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Technical Note

Accuracy of the random-incidence scattering coefficient measurement

Louena Shtrepi [a,*], Arianna Astolfi [a], Gianluca D'Antonio [b], Giuseppe Vannelli [a], Giulio Barbato [b], Stefano Mauro [c], Andrea Prato [d]

[a] Politecnico di Torino, Department of Energy, Corso Duca degli Abruzzi, 24, 10129 Torino, Italy
[b] Politecnico di Torino, Department of Management and Production Engineering, Corso Duca degli Abruzzi, 24, 10129 Torino, Italy
[c] Politecnico di Torino, Department of Mechanical and Aerospace Engineering, Corso Duca degli Abruzzi, 24, 10129 Torino, Italy
[d] Istituto Nazionale della Ricerca Metrologica (INRiM), Strada delle Cacce, 91, 10135 Torino, Italy

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ABSTRACT

The experimental results presented in this study aim at providing an useful insight into the accuracy of the measurement procedure of the random-incidence scattering coefficient as defined in ISO 17497-1:2004. A systematic experimental investigation has been conducted in a full-scale reverberation room. The tested diffusers are characterized by different geometrical distributions of hollow wooden cubes with an edge length of 20 cm, and different configurations of the measurement set-up. The accuracy of the measurement results has been evaluated considering the contribution of the different undefined aspects of the ISO method such as the microphones height, the air gap underneath the turntable, the sample shape, and the correction of the effects of the absorption and scattering coefficients of the base plate. The results showed that the accuracy of the measurement increases when a more rigid turntable and a circular sample are used, and when the air gap below the turntable is covered. Furthermore, the distance of the microphones from the sample surface was found to affect significantly the results, thus to influence the accuracy of the measurements.

1. Introduction

Acoustic properties of surfaces are an important prerequisite to estimate and calculate sound propagation in various applications. The correct use of diffusive surfaces plays a key role in the sound field within an enclosed space, since it determines the acoustic quality for the listeners and music players. It is known that the best concert halls take benefit not only from the basic room shape but also from the corrugations of the walls. Acoustic scattering is responsible for energy mixing, energy extraction from geometrical paths, for filling gaps and increasing reflections density in the impulse response [44]. Being aware of this important role [20,2], the determination of a measure, which could evaluate the degree of surface diffusion, results obvious and necessary.

Continuous research [45,12] brought to the introduction of the standards ISO 17497-1:2004 [24], which refers to the measurement of the random-incidence scattering coefficient in diffuse field, and ISO 17947-2:2012 [25], which refers to the measurement of the directional diffusion coefficient in free-field. In this paper, the former measure has been studied since it has been of more practical use in the simulation models such as ODEON, and CATT-Acoustic [9].

The uncertainty contributions in the measuring method have been investigated in the past decade. ISO 17497-1/Amd 1:2014 [26] introduces further recommendations in order to obtain more reliable results, that are the aspects related to the set-up design and others related to the type of signal and rotation method. However, not all the problematic issues, as will be shown in the following paragraphs, have been faced. Thus, this paper deals with the evaluation of the ISO unspecified aspects, including the manner in which their uncertainty contributions affect the measurement accuracy. It is essential to compare these uncertainties with the sensitivity of the objective room acoustic parameters [28,37,42] and with the perceptual effects caused by different degrees of surface diffusivity in real and simulated spaces [10,43,42,41]: these comparisons will help to decide the effort to put into the accuracy of the standard measuring method.

A challenging research field has been the evaluation of the maximum acceptable uncertainty for measured random-incidence scattering coefficients. For instance, Torres et al. [43] raised up the question of how accurately scattering coefficients must be

* Corresponding author.
E-mail addresses: louena.shtrepi@polito.it (L. Shtrepi), arianna.astolfi@polito.it (A. Astolfi), gianluca.dantonio@polito.it (G. D'Antonio), giuseppe.vannelli@polito.it (G. Vannelli), giulio.barbato@polito.it (G. Barbato), stefano.mauro@polito.it (S. Mauro), a.prato@inrim.it (A. Prato).

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determined for application in room acoustical computer simulations, in order to achieve a good correspondence with audible effects of scattering. As suggested in Vorländer et al. [44], the necessary accuracy of scattering coefficients might result not high. Shtrepi et al. [42] showed that the effects of variations of less than 0.4 in scattering coefficients in simulated models could not be perceived by listeners. However, further research is needed to evaluate this aspect.

One of the critical aspects of the numerical data gathered from the ISO measurements is the absence of a broad reliable database of the diffusive surface properties, to be readily used by practitioners. Cox and D'Antonio [8] have achieved a remarkable database with their studies, and further work has been carried out attempting to build open access databases [35]. However, most of the diffusers presently installed in concert halls have not been designed based on any scientific basis or data. The numerical data gathered from the measurements are important for the comparison between different surface treatments. Furthermore, these numerical data improved the diffusers acoustic optimization [21], which allow to tailor the shape of the diffusor and the required diffusion based on the requirements of the specific case [7].

Based on the critical aspects described above, this study aims at improving the specifications of the ISO 17497-1:2004 [24]. Overall, the experimental results presented and discussed in the following provide further data that could help to improve the measurement procedure and achieve more robust results by reducing the uncertainty contributions of several factors. Four different undefined aspects of the ISO method, which concern the set-up design, have been investigated:

- the microphones height,
- the air gap underneath the turntable,
- the sample shape,
- the correction of the effects of the absorption and scattering coefficients of the base plate.

2. ISO 17497-1:2004 measuring method

2.1. Theory

The measurements presented in this work have been performed according to the standard ISO 17497-1; in this standard, the conventional estimation of the absorption coefficients is based on the ISO 354. Besides the measurements indicated in the ISO 354, further measurements are required, which account for different sample orientations, since the initial parts of the impulse response reflections result highly correlated. In contrast, the later parts are not in phase and strongly depend on the specific orientation of the sample: the scattered energy is contained in this part of the impulse response [24].

Based on this concept, four reverberation times T_j are calculated in order to determine two absorption coefficients, i.e. the random incidence absorption coefficient and the random incidence specular absorption coefficient. The four reverberation times are evaluated in four different conditions of the sample: T_1 is the reverberation time when the test sample is not present and the turntable is not rotating, and T_2 is the reverberation time when the test sample is present and the turntable is not rotating; T_3 is the reverberation time when the test sample is not present and the turntable is rotating, and T_4 is the reverberation time when the test sample is present and the turntable is rotating. T_3 and T_4 are estimated after a phase-locked averaging of the impulse responses in each measuring position, which allows to extract the specular energy from the reflected pulses since the late incoherent parts are canceled.

The calculations indicated in the standard (ISO 17497-1) are given in the following equations.The scattering coefficient is calculated indirectly by:

$$s = \frac{\alpha_{spec} - \alpha_s}{1 - \alpha_s} \tag{2.1}$$

where α_{spec} is the specular absorption coefficient and α_s is the random-incidence absorption coefficient, defined, respectively, as:

$$\alpha_s = 55.3\frac{V}{S}\left(\frac{1}{c_2T_2} - \frac{1}{c_1T_1}\right) - \frac{4V}{S}(m_2 - m_1) \tag{2.2}$$

$$\alpha_{spec} = 55.3\frac{V}{S}\left(\frac{1}{c_4T_4} - \frac{1}{c_3T_3}\right) - \frac{4V}{S}(m_4 - m_3) \tag{2.3}$$

where $V\,(\mathrm{m}^3)$ is the volume of the reverberation room and $S\,(\mathrm{m}^2)$ is the test-sample area, c_1 to c_4 (m/s) are the speeds of sound in air during the measurement of T_1 to T_4 (s), m_1 to m_4 (m^{-1}) are the energy attenuation coefficients of air calculated in accordance with the ISO 9613-1 [22] standard, using the temperature and relative humidity values detected when measuring T_1 to T_4.

As reported in the standard, the values for the reverberation times T_1 and T_3 should be equal. This is true under ideal conditions, but in real cases T_3 results shorter due to slight irregularities of the base plate (e.g. structural asymmetries). The scattering coefficient of the base plate could be evaluated as follows:

$$s_{base} = 55.3\frac{V}{S}\left(\frac{1}{c_3T_3} - \frac{1}{c_1T_1}\right) - \frac{4V}{S}(m_3 - m_1) \tag{2.4}$$

The standard uncertainty of s due to random effects, u_s, can be evaluated, following the GUM combining the variances of accuracy of α_s and α_{spec}.

$$u_s = \left|\frac{\alpha_{spec} - 1}{1 - \alpha_s}\right|\sqrt{\left(\frac{\delta_{\alpha_{spec}}}{\alpha_{spec} - 1}\right)^2 + \left(\frac{\delta_{\alpha_s}}{1 - \alpha_s}\right)^2} \tag{2.5}$$

As reported in the standard, the 95% confidence limit in the scattering coefficient is achieved by evaluating two times the standard deviation.

To evaluate u_s, the standard uncertainties u_1 to u_4 of the reverberation times T_1 to T_4 have to be calculated statistically as standard deviation of N measurements of the reverberation times.

Later, u_{α_s} and $u_{\alpha_{spec}}$, which are the standard deviations of α_{spec} and α_s are estimated as follows:

$$u_{\alpha_s} = \frac{55.3V}{cS}\sqrt{\left(\frac{\delta_2}{T_2^2}\right)^2 + \left(\frac{\delta_1}{T_1^2}\right)^2} \tag{2.6}$$

$$u_{\alpha_{spec}} = \frac{55.3V}{cS}\sqrt{\left(\frac{\delta_4}{T_4^2}\right)^2 + \left(\frac{\delta_3}{T_3^2}\right)^2} \tag{2.7}$$

These results are finally placed into Eq. (2.5) and the standard deviation of the scattering coefficient is evaluated.

2.2. Unsolved aspects of ISO measurement procedure

Since 2004, when the ISO 17494-1 defined the measurement procedure for the scattering coefficients in diffuse field, numerous studies have attempted to investigate different factors causing uncertainties. In the following paragraphs an overview of the aspects that have already been investigated and reported in previous studies is given. Some of them have been already used to enhance the measurement procedure, but others still need to be evaluated in order to improve the reliability of the results. The variety of possible problems include aspects concerning the accuracy of the test method, the reverberation room and sample