Assessment of the quality of absorption measurements of inhomogeneous car materials and furniture in a reverberation chamber for room acoustic FE-simulations

Marc Aretz, Michael Vorländer

Institute of Technical Acoustics, RWTH Aachen University, E-Mail: mar@akustik.rwth-aachen.de

Abstract

The quality of room acoustic simulations strongly depends on the quality of the applied boundary data. Additionally, in small rooms where the low frequency sound field is dominated by modal effects classical geometrical acoustics tools need to be extended by wave-based methods such as the FEM or BEM. This extension opens the door to the realistic simulation of a whole new range of acoustically interesting small spaces, like car passenger compartments or recoding studios. However, reliable measured boundary conditions for these new rooms rarely exist and existing databases generally only supply absorption data, whereas in wave-based simulations acoustic impedances are needed. Even worse, in the case of materials with an inhomogeneous shape and structure a measurement of the acoustic surface impedance appears barely achievable. In this study we therefore present absorption results obtained in a reverberation chamber for a car dashboard, door panels and a headliner as well as some furniture objects and discuss if the measured diffuse field absorption data can also be applied in room acoustic FE simulations, even though the reflection phase cannot be obtained from these measurements. Finally we investigate an alternative approach where we deduce the complex surface impedance of an inhomogeneous absorber at low frequencies from mode eigenfrequencies and damping factors measured in a reverberation chamber.

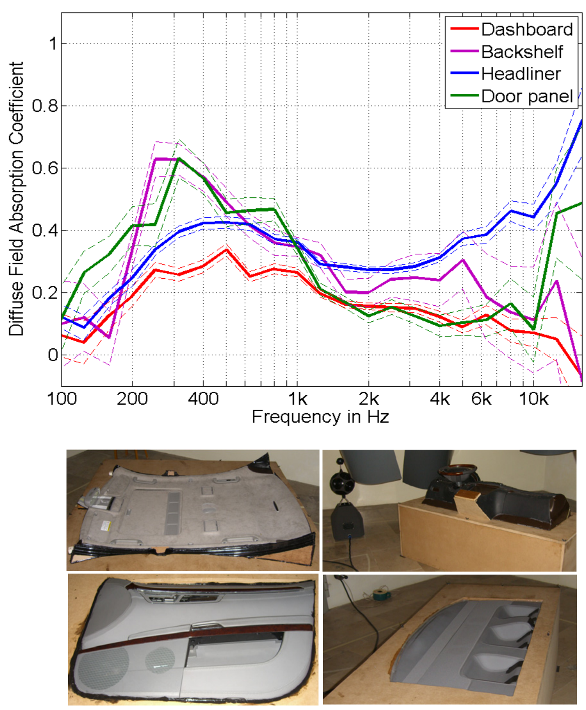

Figure 1: Measured diffuse field absorption coefficients (mean and standard error) for car materials.

Reverberation room absorption measurements for car materials and filing cabinets

In the course of this study we measured diffuse field absorption coefficients for a car dashboard, two car doors, a complete car headliner with roof and a back shelf with metal frame. The car materials were carefully mounted into special measurement boxes. Special attention was given to the sealing at the sample edges in the box to avoid absorption from leakage effects. The measurements with the car materials were compared to measurements where the measurement box was covered with a flat wooden panel. Furthermore we measured the absorption coefficient of wooden filing cabinets in empty, half full and fully equipped condition. The results are given in Figure 1 and 2. All measurements were carried out following the guidelines in DIN-EN-ISO 354 except for the fact that the size of the car material samples did not comply with the minimum required sizes suggested in the norm. For each car material we averaged a total of 36 measurements (3 Sample x 3 Loudspeakers x 4 microphones). The filing cabinets were only measured in one position centred on one side wall but again with three loudspeaker and four microphone positions. As can be seen in the graphs the uncertainty of the absorption results is very low except for the low and high end of the frequency range and reasonable results are obtained both for the car materials and the filing cabinets.

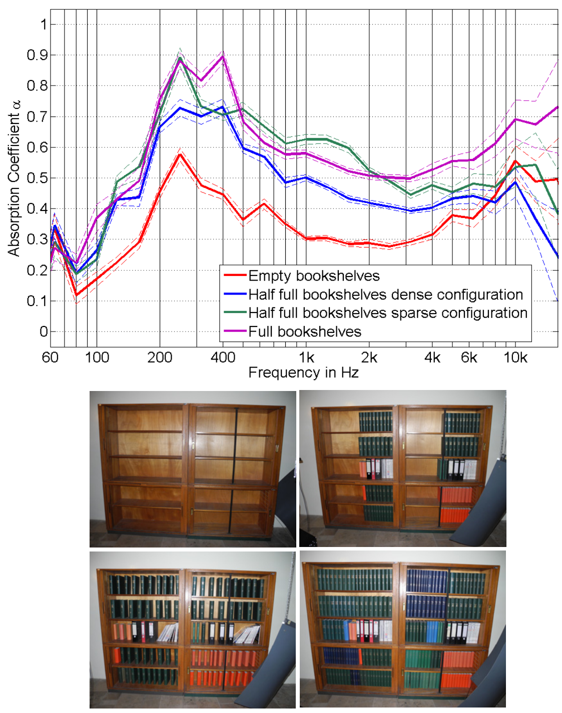

Figure 2: Measured diffuse field absorption coefficients (mean and standard error) for differently equipped bookshelves.

However, in the case of the car materials influences from edge diffraction at the measurement boxes or from the mounting of the samples can not be ruled out.

Applicability of results in the FE domain

The presented measurement results yield reasonable third octave band absorption data for room acoustic GA simulations but room acoustic FE simulations require not only the magnitude of the reflection factor (which can be deduced from the absorption coefficient) but also the phase shift to unambiguously determine the surface impedance at a room boundary. Moreover, due to insufficient modal overlap the uncertainty of the absorption values obtained in a reverberation room generally increases at frequencies below the Schroeder frequency, which is exactly the range of application for the FE simulation.

Since investigations on a large 50mm Rockwool sample (which are not reported in this paper) have shown that by sufficient averaging reasonable absorption values can be obtained even at frequencies far below the Schroeder frequency the following section focuses on the effects caused by the negligence of the reflection phase, when applying absorption data in room acoustic FE simulations.

Influence of the phase shift at a room boundary

In order to investigate the influence of the phase shift at a boundary reflection we compared simulated room transfer functions (RTFs) for a damped model room (with and without phase information in the impedance boundary data) to measured data in an according real room (see Figure 3). The boundary conditions for the PU foam absorbers, which covered three of the room walls were deduced from the Komatsu model with measured flow resistivity data. The first simulation, which shows a very good match with the measured RTF, used complex impedance boundary conditions, whereas the second simulation used a real valued impedance deduced from the absorption coefficient of the PU foam assuming a zero phase reflection factor. It can be seen that the negligence of the phase shift at the boundaries noticeably degrades the quality of the simulation result. This is due to the fact that the shift in the eigenmode frequencies is not accounted for by the real valued impedance.

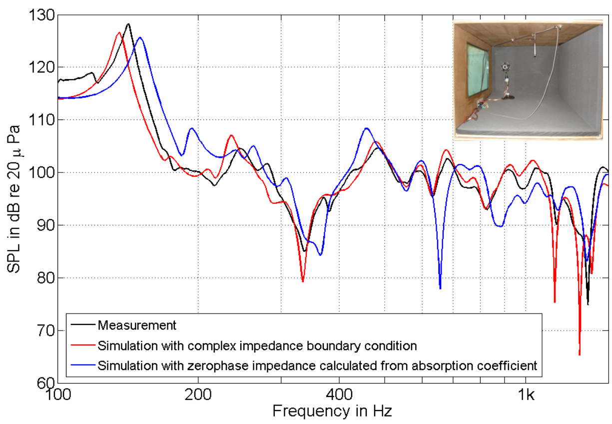

Figure 3: Measured and simulated room transfer function in damped model room**.**

Extraction of the complex reflection factor from distinct room eigenmodes

Since the negligence of the phase shift at a room reflection noticeably degrades the simulation quality and none of the conventional impedance measurement techniques were directly applicable to the measured materials we made some first experiments to investigate if it is generally possible to extract the complex reflection factor from frequencies and quality factors of discrete room eigenmodes. We therefore placed a 7.5 m² and 5cm thick Rockwool sample on one wall of the ITA reverberation room, put a subwoofer in a room corner and a measurement microphone centred on the opposite wall of the Rockwool sample in order to cancel a maximum number of unwanted modes from the other room dimensions. Since the ITA reverberation room is not a perfect cuboid (one tilted wall), this procedure let us extract the frequencies and quality factors of the first 4 relevant eigenmodes. By assuming that the wall opposite the Rockwool sample is perfectly reflecting we calculated the average reflection factor of the wall with the sample as

$$|R_n| = \exp(-(2\Delta f)_n \cdot \tfrac{2\pi L}{c}),\ \arg(R_n) = (4 f_n \tfrac{L}{c} - 2n)\cdot\pi \quad (1)$$

Where L is the distance between the wall with the sample and the opposite wall, c ist the speed of sound, n is the order of the mode, f_n its eigenfrequeny and $(2\Delta f_n)$ its half width. The average reflection factor was then used to calculate an average impedance of the wall with material sample and finally the impedance (and reflection factor) of the sample was calculated by accounting for the fact that the sample only covers part of the wall. As can be seen in Figure 4 this procedure yields reasonable results compared to a calculation from the Komatsu model, although the reflection phase is somehow underestimated. Similar results could also be obtained for the filing cabinets and a PU foam sample (results not displayed in this paper.)

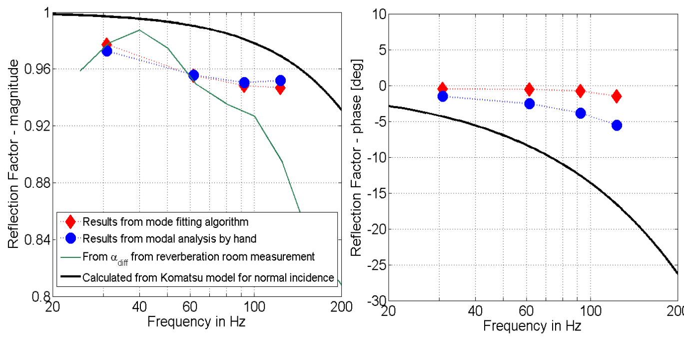

Figure 4: Comparison of low frequency reflection factor of rockwool sample obtained with different methods

Conclusions

In this paper we present diffuse field absorption results for inhomogeneous materials which can be used as input parameters for room acoustic GA simulations. However, it is shown that an application of this absorption data to FE simulations leads to unpredictable errors in the simulation. A first approach to measure average low frequency reflection factors is therefore presented. Further studies are however necessary to investigate the effects of different boundary representations of complex materials on the FE result.