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Assessment of the airborne sound insulation from mobility vibration measurements; a hybrid experimental numerical approach

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ABSTRACT

A new measurement procedure is proposed to assess the airborne sound insulation of a partition under diffuse sound field excitation using mobility measurements combined with a numerical procedure. The advantage of this hybrid approach is that the diffuse acoustic field does not need to be physically created, thus avoiding problems related to the generation of such fields at low frequencies. Furthermore, the acoustic properties of both the source and receiving rooms will not affect the determination of the sound reduction index R. The proposed method is especially suited for frequencies below the so called Schroeder frequency of the room, and is complementary to the standardized measurement approaches as described in ISO 10140-2:2010. The measurement part of the proposed procedure involves the measurement of the mobility by forcing the partition along a grid of excitation points (e.g. by means of a shaker) and measuring its response along a grid of response points (e.g. by means of a scanning laser Doppler vibrometer). Using the resulting matrix of mobility transfer functions, the vibrational response of the partition excited by a diffuse acoustic field is numerically calculated, from which the radiated sound power is computed using the Rayleigh integral. Thus the reliance on source and receiving rooms used in standard sound insulation testing is removed entirely. The proposed method provides an estimate that only depends on the properties of the partition. The method was tested in an acoustic laboratory on a single layer glass plate of $1.35 \times 1.54\ \mathrm{m}^2$, as well as on a funicular shell structure with dimensions of $3 \times 3\ \mathrm{m}^2$. Comparisons with analytical models and standardized ISO10140-2:2010 measurements confirm the validity of the results.

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1. Introduction

In contemporary architectural design, the increased implementation of lightweight constructions with lower sound insulation at low frequencies, combined with the more frequent use of hi-fi systems and home cinema with relatively high power at low frequencies, has increased people's awareness of low frequency noise in their living environment. Indeed, adverse effects on the human well-being have been reported [1]. In automotive and aviation industries similar issues arise due to the use of lightweight structures.

The increase in interest in low frequency sound insulation has stimulated research activities on two fronts. On one hand, questions on the importance of the low frequency part of the spectrum in people's subjective perception of sound insulation have been tackled by listening tests [2], aimed at designing single number quantities that include the frequency range below 100Hz [3,4]. In current standards the assessment of sound insulation in frequency range down to 50 Hz is still optional [5]. On the other hand, researchers have been giving extra attention [6–8] to the problem of high uncertainties on values of the sound reduction index R obtained at low frequencies by airborne sound insulation measurements according to ISO10140-2:2010 [9].

Indeed, sound insulation measurements in the lower frequency range are difficult to perform. Due to the reduced density of room acoustic eigenmodes, microphone based measurements are strongly affected by non-uniformity of the sound pressure field at low frequencies [10–12], resulting in poor reproducibility between laboratories [3,13]. Bravo et al. [14] succeeded to reduce the effect of room acoustic issues in the source room by using a number of loudspeakers close to the panel, which were driven independently in order to create a diffuse incident field down to the lowest frequencies of interest. An optimal set of loudspeaker excitation signals was generated by making use of measured transfer functions between locations close to the speakers and locations close to a grid of points along the building element. Bravo et al. measured the radiated power into the receiving room by means of a dense array of acoustic intensity measurements. However, it turned out that this approach was affected by room acoustic effects in the receiving room [14]. The latter effects were avoided in an approach proposed by Roozen et al. [15] in which the vibrational pattern of the partition was measured by means of laser Doppler scanning vibrometry. The radiated sound power was then calculated by means of a Rayleigh integral [16]. Although combining the excitation scheme of Bravo et al. and the detection scheme of Roozen et al., would be a logical next step, the experimental effort to combine the two approaches was found to be very large [17].

Here, a hybrid experimental-numerical approach is proposed in which the sound transmission through the partition is determined without physically creating a diffuse field in the source room. The partition is mechanically excited along a grid of excitation points (at the 'source' side) and the response is measured along a grid of response points (at the 'receiving' side). The diffuse excitation field is described by well-known relationships for the spatial correlation of a diffuse acoustic field to numerically construct a cross spectral matrix for the excitation on the source side. Using the cross spectral matrix, the response of the structure is computed on the basis of the experimentally determined mobility transfer functions. The incident and radiated power, needed to determine the sound reduction index R are then determined from, respectively, the (virtual) exciting sound pressure levels, and the structural response to the diffuse field excitation, computed by means of the Rayleigh integral as in Roozen et al. [15].

The computation and measurement of mobility transfer functions is a classical subject in the field of noise and vibration [18,19]. Also the spatial correlation functions of a diffuse acoustic field (see Section 2.1.1) are well-known. However, the use of these spatial correlation functions to numerically compute the vibrational response of the partition from a measured matrix of structural mobility transfer functions, is new, to the knowledge of the authors. In combination with the use of the Rayleigh integral the influence of the room acoustic effects of the source and receiving rooms - used in standard insulation testing - is completely removed from the sound insulation measurement.

In literature, point mobility measurements were also used by Piana [20] to obtain an estimate of the sound reduction index of a single leaf panel by making use of an analytical model. Unlike in that work, in which the finite dimensions of the panel were not taken into account, our approach makes use of measured vibration data along the whole sample, avoiding the use of geometrical approximations, even for complex geometries.

Marchetto et al. [21] proposed a combination of mobility transfer functions measurements and acoustic transfer function measurements to obtain the sound reduction index of a building element. The measurement of the acoustic transfer functions requires the use of monopole and dipole sources. Although this method eliminates the effect of the source room acoustics, due to the airborne detection of the radiated sound, the results are still affected by room acoustic effects of the receiving room, especially for low frequencies.

Chazot and Guyader [22] numerically predict the sound reduction index of finite double panels, taking into account source room dimensions, absorption, excitation position, and panel location. The difference with our approach is that we determine the sound reduction index of the partition for diffuse field excitation from *measured* mobilities. Furthermore in the approach presented in this paper, the room acoustic effects of the source and receiving rooms are eliminated, thus yielding an estimate of the sound reduction index that only depends on the properties of the partition itself.

The remainder of the paper is organized as follows. Section 2 deals with the theory to numerically construct the cross spectrum of a diffuse sound field, and to use this to compute the spectrum of the structural vibrations of the partition from a matrix of measured mobilities. This section also explains the subsequent steps to compute the radiated sound power from the computed vibration spectrum, and to determine the sound reduction index. Validating experiments that were performed on a single layer glass plate are discussed in section 3. In section 4 measurements on a funicular shell ceiling system are discussed. The experimental results are compared both with results obtained with a numerical finite element model of the building element