A novel way to determine sound absorption, sound transmission and sound power.

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Introduction

Recently, the University of Twente and Soundinsight have developed a range of methods and a new probe which, without relying on any assumption of the global sound field, can be used to measure the incident and reflected sound intensity in any sound field. We can thus separate the incoming from the reflected waves in the actual sound field, based on which we can determine in-situ absorption/emission coefficients, in-situ transmission loss and in-situ radiated power. In this paper, we will explain the fundamental ideas behind these methods and focus on a method to measure sound absorption.

Theory

The sound absorption coefficient is a measure of how much of the incoming acoustic sound power is absorbed by an absorbing material (or more correctly through a given area). The coefficient is defined as the ratio of the active power and the incident power flowing by that area:

$$\alpha = \frac{P_{ac}}{P_{in}}. \tag{1}$$

The active power, which can be measured using a regular intensity probe, denotes the nett acoustic power, i.e. the power associated with the combination of the incoming and the reflected wave. The incident sound power on the other hand, i.e. the sound power associated with the incoming sound wave could, until recently, only be measured if the sound source was known. (All available methods rely on this information. The global sound field is then assumed to consist of plane waves or spherical waves.) However, looking more closely to absorbing materials, the absorption coefficient actually depends on the sound field impinging on the material as well; the absorption coefficient being dependent on the angle of incidence is a well-known example of this. Generalizing this observation to more complex materials and sound fields, one can state that the absorption coefficient is not a material property alone but it also depends on the actual sound field impinging on the material.

In cooperation with dr. ir. E. Kuipers, the author developed a range of, so-called, local plane wave methods, to directly measure the absorption coefficient in the actual sound field just in front of the material, see [1] and the references therein. The method does not rely on any prior knowledge of the sound source. It just measures the incident intensity at the location of interest. This has been accomplished using a local plane wave assumption, allowing the local sound field to be split into an incident and a reflected wave. The associated intensities can then be measured and integrated over the area to calculate the power ratio given in Equation (1).

In the most simple version of the method (the so-called local plane wave method; LPW), we use the measured pressure, P, and measured particle velocity normal to the absorbing surface, U·n, (or 2 nearby pressures as in a 2p-intensity probe). Based on these two measured quantities, we can formulate the simple system of equations for two plave waves and solve for the complex amplitude A of the incoming wave and the amplitude B of the reflected wave, i.e.,

$$\begin{aligned} A &= \frac{1}{2}\left(P + \rho_0 c_0 \vec{U} \cdot \vec{n}\right) \\ B &= \frac{1}{2}\left(P - \rho_0 c_0 \vec{U} \cdot \vec{n}\right) \end{aligned}. \tag{2}$$

The density and speed of sound are denoted by ρ_0 and c_0 respectively. We can then calculate the intensity associated with the incoming wave as

$$I_{in} = \frac{A\overline{A}}{2\rho_0 c_0}, \tag{3}$$

where the bar denotes the complex conjugate. Note that the actual angle of incidence of the wave impinging on the surface may be different from normal incidence; we only need an approximation of the intensity flowing normally into the surface.

Despite its simplicity, this method works fine for engineering purposes, even for larger angles of incidence. To illustrate the method, we consider two cases of sound impinging on a Louvre door, as illustrated in Figure 1.

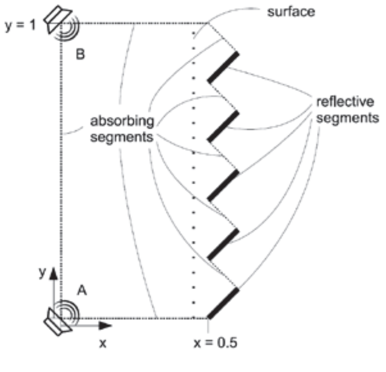

Figure 1: A ‘Louvre door’ consisting of reflective and ‘absorbing‘ segments.

In the first case, an omnidirectional sound source is positioned at A, as shown in Figure 1. As most sound ‘rays’ emitting from source A, imping normally to absorbing segments, one would expect the Louvre door to effectively absorb sound emitting from A. In the second case we position the source in B. As now most sound ‘rays’ imping normally to reflective segments, one would expect less absorption.

A finite element model of the Louvre door confirms this expectation. In figure 2 and 3, the absorption coefficients are shown for the source at A and, respectively, B. These values have been obtained by integrating the active intensity and incident intensity, according to Equation (3), over the line at x = 0.45 [m] (the dotted line in Figure 1).

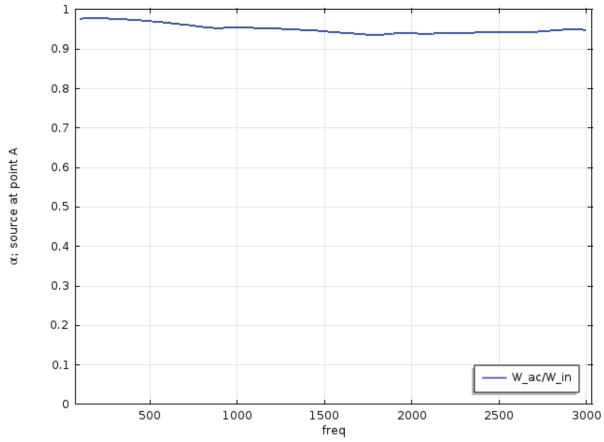

Figure 2: The absorption coefficient of the Louvre door due to an omnidirectional source at position A.

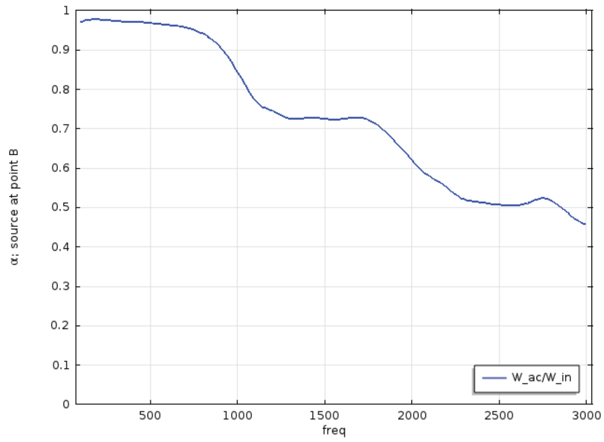

Figure 3: The absorption coefficient of the Louvre door due to an omnidirectional source at position B.

As is clearly seen and expected, the absorption coefficient significantly reduces if the sound source is at B, whereas it is close to unity if the source is at A.

In Figures 4 and 5, the incident (red, pointing right) and reflected (blue, pointing left) intensities are shown as arrows on the line x = 0.45 [m] for a frequency of 3000 Hz. The incident intensity is seen to be smooth if the source is at A and is also larger closer to the source. The reflected intensity is seen to be nearly absent, except for some reflection near the lower right corner. In Figure 5 on the other hand, the reflected intensity is much larger (some are in the order of the incident intensity). The spatial variation in the reflected intensity can be seen to follow the reflective segments quite nicely.

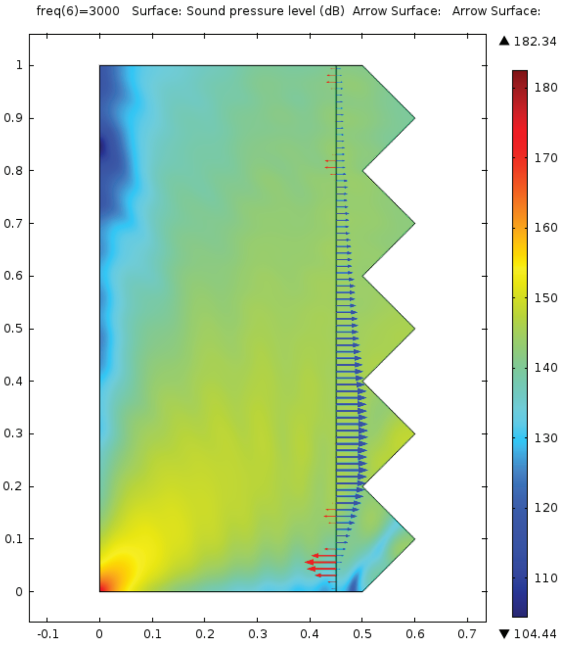

Figure 4: Sound pressure level (color), incident (blue) and reflected intensity vectors (red) at x=0.45 [m] due to a omnidirectional source at position A (3000 Hz).

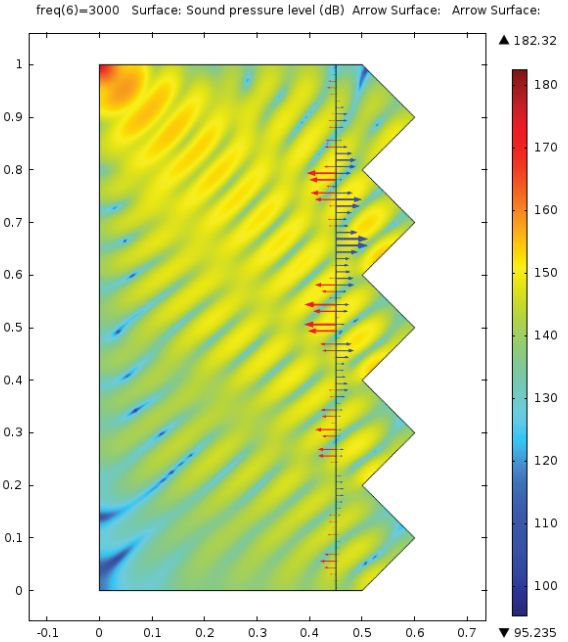

Figure 5: Sound pressure level (color), incident (blue) and reflected intensity vectors (red) at x=0.45 [m] due to a omnidirectional source at position B (3000 Hz).

Based on this theoretical study, one can conclude that it is very well possible to measure in-situ sound absorption coefficients without having to rely on information about the sound source. Using an intensity probe, this is already possible.

If the angle of incidence becomes larger, one can show that the accuracy of the proposed method decreases, see [1]. Therefore, we have expanded the LPW method with additional methods, which we call the local specular method (LSPW) and the local arbitrary method (LAPW) to correct for this reduction in accuracy. In the LSPW method, we still assume two plane waves but we allow the incident and reflected wave to (locally) imping, respectively emit, at an angle. For the LSPW, the angle of emission of the reflected wave is assumed to be equal to the angle of incidence (specular reflection). For the LAPW, the angles are assumed to be independent. Needless to say, the pressure and normal particle velocity are not sufficient to calculate all given unknowns. Hence more local information is needed and for that purpose, we developed a small 8 mems-microphone array, see Figure 6. How the absorption coefficient is calculated based on the microphone signals is given in [1].

Experimental validation

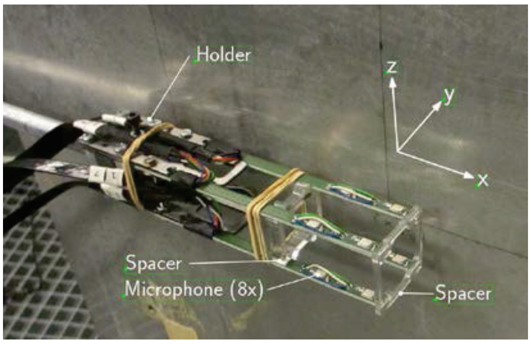

Figure 6: The newly developed 8 mems-microphone array (taken from [1]).

To validate our model, measurements were performed using the 8 mems array to measure the absorption coefficient of a car seat in an large office. A loudspeaker was used to emit broadband sound about 2 m above the car seat.

Figure 7: The car seat (note the stitches).

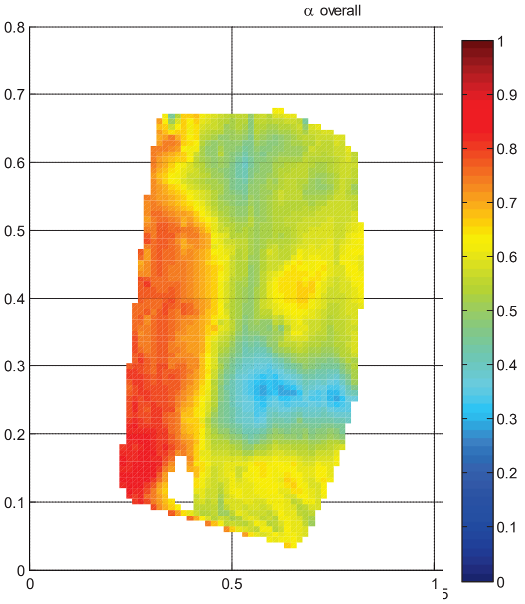

Figure 8: The overall local sound absorption coefficient (I_{ac}/I_{in}) of the car seat.

Figure 8 shows the measured overall local absorption coefficient (I_{ac}/I_{in}). It can be seen that the overall absorption coefficient is near to 1 at the sides of the seat, hence on this position we have good absorption. One can clearly see the reduced absorption coefficient near the stitches. Apparently, a dense compressed absorptive material results in much lower absorption coefficients.

Further development

In cooperation with Soundinsight, the mems microphone array has been further developed into a probe (the Sonocat) shown in figure 9. The new probe consists of a sphere on a small tube. The 8 mems microphones are positioned behind small holes in the sphere. The advantage of such a design is its robustness but the sphere also affects the local sound field more than an open structure would do. This seems unwanted but, as we use local plane wave approximation anyway, we can easily compensate for the diffraction of the sphere. In this way, we can measure absorption values upto 10 kHz.

Figure 9: The Sonocat.

Conclusion

Based on a local plane wave assumption, we have shown that it is possible to measure the absorption coefficient of any material in any sound field, without a need to know the actual global sound field or sound source. In our methods, the incident intensity is measured directly. This is a great benefit as the acoustic engineer is now able to measure whether the sound that needs to be reduced (like for instance in a car), is also effectively absorbed. For instance, you can now assess the effectiveness of the absorbing materials; does the material indeed absorb the noise produced by the car while driving.

Literature

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