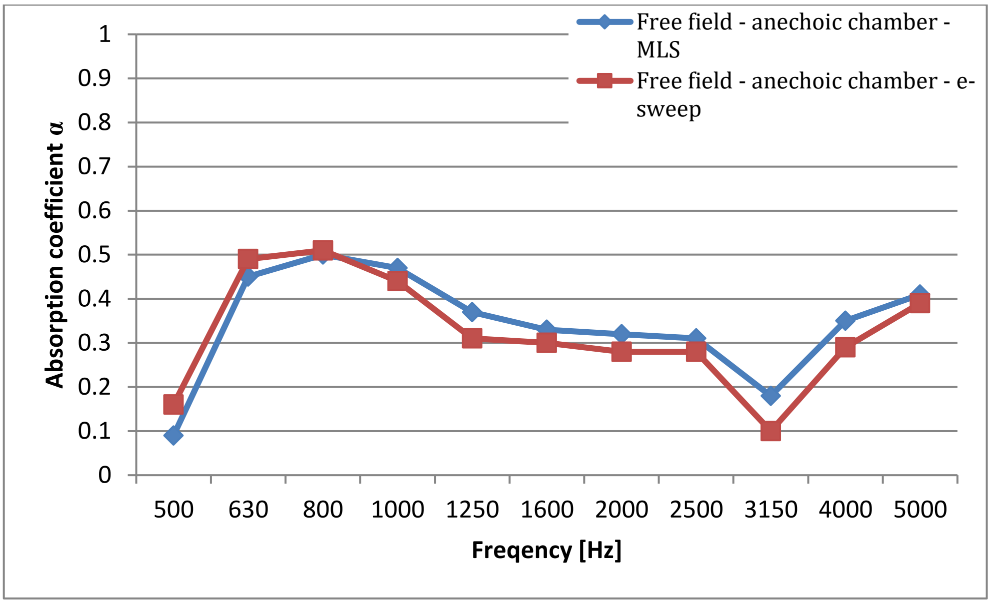

Fig. 5. Anechoic chamber – comparison of results for OSB – MLS and e-sweep signal.

4. Conclusions

The main objective of the research was to verify the possibility of using the impulse method to measure the sound reflection coefficient in situ for materials used in construction. The samples were placed in a small, partially reverberant room, as well as in an anechoic chamber (free field conditions). Pulse methods are used to measure the reverberation time in rooms. They make it possible to determine the sound absorption coefficients of the wall surfaces delimiting the room. However, in such measurements, we can determine one average sound absorption coefficient for all surfaces of the walls of the room. The use of impulse methods to determine the absorption coefficients of wall elements increases the possibilities of subsequent mapping of room parameters in acoustic modeling. It also enables the determination of acoustic parameters of acoustic screens protecting workplaces in industrial halls.

The results show a low efficiency of this method, especially in the low frequency range, regardless of the type of signal used. The determined values of the sound absorption coefficient are burdened with a significant error, which results, among others, from interference (reflection) and the size of the surface of the test sample in relation to the acoustic wavelength. These studies have shown the need to develop improved impulse response analysis algorithms to compensate for the impact of room acoustics on the results.

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Additional information

The authors declare no competing financial interests.

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