IN-SITU MEASUREMENT OF THE ABSORPTION COEFFICIENT

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ABSTRACT
The Adrienne method [1] is a measurement technique developed for in-situ measurements of sound reflection, diffraction and airborne sound insulation. Two measuring systems for determining the absorption coefficient were designed based on this method. The goal of this paper is to compare the Adrienne method of in-situ measurement of the absorption coefficient with another method which uses multiplication of the impulse responses with the ratio between estimated time of arrival of the direct and reflected incoming sound impulse, as used in some commercial acoustic measurement applications such as Easera. Speaker equalization was used in order to shrink the impulse response in time and to improve the accuracy of the measurement systems.

1. INTRODUCTION
One of the most important material properties when considering its use for acoustical treatments of spaces is clearly the absorption coefficient. It is related to the reflection coefficient, thus some methods for measuring the absorption coefficient calculate it from the ratio of the reflected and the incident sound wave on the material sample to be measured. But more general, we can divide these methods in laboratory methods where samples of a certain material of defined sizes are used according to the procedures defined in norms, and field methods which are used when measurements of absorption coefficient of already built-in materials are required. These measurements are also called "in-situ" measurements and in general they have to be adapted to the specific geometry of the measurement space.

1.1 Laboratory measurement methods
Laboratory measurements provide the most precise results with the least measurement uncertainty. The best method is the reverberation chambers method. This method yields the diffuse-field absorption coefficient which is appropriate almost for all application in interior acoustical design. A second method is used for small samples of the materials to be measured, either by using the standing wave ratio for discrete frequencies, or by using the transfer function between two fixed

points inside the tube where the pressure is measured using equalized microphones. All these measurements are well defined in corresponding norms and are used in many acoustical measurement facilities.

1.2 In-situ measurement methods
Other methods have been developed to measure the acoustic absorption/reflection coefficients in-situ. The simple, often used reflection method is standardized in [1], in ISO 13472-1 but also in the American norm ANSI S1.18-1999 (R2004).
Various authors tried to improve this measurement method by introducing two microphone measurement techniques [2] or a microphone array [3]. There is even a method developed to be used only with so-called background noise as the noise source (without loudspeaker) [4]. Another method is using the so-called handheld PU probe [5]. Nevertheless, the simplest method remains the reflection method using one single-driver loudspeaker and one microphone on a fixed position from the loudspeaker because it is the easiest to implement, but also the most cost effective in relation to the price of the measurement equipment.

2. MEASURING SYSTEMS
In this paper two measuring systems and two versions of the reflection measuring method are compared. The methods include the Adrienne method for in-situ measurement of the absorption coefficient, and a second method which is basically similar to the first mentioned method, except it uses multiplication of the impulse responses with the ratio between estimated time of arrival of the direct and reflected incoming sound impulse, as used in some commercial acoustic measurement applications such as Easera.
The measuring systems were designed to fulfill the requirements in the mentioned norm, but also considering the solutions of some other commercially available measurement equipment, such as the Zircon loudspeaker – microphone probe. The systems are shown in Figure 1. In both systems, the loudspeaker driver are built in a wooden cabinet without ports and the microphone is fastened to the cabinet using a stiff positioning system which enables positioning of the microphone always on the same distance from the loudspeaker, regardless where the whole system is pointing. The systems are fastened on a stand which enables turning it horizontally and vertically around the same central point, representing the acoustical centre of the whole system, as prescribed in the norm. The systems could also be adjusted in height in order to maximize its distance to all other reflecting surfaces, which defines the lower measurement frequency.
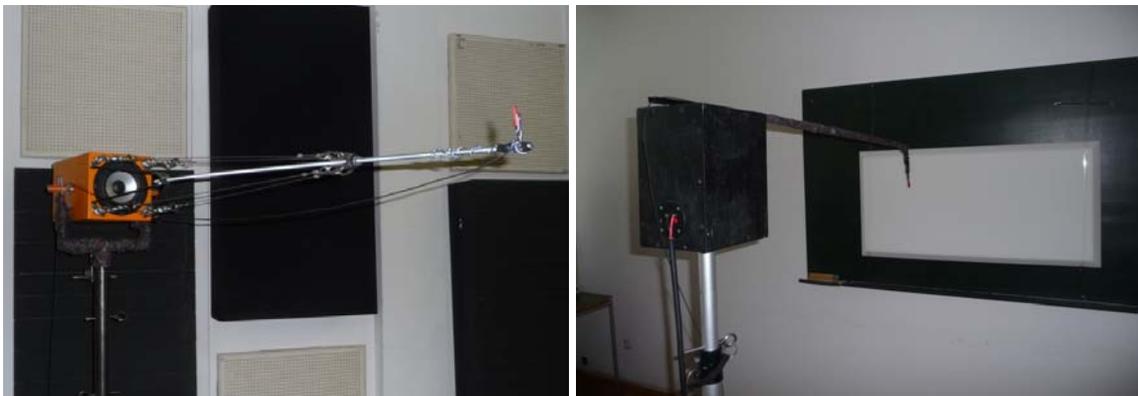
Figure 1: Measuring systems: System 1 (left), System 2 (right).

The system 1 was already used in measuring the absorption coefficient of large surfaces, such as road noise barriers or even ceilings in industrial halls. But our goal was to use this system also indoors, in rooms where the measured surfaces (typically walls) were smaller in dimensions, directly influencing the lower frequency of the correctly measured absorption coefficient.

3. MEASURING PROCEDURE
The measurement procedure is based on the impulse response measurement using an exponential sine sweep. First of all, it is interesting to compare the raw recorded excitation signal, figure 2.
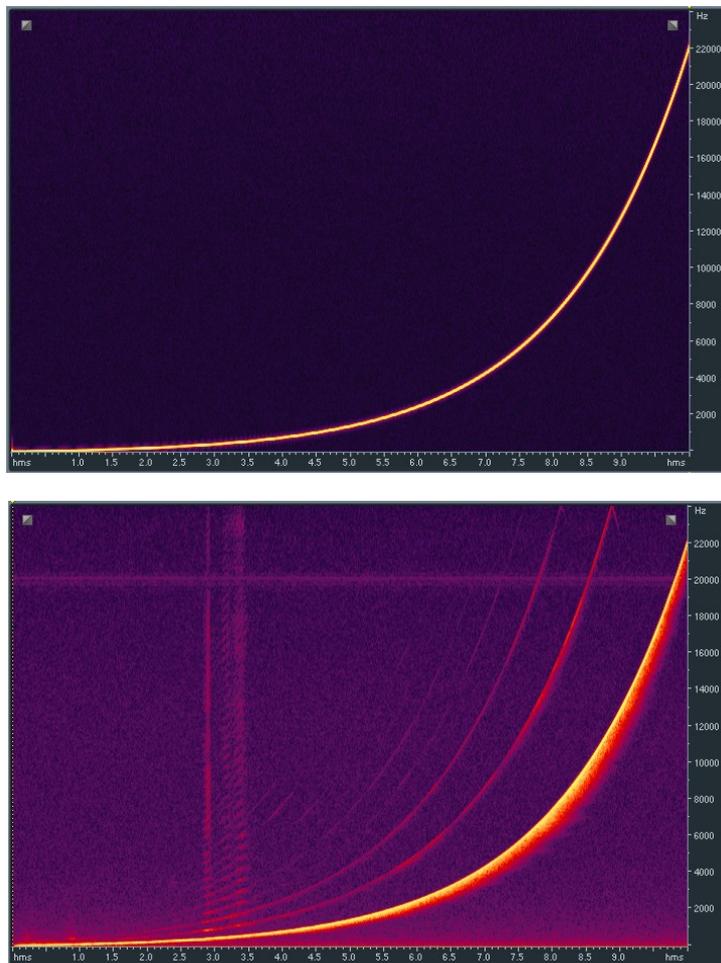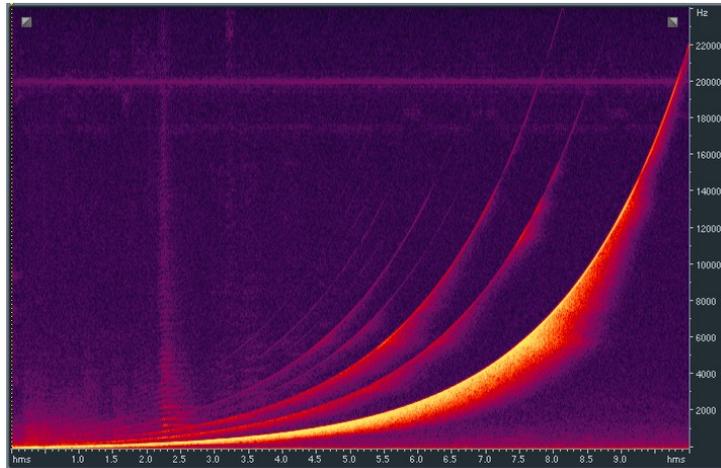
Figure 2: Frequency-time spectrogram of the excitation signal: top – originally generated signal; center – excitation signal recorded with system 1; bottom - excitation signal recorded with system 2.

It is obvious that both systems introduce significant harmonic distortion (although system 1 less then system 2). Furthermore, strong spurious resonances can easily be observed (system 1 around 3 sec. from beginning of the sweep, and system 2 around 2.5 sec.) showing that the loudspeakers and stands are not well uncoupled from the microphone. In both methods the sound source emits a sound wave that travels past the microphone position to the device under test and is then reflected on it, Figure 3. In this paper, the surface under test is an industrially made absorber, and for reference a hard surface which should have the absorption coefficient less than 0.05.
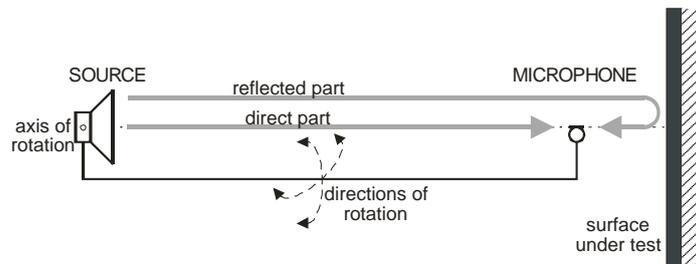
Figure 3: The measurement set-up: the source and the microphone are on a distance of 125 cm, and the microphone is placed 25 cm from the measured surface.

The direct component and the reflected component from the device under test must be separated. This separation has to be done using the signal subtraction technique. The reflected component is extracted from the overall impulse response after having removed the direct component by subtraction of an identical signal. The basic difference between the two methods is that for the first, the difference in acoustic pressure, due to a longer distance for the reflected part of the impulse response compared to the direct part, is compensated by multiplying the impulse response with time, and for the second the correction factor is obtained by dividing the arrival time of the reflected component with the arrival time of the direct component. An example of impulse response measured in free-field and in front of a hard surface with system 2 is shown in figure 4.

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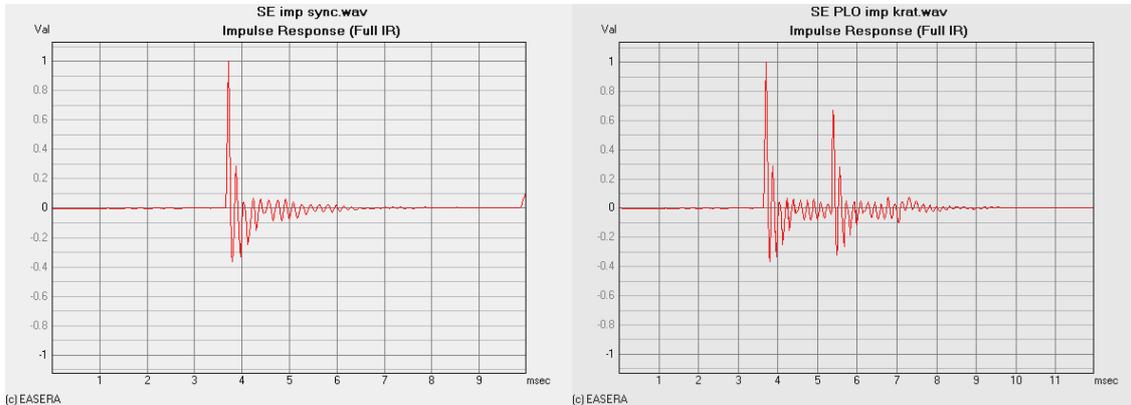
Figure 4: Impulse responses in the measurement position: left – free field, right – hard surface.

It is often being documented that in-situ measurements are liable to various spurious errors and distortions. Non-linearity is one of the problems [6], the need for system calibration another one [7]. There is still a lot of work which has to be done in order to improve this method and make it more robust and less susceptible to various errors. Exponential sine-sweep signal is often used because of its insusceptibility to harmonic distortion. A technique to better separate the direct and the reflected components in the impulse response is to use inverse filtering of the sweep signal in order to compensate for the non-ideal frequency response of the loudspeaker and the microphone [8, 9]. The inverse filtering yields a shorter impulse response improving the detectability of the part of the impulse response reflected from high-absorbent materials, but has no influence on the final results.

3. COMPARISON OF RESULTS

Figure 5 shows the absorption coefficient given by the manufacturer and measured for random incidence. For comparison, the same material was measured in Kundt's tube using the standing wave ratio method. Figure 6 shows the measurements for all positive degrees of incidence, as well as for 0°, the negative values show the same behaviour. It is obvious that greater angles improve the absorption coefficient as sound travels through a thicker area of absorption material. Finally, Figure 7 shows the direct comparison between the two methods, first using Adrienne window, the second as measured in the Easera software. Both curves were calculated as average absorption coefficient in harmony with the norm. The results show a very good alignment for high frequencies, above 1 kHz, with same tendency for the medium frequency range (but the values calculated with Adrienne are little higher), but a disagreement for lower frequencies.
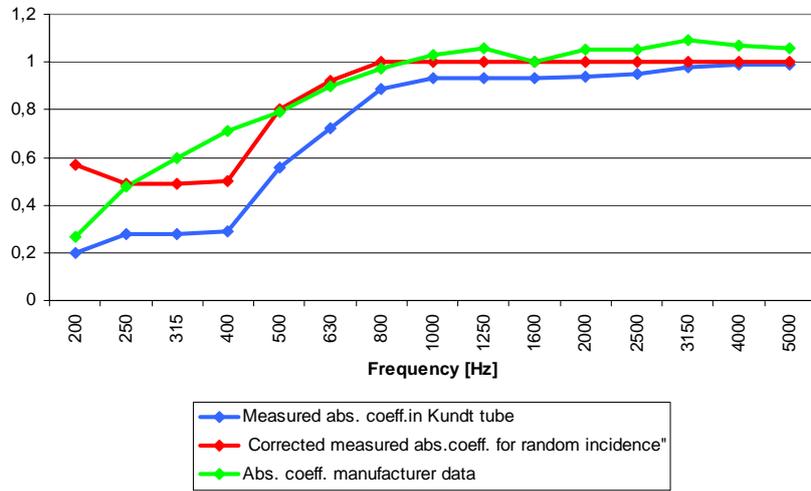
Figure 5: Absorption coefficient of the measured sample using Kundt's tube, and the manufacturer data as reference.
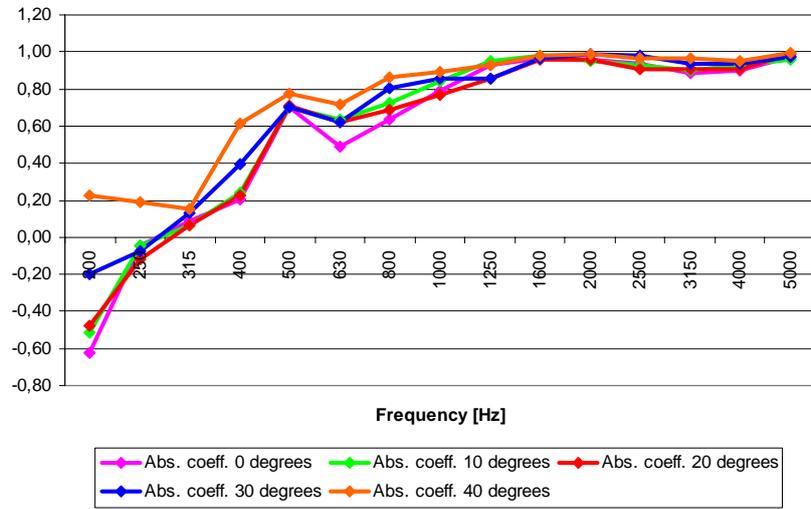
Figure 6: Absorption coefficient measured for various angles of incidence.
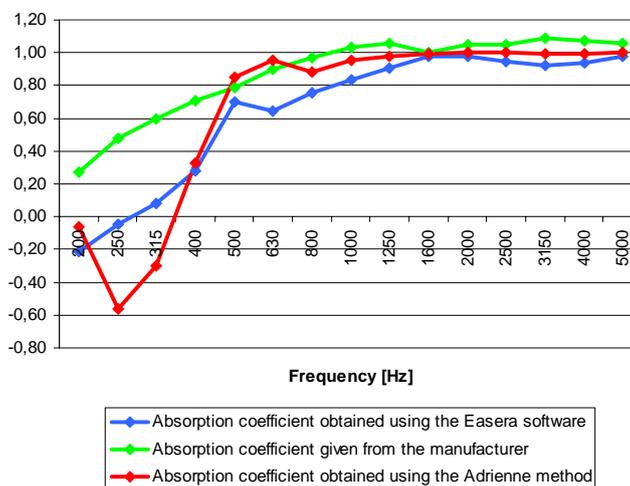
Figure 7: Comparison of absorption coefficient data gained using the Easera software, the Adrienne method and the data given by the manufacturer of the tested device.

4. CONCLUSION

In-situ measurements of absorption coefficient are not easy to carry out due to unfavorable measurement conditions, but they cannot be avoided if the material which is to be measured is already built in. The Adrienne method is an often used method, but there are also some others which use a slightly different approach for calculating the absorption coefficient. Both methods are compared in this paper and the overall conclusion is that they are in good agreement if the measured absorption coefficient is very high. For lower values there is a disagreement, the second method tends to show lower values which agree less with the manufacturer data.

The design of the loudspeaker – microphone system can also be critical due to resonances which occur within the system. But the main limitation of all systems based on the Adrienne method is the geometry of the measuring space.

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