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Determining radiated sound power of building structures by means of laser Doppler vibrometry

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ABSTRACT

This paper introduces a methodology that makes use of laser Doppler vibrometry to assess the acoustic insulation performance of a building element. The sound power radiated by the surface of the element is numerically determined from the vibrational pattern, offering an alternative for classical microphone measurements. Compared to the latter the proposed analysis is not sensitive to room acoustical effects. This allows the proposed methodology to be used at low frequencies, where the standardized microphone based approach suffers from a high uncertainty due to a low acoustic modal density.

Standardized measurements as well as laser Doppler vibrometry measurements and computations have been performed on two test panels, a light-weight wall and a gypsum block wall and are compared and discussed in this paper.

The proposed methodology offers an adequate solution for the assessment of the acoustic insulation of building elements at low frequencies. This is crucial in the framework of recent proposals of acoustic standards for measurement approaches and single number sound insulation performance ratings to take into account frequencies down to 50 Hz.

1. Introduction

The sound insulation quality of building elements is typically specified in terms of a frequency dependent sound reduction index $R(f)$ (dB), given in one-third octave bands in the frequency range of 100–3150 Hz. Different single-number quantities based on respective spectrum adaptation terms have been proposed and used for later communication between engineers, policy makers or other stakeholders. Among these are the ISO 717-1:2013 standard [1]. In Europe, often used descriptors are the weighted sound reduction index R_W (dB), the weighted apparent sound reduction index R'_W (dB), and the weighted standardized level difference $D_{nT,w}$ (dB).

A standardized manner to determine the sound reduction index R of a building element in laboratory conditions is described in ISO 10140:2010 [2]. It is known that the acoustic characteristics of the transmission suite can influence the measured sound reduction index [3–6], especially at low frequencies. Driven by an increasing awareness of the importance of low frequencies in people's perception of the isolation performance of building elements, there is a growing need to

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extend the reliable frequency range of sound insulation measurements towards frequencies below 100 Hz. However, at low frequencies, the sound reduction index is highly dependent on parameters such as the size of the testing chambers, the sound source location and the rooms surface absorption conditions [7], making it difficult to generalize test results to real-world situations. This uncertainty at low frequencies has two causes. One cause is that at low frequencies the spatial dependence of the pressure fields in the receiving room (and sending room) is high due to the finiteness of the room [8–10]. In practice, this causes inaccuracies in the measurement of the radiated sound power by means of microphones at a limited number of spatial positions. Another cause is the modal behavior of the receiving room, which influences the active sound power radiated by the vibrating wall (see for instance [3] and Section 4.2.2 of this paper).

To assist the experimentalist with this problem, ISO 10140-4 includes an informative annex A, in which some guidance is given for improving the measurements in the low frequency range. The recommendations concern the spatial sampling of the sound field, the number of sources, the averaging time, and the minimum separation distances between the loudspeakers, the microphones and the surfaces of the test rooms. In a paper by Hopkins and Turner [11] a modified measurement protocol was proposed in addition to the ISO standard, to reduce the measurement uncertainty for low frequencies. The fundamental problem, being the lack of diffusion of the sound fields in the low frequency range, however, remains.

In order to overcome the room acoustical complications that occur when measuring the sound field produced by a transmitting building element in a receiving room, a logical step is to try to measure the sound producing vibrations of the building element directly. In this paper the effectiveness of a laser Doppler vibrometer (LDV) measurement technique was investigated for this purpose.

Laser Doppler vibrometer (LDV) techniques have been used for a large variety of applications, but mainly in structural dynamics [12], or in electro-acoustics [13]. In relation to building acoustics, LDV has been successfully applied for the determination of the wall vibration in laboratory conditions. Sound transmission of windows has been investigated by Kaiser et al. [14] who have performed measurements and simulations of double glazing systems up to 1000 Hz. A laser Doppler vibrometer was used to validate their numerical model. They showed that both the structural mode shapes and the resonance frequencies were in good accordance. Recently Churchill and Hopkins [15] used a scanning laser Doppler vibrometer for the measurement of the dynamic properties of a cross laminated timber plate, with emphasis on the analysis of structural eigenmodes.

In this paper the radiated sound power of a building element in a transmission suite is numerically determined from the vibrational response of the building element. The vibrational response is determined by means of advanced scanning LDV measurements. This approach is compared to the classical microphone based measurement methodology according to ISO 3741:2010. Special attention is given to the correspondence and differences at low frequencies, where the microphone approach is known to be strongly sensitive to effects caused by the lack of a diffuse sound field.

In Section 2 different methodologies are outlined. Section 2.1 briefly deals with the standardized methodology to determine the transmitted sound power by means of microphone measurements according to ISO 10140. Section 2.2 gives an outline of the newly proposed methodology to determine the transmitted sound power from LDV measurement data. The discussion on the newly proposed methodology is subdivided into two parts, the first part (Section 2.2.1) being the measurement of the vibrational response of the test wall by means of a scanning laser Doppler vibrometer. Special attention is given to the desirability of measuring points on the wall sequentially in time. This enables a large number of points to be measured. The second part (Section 2.2.2) is devoted to the calculation of the radiated sound power from vibration measurements.

The proposed methodology is applied to two test walls. In Section 3 the test set-up is described. In Section 4 the measurement results are presented, in which first a discussion on the vibrational patterns of the test walls is presented (Section 4.1), and secondly the determination of the radiated sound power is discussed (Section 4.2). Conclusions are given in Section 5.

2. Theory

In this section an outline of the laser Doppler and microphone methodologies is given.

2.1. Determination of transmitted sound power according to ISO 10140

The most frequently used methodology to determine the sound reduction index of a building element mounted between the sending and receiving room of a measurement facility is prescribed in ISO 10140:2010. The methodology is based on microphone measurement data of the average sound pressure level in the sending (L_{p1}) and receiving room (L_{p2}), see Fig. 1. In order to account for the contribution of the reverberant sound to the total measured sound field in the receiving room, a correction term $10\log(S/A)$ is added to the $(L_{p1}-L_{p2})$ level difference, to obtain the sound reduction index R:

$$R = L_{p1} - L_{p2} + 10\log\left(\frac{S}{A}\right) \quad (1)$$

where S is the area of the free test opening in which the element is mounted, and A is the equivalent sound absorption in the receiving room (which can be determined from reverberation time measurements).