Uncertainties in the ISO method for measuring random-incidence scattering coefficients

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1. Introduction

The interest in the definition and measurement of sound scattering over a surface has raised in the last years. Particularly in room acoustics, it has been demonstrated that the inclusion of sound scattering brings better results, when simulating a hall with ray-tracing programs [1]. Usually, the sound scattering is taken into account through the scattering coefficient, defined by the following relation:

$$s = \frac{\text{scattered energy}}{\text{total reflected energy}} = 1 - \frac{\text{specular energy}}{\text{total reflected energy}}$$

One method of measuring this ratio is based on the principle that the scattered energy lies predomnantly in the tail of an impulse response related to a source and microphone position over a test surface [2]. The idea is to measure the impulse response for different orientations of this surface and average them. A resulting impulse response is obtained which is related only to specular reflections. When comparing the impulse responses obtained for these different orientations of the test surface, one can notice that the initial parts remain always the same, while the tails differ in phase. Averaging a sufficient number of impulse responses, the tail energy tends to be cancelled out (assuming a statistical independence of these impulse responses [2]), resulting in an impulse response which contains only the information related to the specular component of the reflection. This method can be applied either in the free field or in the diffuse field. Up to now the preference of the research community is to apply and investigate it for the diffuse field, with the goal to dertermine random-incidence scattering coefficients as imput data for simulation software. An ISO working group has hold regular meetings to discuss about the standardisation of the latter application and has already a draft document.

In the diffuse field, it is necessary to determine three different types of reverberation time: one from the response of the reverberation chamber without the sample; one from the response with the sample and the last one determined from the impulse response related to the specular components. Actually, a fourth reverberation time is also determined, in order to cancel the scattering that can be caused by the base plate, where the samples are usually placed on. The scattering coefficient is then determined from an equation which is a function of the absorption coefficient, α, and of another quantity defined as the "specular" absorption coefficient, α_{spec} [2].

$$s = \frac{\alpha_{\text{spec}} - \alpha_s}{1 - \alpha_s}$$

This paper addresses briefly parts of investigations that have been conducted in the Institute of Technical Acoustics in Aachen. Some measurements done in the past [3] were performed again and the results compared. One of the samples formerly measured by Mommertz [3] was used for a repeatability test. The scattering coefficient of a scaled sample built with random distributed hemispheres was measured nine times in the same conditions. The results are showed in Figure 1.

Up to now the measurements have been performed in a scaled reverberation room, which is approximately 1/5 compared to the real room at ITA. This is one possible procedure for measuring the scattering coefficient with this method.

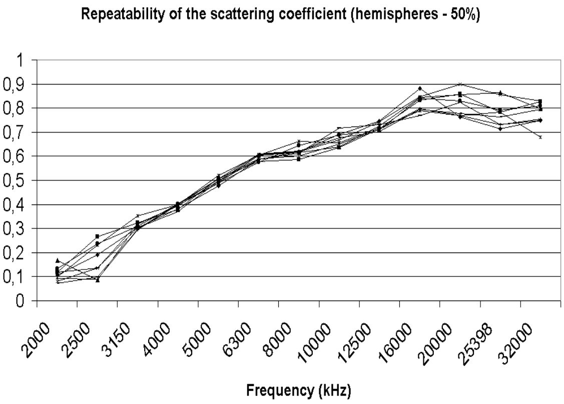

Figure 1: Results for nine scattering coefficient measurements of a sample built with randomly distributed hemispheres over a circular area (ϕ = 0,6 m). The frequency values are not corrected for the scale factor.

The dispersion of values showed in Figure 1 at low frequencies is related to the frequency response of the sound source (a special omni-directional loud-speaker).At higher frequencies it may be strongly related to the air absorption. In the next section some facts about the error estimates for this measurement method will be discussed.

Other samples were also measured, including two scaled diffuser surfaces that exist in the studio at the PTB (Physikalisch-Technische Bundesanstalt), in order to provide data for a third round robin in room acoustics simulation (http://www.ptb.de/deutsch/org/1/14/1401). A sinus shaped surface was also measured and the results are expected to be compared with numerical simulations.

2. Uncertainty

The last ISO/CD draft 17497 brings an equation for estimating the maximal error of a measurement, which was proposed by Mommertz:

$$\Delta s = \frac{\Delta T}{T} \cdot \frac{1}{1 - \alpha_s} \cdot \left[\frac{2A_1}{S}(2 - s) + s + 2\alpha_s (1 - s) \right]$$

where $\Delta T/T$ is the relative error of the reverberation time, A_1 is the equivalent absorption area of the empty room, S is the area of the test sample, s is the scattering coefficient and α_s is the absorption coefficient.

Alternatively, Cox [4] has proposed an equation for the uncertainty of a measurement, which would be more convenient, nowadays, since “maximal error” is not a common sense in the metrology field. The uncertainty of a measurement is supposed to be universal (can be applied to any kind of measurement and to any data involved in the measurement), internally consistent (can be deduced from the components which contribute to this uncertainty) and transferable (the uncertainty determined in one process can be used directly as a term of uncertainty in another process). The equation proposed by Cox, for the method here discussed, is:

$$\delta_s = \left|\frac{\alpha_{spec} - 1}{1 - \alpha_s}\right| \sqrt{\left(\frac{\delta_{\alpha_{spec}}}{\alpha_{spec} - 1}\right)^2 + \left(\frac{\delta_{\alpha_s}}{1 - \alpha_s}\right)^2}$$

where δ_s is the uncertainty (within a confidence limit of 95%) of the scattering coefficient, α_{spec} is the specular absorption coefficient, α_s is the absorption coefficient, $\delta_{\alpha_{spec}}$ is the uncertainty of the specular absorption coefficient and δ_{α_s} is the uncertainty of the absorption coefficient.

The uncertainty of the absorption coefficients can be calculated from:

$$\delta_{\alpha_s} = \frac{55{,}3V}{cS} \sqrt{\left(\frac{\delta_2}{T_2^2}\right)^2 + \left(\frac{\delta_1}{T_1^2}\right)^2}$$

$$\delta_{\alpha_{spec}} = \frac{55{,}3V}{cS} \sqrt{\left(\frac{\delta_4}{T_4^2}\right)^2 + \left(\frac{\delta_3}{T_3^2}\right)^2}$$

where T_1, T_2, T_3 and T_4 are the reverberation times specified in the standard for reverberation chamber measured with the sample, without the sample and obtained from the averaged impulse responses over a complete rotation of the base plate with and without the sample. δ_1, δ_2, δ_3 and δ_4 are their respective uncertainties, which can be calculated from:

$$\delta = 2\sqrt{\sum_{i=1}^{N} \frac{(T_i - \overline{T})^2}{N(N-1)}}$$

where T_i is the reverberation time obtained for one (of the 6 suggested by the standard) combination of source-receiver. $\overline{T}$ is the mean reverberation time.

At first the scattering coefficient of the sample built with randomly distributed hemispheres was measured and the error estimates from the two presented equations compared. These results were also compared with the standard deviation after 9 measurements (Figure 2).

The equation proposed by Cox follows very closely the standard deviation, which is expected and means that this parameter is the one that most contributes for the uncertainty. It should also be expected that the uncertainty values were larger than the standard deviations. Some other factors that can influence the results may be not very well represented in this equation. Although this seems to be the right way to show the errors present in a measurement, following also the tendency from the metrology field (i.e, the use of uncertainty as an error estimate), for now it is still safer to use the equation for the maximum error. Next a larger number of measurements shall be performed, as well as a closer investigation of the method proposed by Cox for calculating the uncertainty.

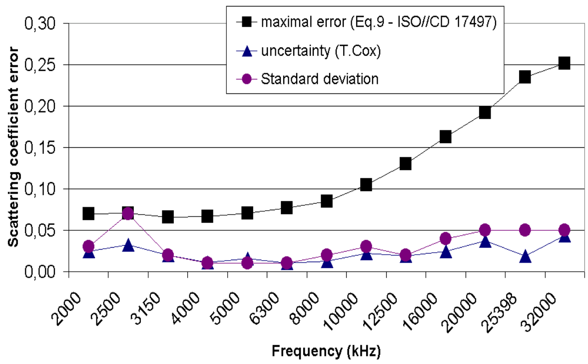

Figure 2: comparison of the two equations for error estimates. The standard deviation after 9 measurements is also showed.

3. Future work

The scattering coefficient is frequently measured in scaled reverberation chambers. The samples usually are built with a scale factor of 1/5 or 1/10, which means that measurements must be performed up to 30 or 40 kHz. When measuring the scattering coefficient it is important not to have an excessive large absorption area, because otherwise the decay curves are too short and it becomes difficult to differentiate the “specular” decay from the “scattered” decay. Usually the samples are constructed with hard, high-reflective materials in order to avoid this problem. Depending on the environmental conditions, however, the air absorption can be too large, specially in the range of very high frequencies. This influence and the possibilities to avoid this effect will be investigated.

Another subject to be treated now is the numerical calculation of the scattering coefficient of a simple surface, which can bring a better view of other parameters that can influence the results, such as the edge effect.

4. Bibliography

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