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Review

Measuring sound scattering coefficients of uneven surfaces in a reverberant workplace – Principle and validation of the method

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ABSTRACT

In workplaces, wall facings are often based on periodic or aperiodic sound scattering surfaces. It is necessary to develop acoustic characterization methods for these kinds of walls to predict the acoustic pressure cartography in the room in order to improve the acoustical treatment. However, this characterization is quite difficult because of the partially reverberant conditions. We developed a measurement system which determines in situ the sound scattering coefficients of relief surfaces. The measurement method, originally operating in free-field conditions, was adapted for indoor use. To overcome problems of parasite echoes coming from reverberation and from noisy sources present on the site, we developed a dedicated emission/reception system. An acoustic antenna with constant directivity over the full frequency range allows spatial filtering of the parasite echoes and an impulsive sound source enables the use of a broad temporal window, resulting in adequate time separation of the different signals received by the antenna. Measurements of the sound scattering coefficient of a corrugated panel were carried out for several incidence angles in free-field and in a noisy workshop and allowed the in situ validation of this system.

Contents

1. Introduction

Sound diffusion mechanisms are involved in explaining the behaviour of scattering facings often present in industrial workplaces. To provide tools for better predicting the noise level at the workplace in order to propose the most appropriate acoustic treatments, measurement methods to determine the sound scattering coefficient of wall facings in industrial rooms are necessary. Many methods have been developed both to study the sound diffusion mechanisms and to quantify the various types of sound scattering coefficient.

The standard definition of the sound scattering coefficient is the ratio of the energy reflected outside the specular zone to the total reflected energy. Many other definitions of this coefficient exist in the scientific literature. Cox used a concept given by Schroeder [1]

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and proposed to quantify the diffusion uniformity by means of the standard deviation of the reflected energy distribution [2]. A similar approach for quantizing the diffusion of periodic surfaces was proposed by Takahashi [3]. Hargreaves et al. [4] proposed a new diffusion uniformity coefficient based on the circular autocorrelation function of the polar reflected energy diagram. The circular autocorrelation function quantifies the similarity between different sections of the polar reflected energy diagram. Angus [5] also defined the spherical harmonics diffusion uniformity coefficient. He uses the fact that every hemispherical distribution of a scattering surface can be decomposed in a set of surface spherical harmonics, by analogy with Fourier analysis.

Further to these definitions, the main methods used to measure the sound scattering coefficient of uneven surfaces depend on the type of incident sound field: a free field or a diffuse field [6,7].

The Adrienne method [8] adapted for outdoor surfaces can separate the direct and reflected pulse by time windowing. The correction for spherical spreading of the sound wave by time multiplication of the impulse responses illustrates the originality of the Adrienne method.

The International Organization for Standardization (ISO) published a standard for measuring random incidence scattering coefficients of diffusers in a reverberation room [9]. The method can be applied on both real-scale sample rooms and on scale-down model rooms. The proposed measuring technique originates from the Vorlander and Mommertz method [10].

The method for measuring the autocorrelation diffusion uniformity coefficient has been standardized by the Audio Engineering Society (AES) [11].

Mommertz [12] proposed to determine the directional scattering coefficient based on polar reflection data, measured or calculated on a semicircle in the case of a single-plane diffuser. Farina developed a new measurement methodology for measuring both the diffusion uniformity coefficient and the scattering coefficient [13,14]. In this approach, numerous impulse responses are measured with a single microphone, repeatedly placed in subsequent positions in a straight line parallel to the diffuser.

In the Vorlander and Mommertz method [10], scattered energy is estimated on the energy loss by coherently averaging impulse responses. It is also possible to estimate this in a free field environment by coherently averaging reflected pulses only.

In this paper, we propose an adaptation of this free field method to determine the sound scattering coefficients of scattering surfaces present in reverberant workplaces. The experimental device used originally for measuring the sound absorption coefficients of flat surfaces in a workshop [15] has been adapted and improved to determine the sound scattering coefficients.

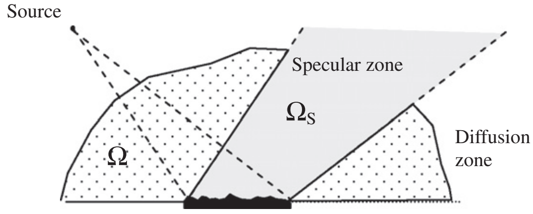

Fig. 1. Specular and diffuse zone illustration.

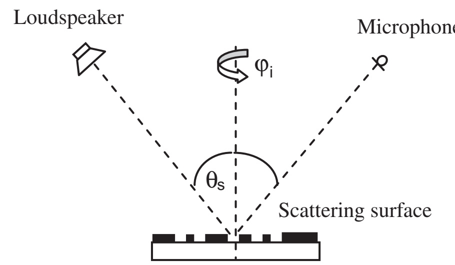

Fig. 2. Method to determine the sound diffusion coefficient in free field [10].

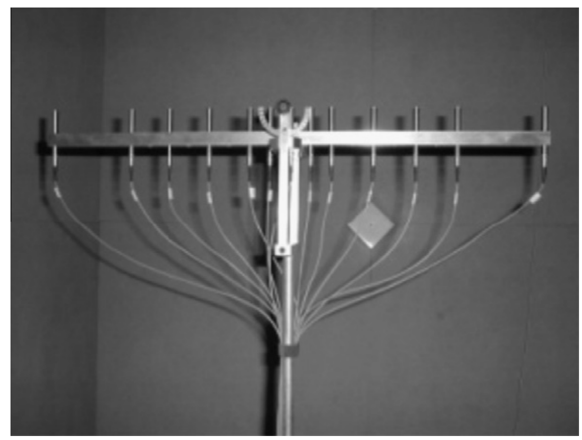

Fig. 3. Acoustic array comprising 13 microphones [17].

2. Measurement of the sound scattering coefficient in free field

The sound scattering coefficient is defined as the ratio of the reflected energy outside the specular zone to the total reflected energy:

$$\delta = 1 - \frac{\int_{\Omega_S} E(\Omega)d\Omega}{\int_{\Omega} E(\Omega)d\Omega} \quad (1)$$

with Ω_S the solid angle corresponding to the specular zone and Ω the solid angle corresponding to all the reflected energy (see Fig. 1).

A loudspeaker and a microphone are positioned in the specular direction under far field conditions. The scattering surface under investigation is fixed to a rotating plate such that measurements can be taken for several orientations (see Fig. 2). For an incidence θ_s of the source and the receiver and for an orientation ϕ_i, the reflected sound pressures $p_{r,\varphi_i}(t, \theta_s)$ can be expressed as the superposition of a diffuse $p_{diff,\varphi_i}(t, \theta_s)$ and a specular $p_{spec}(t, \theta_s)$ part [10]:

$$p_{r,\varphi_i}(t, \theta_s) = p_{spec}(t, \theta_s) + p_{diff,\varphi_i}(t, \theta_s) \quad (2)$$

The specular sound pressure is obtained for a significant number n of averaged acoustic reflected pressures following the angle φ_i ($i = 1 \ldots n$): the specular part remains coherent with respect to φ_i, whereas the averaged diffuse part decreases:

$$p_{spec}(t, \theta_s) \cong \frac{1}{n}\sum_{i=1}^{n} p_{r,\varphi_i}(t, \theta_s) \quad (3)$$

In far field conditions, the total reflected energy averaged in the specular direction θ_s can be expressed by the Fourier transform of the temporal acoustic pressures:

$$E_{tot}(f, \theta_s) = K(f, \theta_s) \cdot \frac{1}{n}\sum_{i=1}^{n} |p_{r,\varphi_i}(f, \theta_s)|^2 \quad (4)$$