In-Situ Measurements of Surface Reflection Properties

Markus Müller-Trapet (mmt@akustik.rwth-aachen.de)
Michael Vorländer (mvo@akustik.rwth-aachen.de)
Institute of Technical Acoustics
RWTH Aachen University
Neustraße 50, 52066 Aachen

ABSTRACT

In order to characterize surfaces with respect to their sound reflecting properties, the absorption and the scattering or diffusion coefficient can currently be measured under standardized laboratory conditions. However it is questionable whether the data from measurements performed under such laboratory conditions can be used to accurately model the actual sound field in rooms. Additionally, it is not always possible to obtain a transportable sample of a material.

In-situ measurement methods can overcome these shortcomings, as they measure the desired quantities at the location where the material is installed. For this purpose, a portable setup was built that allows for a complete hemispherical measurement of the sound pressure distribution using less than 30 sensors. This contribution will present the setup together with the challenges for post-processing the acquired data. First measurement results will be presented and discussed.

1 INTRODUCTION

In order to obtain physically correct simulations of enclosures the knowledge about the boundary conditions - i.e. the sound reflecting properties of the surfaces - have to be known as exactly as possible. Especially for the application in room acoustics, this poses the problem of how to obtain this data. Compared to laboratory measurements, in-situ measurements are able to better assess the properties of materials because the measurement is performed where the absorber is installed and hence includes all effects that arise due to the size and mounting of the material.

The idea of measuring the angle-dependent absorbing characteristics of materials in-situ is not new and several approaches exist for the problem. However, a robust and reliable method has not been established. Additionally, no solution exists for a measurement of the scattering properties of architectural surfaces.

The approach to this problem presented in this contribution consists of a sequential hemispherical microphone array together with appropriate signal processing steps. This allows for a direct measurement of the reflection directivity due to an incoming wave, yielding data that can be used to deduce the angle-dependent complex reflection factor as well as a sound pressure distribution which permits the analysis with respect to the scattering properties.
This paper will present the measurement setup and the necessary post-processing steps to obtain the complex reflection factor.

2 MEASUREMENT SETUP

Figure 1 shows the setup for the reflection measurements in the anechoic chamber of the Institute of Technical Acoustics in Aachen. The hemispherical array was set up above a 25 cm layer of polyurethane foam with a flow resistivity of 5.4 kPa. A loudspeaker in a spherical enclosure was placed at a distance of approximately 2 m to the array center.

Figure 1: Array setup for in-situ reflection measurements
The array consists of 24 microphones distributed on two semicircles with different radii of 0.512 m and 0.527 m. A step motor that is attached to the array axis is used to rotate the array and thus obtain a total of 2304 measurement positions on a hemisphere in less than 25 minutes. The complete setup can be disassembled into 12 pieces that fit into most cars and can hence easily be transported to almost any location.

Measurements were performed in the frequency range between 100 Hz and 8 kHz by using exponential sweeps at a sampling rate of 48 kHz as the excitation signal.

3 POST-PROCESSING

One of the problems of in-situ measurements is the separation of incoming and reflected wave, because this information is needed for the reflection models that are used to determine the reflection factor. The temporal separation by time-windowing, which seems like the obvious solution, might result in a severe limitation of the usable frequency range, as shorter time windows lead to a loss of low-frequency information. This is especially important for gracing angles and situations where the microphones are placed close to the reflecting surface.

A technique that seems practically applicable is the subtraction method, used also by Mommertz. In this method, the reflection factor is obtained by subtracting the direct sound, which is obtained in a separate free-field reference measurement, from the actual in-situ measurement. This does not limit the frequency range or setup with respect to angle of incidence and placement of the microphones. Since a straight-forward application of the subtraction method rarely gives good results, an optimization approach following the one described by Robinson and Xiang was used. The reference measurement was adapted until the subtraction result yielded a minimum signal energy. This was carried out for all microphone positions. Figure 2 shows a typical result of the subtraction process.

![Figure 2: Typical result of the optimized subtraction method. The reference measurement was shifted temporally by -0.5ms for the sake of clarity.](image)

It can be seen in Figure 2 that the peak of the direct sound can be removed from the reflection measurement, but a residual signal with mostly high-frequency energy is still left. In another
processing step this remaining energy can be windowed out, further improving the subtraction result for high frequencies.

Using the subtraction technique, the complex reflection factor assuming plane wave reflection can be obtained with the following Equation:

\[
R(k, \vec{r}_{src}, \vec{r}_{rec}) = \frac{R_2}{R_1} \left( \frac{S_{tot}(k, \vec{r}_{src}, \vec{r}_{rec})}{S_{ref}(k, \vec{r}_{src}, \vec{r}_{rec})} - 1 \right) e^{jk(R_2-R_1)},
\]  

where \( k \) is the wave number, \( \vec{r}_{src} \) and \( \vec{r}_{rec} \) are the positions of the source and receiver, respectively and \( R_1 \) and \( R_2 \) are the path lengths of the direct and reflected sound, respectively. The geometrical setup for one microphone is depicted in Figure 3.

\[\text{Figure 3: Schematic of a reflection measurement setup with source S, image source IS and receiver Rec.}\]

Since the microphone array allows for a simultaneous measurement at different positions, the evaluation concerning the reflection factor can be done for varying angles of incidence with a single source position. This fact has been exploited by grouping and evaluating the measurements by angle of incidence, assuming the reflection factor to be the same for the same angle of incidence.

4 RESULTS

Figure 4 shows the result of the complex reflection factor from a single measurement. The curve parameter is the angle of incidence, ranging from 45 to 65 degrees. As expected, the reflection factor is lowest for 45 degrees and increases with the angle of incidence.

In order to check the validity of the results, calculations of the complex reflection factor were also carried out with the Delaney-Bazley model of a porous absorber with the optimizations by Komatsu. For these calculations, the material properties mentioned in Section 2 were used. This was done both for the locally and laterally reacting case. A comparison for two different
angles of incidence is presented in Figures 5 and 6. The data is plotted with the modulus in the upper part of the graph and the phase wrapped to 360 degrees in the lower part of the graph.

**Figure 4**: Reflection coefficient for different angles of incidence

In general, a very good agreement in both the modulus and phase can be found between the measurement and the laterally reacting model calculation above 300 Hz. It can be observed that the model for locally reacting materials does not correspond well with the measurement results.
indicating that the absorber is laterally reacting. For an incident angle of 45 degrees, the phase of the measurement result follows the trend of the model calculation but is disturbed by noisy artifacts. However, since the reflection factor is very low, relating to an absorption coefficient of almost one, the phase is not that important.

For frequencies below 300 Hz larger deviations can be found between measurements and model calculations for higher angles of incidence. This is due to the assumption of plane wave reflection at the absorber. For low frequencies and microphones close to the absorber surface, a better agreement could be found for the spherical reflection model according to Di and Gilbert [8]. This however makes the process of determining the result more complicated, as the reflection factor has to be found by optimization.

![Graph](image.png)

**Figure 6**: Comparison of measured and calculated reflection factor for an incident angle of 45 degrees

After the subtraction process, the reflected data is available on a hemispherical shell, which permits further processing with relation to the scattering properties of the sample. Figure 7 shows the complex pressure distribution at 1 kHz for the total pressure, the optimized reference and the result of the subtraction method. Please note that the axis limits for the subtraction result are reduced by a factor of 4.

This data can be evaluated to obtain the diffusion coefficient according to IS17497-2-9 but since the calculation is based on the far-field result, wave-field extrapolation has to be employed, which can be carried out in the Spherical Harmonics (SH) domain 10. This processing is out of the scope of this contribution and will be the topic of further research.
5 CONCLUSIONS

In this work, an in-situ measurement setup for angle-dependent reflection properties of surfaces was presented. The mechanical setup as well as the post-processing steps were described and first results for measurements above a porous absorber were presented.

Good agreement was found for the complex angle-dependent reflection factor between the measurement results using the subtraction method and calculations according to the improved Komatsu model for laterally reacting materials. For lower frequencies, the measurement results yielded a higher reflection factor than the model calculations, which is due to the assumption of plane wave reflection at the absorber.

The obtained data can be used to gather information about the scattering properties of materials, as the result after the subtraction process provides the reflection directivity needed for
the calculation of the directional diffusion coefficient. This, however, involves further signal processing, which will be investigated in the future.

ACKNOWLEDGMENTS

The authors would like to thank Frank Dierkes and Rob Opdam for their help during the measurements and the evaluation. All measurements, post-processing as well as plotting was done using the ITA-Toolbox for MATLAB (http://ita-toolbox.org).

REFERENCES


