

A Numerical Study of a Method for Estimating Sound Absorption Coefficient under a Synthesized Diffuse Acoustic Field

Olivier Robin, Celse Kafui Amedin, Alain Berry, and Nouredine Atalla
Université de Sherbrooke

Olivier Doutres
École de Technologie Supérieure

Franck Sgard
I.R.S.S.T.

ABSTRACT

A method for estimating the sound absorption coefficient of a material under a synthesized Diffuse Acoustic Field was recently proposed, as an alternative to classical sound absorption measurements in reverberant rooms (Robin O., Berry A., Doutres O., Atalla N., 'Measurement of the absorption coefficient of absorbing materials under a synthesized diffuse acoustic field', J. Acoust. Soc. Am., 136 (1) EL13-EL19, 2014). Using sound field reproduction approaches and a synthetic array of acoustic monopoles facing the material, estimation of the sound absorption coefficient under a reproduced Diffuse Acoustic Field in a hemi-anechoic room was shown to be feasible. The method was successfully tested on a few samples of melamine foam of close thicknesses and areas, but the influence of several parameters such as the source height, or the samples dimensions together with the nature of the porous material was not fully investigated.

In this paper, the robustness of the method is numerically studied by examining the influence of the aforementioned parameters on the estimated sound absorption coefficient, with various square samples of homogeneous materials and a synthetic array of fixed dimensions. The principle of the method will be first recalled, and the main results of these numerical experiments will be then reported.

CITATION: Robin, O., Amedin, C., Berry, A., Atalla, N. et al., "A Numerical Study of a Method for Estimating Sound Absorption Coefficient under a Synthesized Diffuse Acoustic Field," *SAE Int. J. Passeng. Cars - Mech. Syst.* 9(3):2016, doi:10.4271/2016-01-1847.

INTRODUCTION

The sound absorption coefficient of absorbing materials under a Diffuse Acoustic Field (DAF) excitation is classically measured using the normalized Reverberant Room method, described in ISO 354 [1] and ASTM C423 [2]. Both standards provide several recommendations in order to increase measurement accuracy, such as verifying that either minimum reverberation time or sufficient sound field homogeneity are ensured (as examples, a maximum equivalent absorption area for ISO354, or a maximum decay rate standard deviation between different receivers for ASTM C423).

In order to meet the standards specifications (i.e. usually improving room's diffusivity), various types of diffusers (hanging, rotating, corner or boundary) are commonly used, but for years their optimal number or type has been a debated subject [3, 4, 5, 6] as well as the indicators used to properly qualify the sound field diffusivity [6,7]. Size, distribution, position and nature effects of tested materials are also of great importance on the results obtained [8, 9, 10], with values of absorption coefficients that can exceed unity (and then rounded to unity or less to perform room acoustic simulations as an example). As a general consequence and despite the standards requirements, a poor

inter-laboratory reproducibility of measured absorption coefficients under DAF excitation was reported in several recent [11,12] and former [13,14] studies, even when testing the same specimen. The reverberant room is used as a laboratory tool to recreate an experimental excitation as close as possible to its mathematical model [15] (i.e. the diffuse acoustic field), but the limitations cited above might then be encountered.

This paper proposes an alternative approach for the estimation in free-field conditions of the absorption coefficient of an absorbing material under a synthesized DAF excitation at the material surface by using a synthetic array of acoustic monopoles facing the material. The method consists of two steps: (1) a database of measured reflection coefficients at normal and oblique incidence angles is first generated with the classical two-microphone approach and a source-image model, using a point source that is moved over a plane parallel to the material surface, and (2) sound field reproduction approaches are then used to calculate a Cross-Spectral Density (CSD) matrix of source amplitudes to accurately reproduce the theoretical statistical properties of a DAF excitation on the material surface.

using the synthetic array. Coupling this calculated matrix to the measured reflection coefficients database, allows estimating in a post processing phase the absorption coefficient under a synthetic DAF.

The method was validated on samples of melamine foam of comparable thicknesses and areas [16]. This paper first recalls the principles of the method. Next, using FEM calculations, the experiment is numerically reproduced using a synthetic array with similar characteristic to the one used in [16], now with square melamine samples for which the sidelength and the thickness are varied in order to investigate size and thickness effects.

THEORY

Sound Absorption Coefficient under a Single Point Source

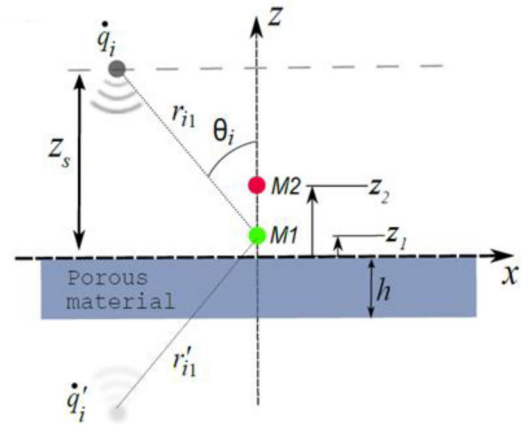
Figure 1(a) describes a simple and well-known situation [17]. A single point source is positioned at a given position i at a height $z=z_s$ above a layer of porous material. Two microphones denoted M_1 and M_2 are placed above the porous material and centered on its surface at heights $z=z_1$ and $z=z_2$, respectively. Under the assumption of an ideal point source (defined by its volume acceleration $q_i(\omega)$) and a semi-infinite porous layer, the acoustic field at any of the microphone positions is a superposition of two spherical acoustic waves, generated by the source $q_i(\omega)$ and the corresponding image source $q'_i(\omega)$ positioned at a distance r_i and a distance r'_{i1} from the receiver, respectively. For a small separation of the two microphones so that the angle θ_i is almost identical for both microphones, the measured acoustic pressure $p_{ij}(\theta_i, \omega)$ for a given position i of the point source at microphone M_j ($j=1,2$) can be written [17]

$$p_{ij}(\theta_i, \omega) = \rho_0 q_i(\omega) \frac{e^{-jk_0 r_{ij}}}{r_{ij}} + R(\theta_i, \omega) \rho_0 q'_i(\omega) \frac{e^{-jk_0 r'_{ij}}}{r'_{ij}}, \quad (1)$$

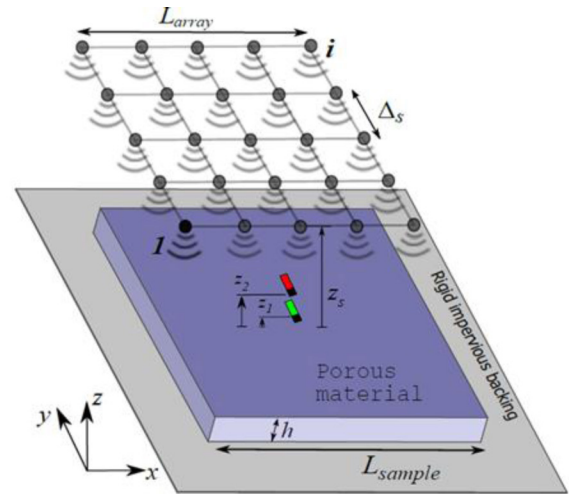
with ρ_0 the air mass density, ω the angular frequency, k_0 the acoustic wavenumber ($k_0=\omega/c_0$) with c_0 the speed of sound, r_{ij} the distance between the source at the i -th position and the microphone M_j , r'_{ij} the distance between the image source and the microphone M_j and $R(\theta_i, \omega)$ is the reflection coefficient of the material surface corresponding to the i -th position of the point source. The measurement of $H(\theta_i, \omega) = p_{i2}(\theta_i, \omega) / p_{i1}(\theta_i, \omega)$ allows for calculating the reflection coefficient at a given incidence angle using the classical relation [17]

$$R(\theta_i, \omega) = \frac{\frac{e^{-jk_0 r_{i2}}}{r_{i2}} - H(\theta_i, \omega) \frac{e^{-jk_0 r_{i1}}}{r_{i1}}}{H(\theta_i, \omega) \frac{e^{-jk_0 r'_{i1}}}{r'_{i1}} - \frac{e^{-jk_0 r'_{i2}}}{r'_{i2}}}. \quad (2)$$

The corresponding absorption coefficient can be deduced using the relation $\alpha(\theta_i, \omega) = 1 - |R(\theta_i, \omega)|^2$.



a.



b.

Figure 1. (a) Description of the problem and coordinate system for a spherical wave model using a single point source - (b) Description of the problem using an i-source array, with uniformly distributed sources positioned with the same source separation Δs (adapted from Robin et al. [16]).

Sound Reflection Coefficient under a Synthesized Pressure Field

Figure 1(b) illustrates the proposed approach. A square sample of porous material of sidelength L and thickness h is placed on a rigid impervious backing. The two microphones $M1$ and $M2$ and the array center point source are centered on the material's surface. Using the two-microphones method described in the previous section, the reflection coefficient can be measured under various incidence angles corresponding to successive source positions i of point sources, thus creating a virtual array of monopoles in front of the material surface. The Green's functions corresponding to the propagation from the real (respectively image) point source to the microphone M_j will now be denoted $g_{ij}(\omega) = e^{jk_0 r_{ij}}/r_{ij}$ (respectively $g'_{ij}(\omega) = e^{jk_0 r'_{ij}}/r'_{ij}$).

It can be shown (calculation details can be found in Robin [16]) that with a database of measured reflection coefficients $R(\theta_i, \omega)$ at several i incidence angles and a calculated CSD matrix of source volume accelerations S_{qq} (that when applied to all the virtual sources would