The design of an in-situ absorption measuring system using the Adrienne method

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Introduction

The *Adrienne* method is an often used measurement technique developed for outdoor (in-situ) measurements of sound reflection and airborne sound insulation. It is standardized in the CEN/TS 1793-5 norm [1]. This norm was used as the basis for the design of a measuring system for determining the absorption coefficient and sound insulation of noise barriers, ceilings and other wall systems where no laboratory data about the acoustical performance is known.

The goal of this paper is to compare the *Adrienne* method for in-situ measurement of the absorption coefficient and an alternative 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 [2].

Measuring system

The measuring system was designed to fulfill the requirements of the already mentioned norm [1], but also taking into account the design of some other commercially available measurement equipment, such as the Zircon loudspeaker – microphone probe [3]. The system is shown in Figure 1. The loudspeaker driver is built into a wooden cabinet without ports. The microphone is fastened to the cabinet using a solid positioning system which enables to fix the microphone always on the same distance from the loudspeaker, regardless of the angle where the system is rotated. The measuring system is fixed on a stand which enables rotating it horizontally and vertically around the same central point, representing the acoustical centre of the whole system, as prescribed by the norm. The system can also be adjusted in height in order to maximize its distance to all other reflecting surfaces which limit the lower measurement frequency.

As there is a considerable amount of fastening screws and bolts connecting together the loudspeaker and microphone and the whole system to the stand, after initial tests there was fear that they could influence the measurement results, i.e. the microphone could pick up structure born noise. Thus, all the fastening points were again elastically interconnected, and the whole microphone – loudspeaker system was elastically fixed to the stand as well.

The system was already used in measuring the absorption coefficient of large surfaces, such as test samples of road noise barriers or even ceilings in industrial halls, Figure. 2. But, our goal was to use this system also indoors, i.e. in rooms where the measured surfaces (typically walls) were of smaller dimensions and closer to other reflecting surfaces, directly influencing the lower limiting frequency of the measured absorption coefficient.

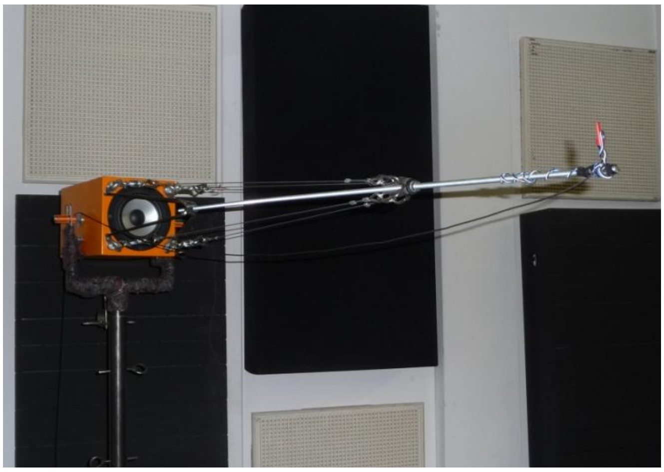

Figure 1: The loudspeaker – microphone measuring system designed for in-situ measurement of the absorption coefficient of sufficiently large surfaces.

Figure 2: Typical application of the measuring system: upper picture – sample of a road noise barrier, lower picture – perforated sheet metal ceiling of an industrial hall.

Measurement procedure

It is often being documented that in-situ measurements of absorption coefficients are prone to various spurious errors. Non-linearity is one problem [5], the need for system calibration another one [6]. 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.

In this paper, two measurement procedures are compared. In the *Adrienne* measurement procedure, the sound source emits a sound wave that travels past the microphone position towards the surface under test, reflects from it and travels again toward the microphone, Figure 3.

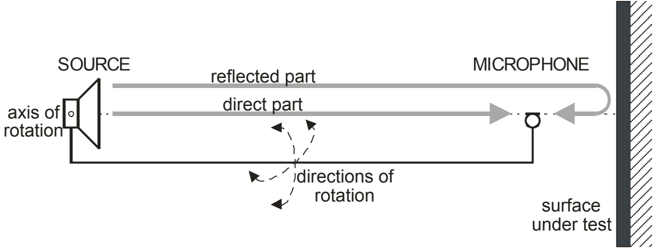

Figure 3. The measurement set-up: the source and the microphone are on a distance of 125 cm, and the microphone on 25 cm from the measured surface.

The power spectra of the direct and the reflected components, corrected to take into account the path length difference of the two components, gives the basis for calculating the reflection and the absorption index. The direct component and the reflected component from the surface 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 microphone and the source have to maintain fixed positions relative to each other in order to implement the signal subtraction technique. The basic equation for measuring the reflection index is given in (1)

$$RI_j = \frac{1}{n_j}\sum_{k=1}^{n_j} \frac{\int_{\Delta f_j} \left|F\left[t \cdot h_{r,k}(t) \cdot w_r(t)\right]\right|^2 df}{\int_{\Delta f_j} \left|F\left[t \cdot h_i(t) \cdot w_i(t)\right]\right|^2 df} \qquad (1)$$

where h_i and $h_{r,k}$ are the incident and the reflected components of the impulse response (k represents the k-th angle of rotation), and w is the *Adrienne* temporal window adapted to the incident and reflected components. F is the symbol of the Fourier transform, and j is the index of the corresponding 1/3 octave band. The basic difference between this method and the alternative one is that in the *Adrienne method* the compensation of the spreading loss, due to a longer traveling distance of the reflected component of the impulse response compared to the direct one is done by multiplying the impulse response with time, t in (1).

The alternative measurement procedure used for calculating the absorption coefficient and compared to the first method is implemented in the *Easera* acoustic measurement software [2]. Although this procedure is not described in detail, it also uses windowed impulse responses as the basis for calculations. Similarly to the first method, a correction factor has to be implemented in order to compensate for the difference in the path length between the direct and the reflected component of the impulse response. The correction factor is obtained by dividing the arrival time of the reflected component with the arrival time of the direct component, rather than multiplying the whole time response with time. The excitation used in the measurements to obtain the impulse response of the whole system under test was a sine sweep signal. The obtained impulse response was the basis for calculating the absorption coefficient with both methods. Finally, the calculated absorption coefficients for both methods were compared.

For the test, an acoustic porous absorbing material of known absorption coefficient was used, as given by the manufacturer [4]. These coefficients are usually given for 1/3 octave frequency bands, measured for random incidence in a reverberation chamber.

The material was glued on a hard, smoothly plastered wall in a huge amphitheatric lecturing hall. The wall was more than 5 meters tall, thus the measurement system and the material sample were fixed at half of this height, at 2.50 m. The material was measured for the following angles of incidence: -40°, -30°, -20°, -10°, 0°, 10°, 20°, 30° and 40°, all in the horizontal direction. For reference, one measurement for 0° incidence was done just for the smoothly plastered wall, without any absorption material. The last measurement required for the calculation was done in "free-field" conditions, with the system pointing as far from reflecting surfaces as possible, at least in the range important for the measurements.

Comparison of results

Figure 4 shows the typical time pattern of the measured impulse response, showing two pronounced peaks: the first belonging to the direct, and the second to the reflected component of the signal. The unwanted reflections can be easily seen starting from 12 ms.

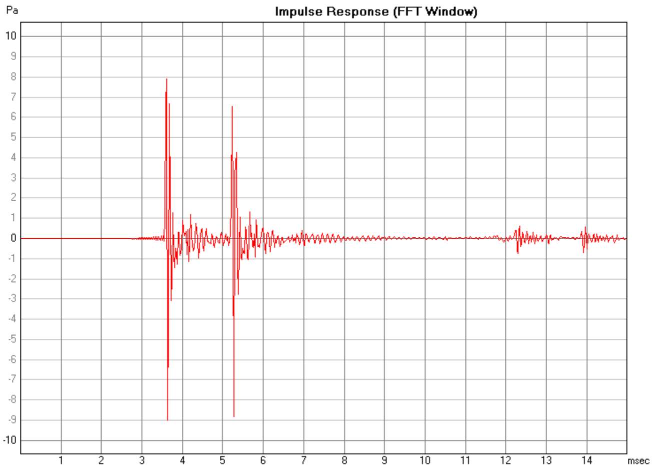

Figure 4: The impulse response measured for the plastered wall with direct (at aprox. 3.6 ms) and reflected components (at aprox. 5.2 ms).

Figure 5 shows the impulse response from Figure 4 in the frequency domain, but also the "free-field" frequency response, both after time-windowing with the signals set to zero after 12 ms because of the reflections. It is obvious that the "free-field" frequency response represents the response of the loudspeaker and the response from the hard surface response shows a strong comb-filtering effect due to reflections from the wall.

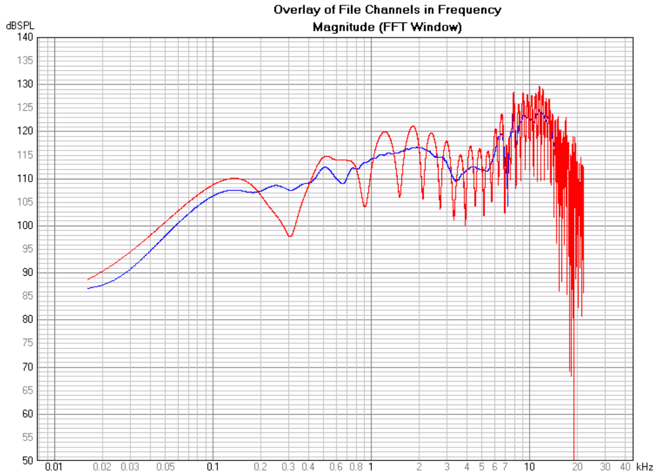

Figure 5: The frequency spectra of the "free-field" impulse response (blue) and the impulse response of the wall (red).

These power spectra have to be processed in order to gain the frequency dependent reflection coefficient, as shown in Figure 6. It can be seen that it is not an ideal curve at almost 0 dB (as the wall reflects almost all energy back). Nevertheless, these values can be used to calibrate the measurement of the absorptive material for 0° incidence.

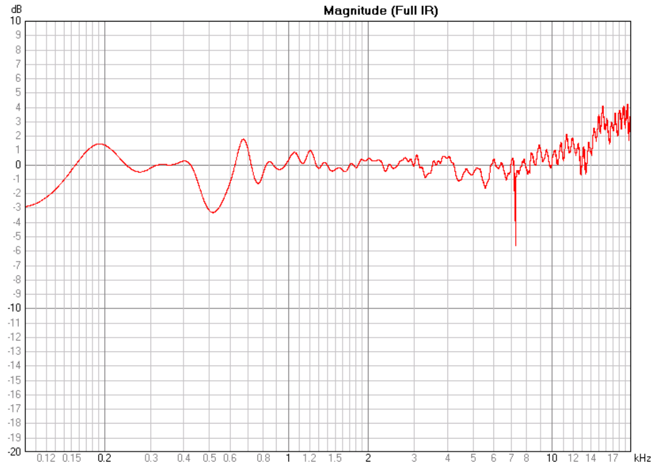

Figure 6: The frequency dependent, logarithmic values of the reflection coefficient for a hard plastered wall.

For comparison, Figure 7 shows the impulse response for the 0° incidence on the absorptive material, also with direct and reflected components. If compared to Figure 4, it can be easily seen that the reflected component is of much lower amplitude, almost vanishing in the residual part of the impulse response of the direct component.

It is important to notice that, considering the norm, the first limiting reflections are limiting the lower frequency to 200 Hz. Frequencies bellow 200 Hz cannot be considered as correctly measured. Figure 8 shows the absorption coefficients given by the manufacturer and measured for random incidence. For comparison, the same material was measured in a Kundt's tube using the standing wave ratio method. As this method provides only the normal incidence absorption coefficients, the values were corrected for random incidence, as suggested in [7]. It can be seen that the corrected results of the measurement in Kundt's tube follow well the manufacturer data.

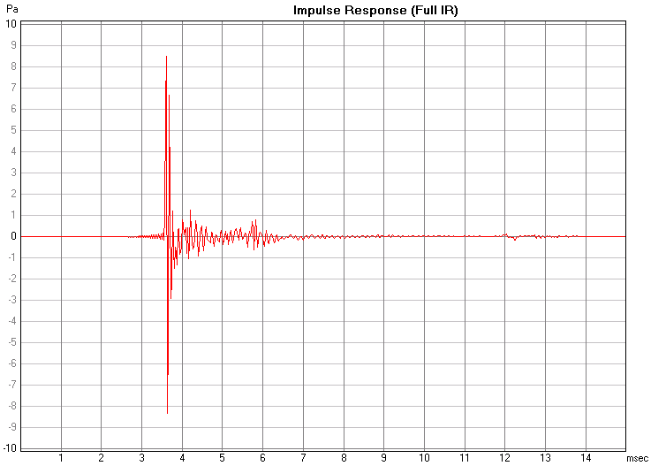

Figure 7: The impulse response measured for the test absorptive material. The reflected component is of much lower amplitude then the direct one.

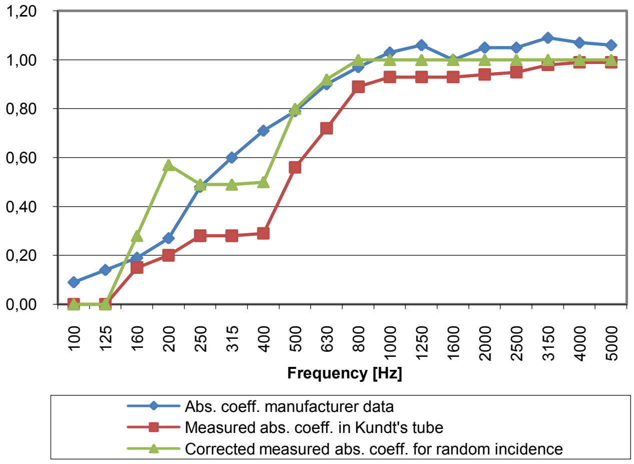

Figure 8: Absorption coefficients of the measured sample using Kundt's tube, and the manufacturer data as reference.

Next in Figure 9, the 0° incidence measurement of the material is shown, but also the same curve with corrected values using the calibration measurement on hard surface, all calculated with the alternative method. Again, the Kundt's tube results are given for reference as they were both measured for normal incidence. The calibration improves the resemblance, although the data for both measurements do not match very good for frequencies bellow 1 kHz.

Figure 10 shows the measurement results for all positive degrees of incidence, as well as for 0°, the negative degrees being very similar to the positive one. It is obvious that greater angles improve the absorption coefficient as sound travel through a thicker layer of absorptive material.

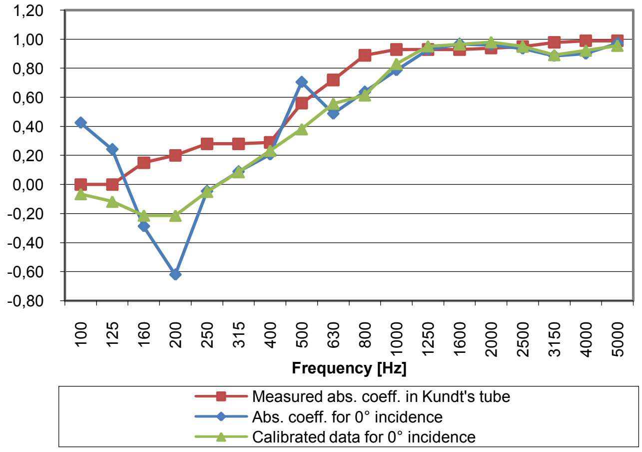

Figure 9: Absorption coefficients measured for 0° incidence using the alternative method, corrected values and values measured in Kundt's tube for reference.

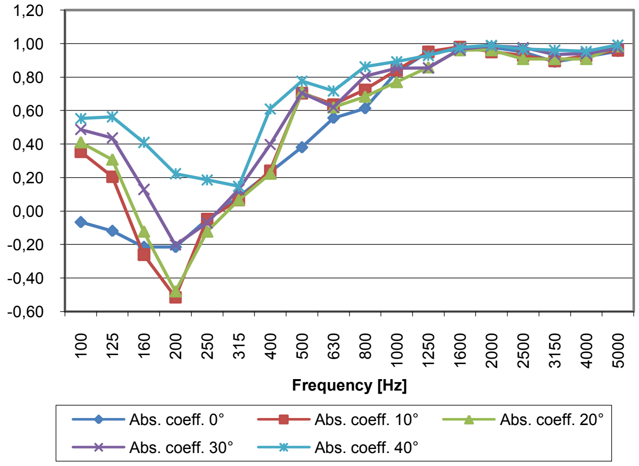

Figure 10: Absorption coefficients of the absorptive material measured from 0° to 40° in 10° steps.

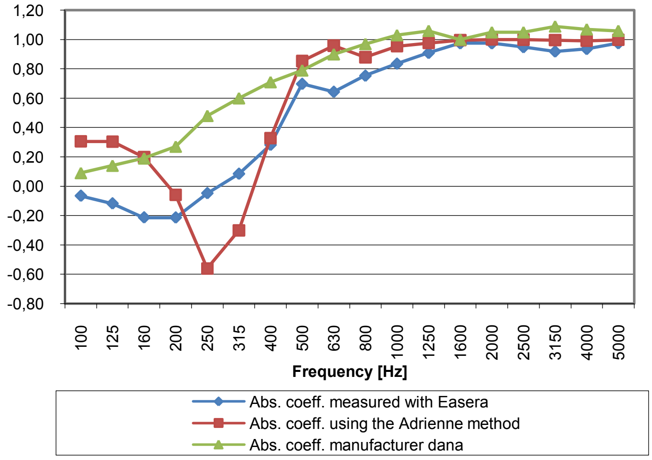

Figure 11: Comparison of absorption coefficient values obtained using the *Easera* software, the *Adrienne* method and the manufacturer data as reference.

Finally, Figure 11 shows the direct comparison between the two methods, first using the *Adrienne* window and the alternative method as measured in the *Easera* software. Both curves were calculated as average absorption coefficient according to the norm. The results show a very good agreement for high frequencies above 1 kHz, same tendencies for the medium frequency range (but the values calculated with the *Adrienne* method are somewhat higher), but a disagreement for lower frequencies.

Conclusion

It is not easy to carry out in-situ measurements of absorption coefficients 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 is also an alternative method which uses 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 disagreement, the alternative method tends to show lower values which agree less with the manufacturer data.

Some of this disagreement could be connected with the design of the loudspeaker – microphone system as it is noticed that the first unwanted reflections arrives when the sound is reflected from the wall, and then again from the loudspeaker cabinet. Currently, a new system is designed with improved loudspeaker and stand geometry which should extend the frequency measurement range.

References

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