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Influence of panel fastening on the acoustic performance of light-weight building elements: Study by sound transmission and laser scanning vibrometry

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ABSTRACT

Structural details and workmanship can cause considerable differences in sound insulation properties of timber frame partitions. In this study, the influence of panel fastening is investigated experimentally by means of standardized sound reduction index measurements, supported by detailed scanning laser Doppler vibrometry. In particular the effect of the number of screws used to fasten the panels to the studs, and the tightness of the screws, is studied using seven different configurations of lightweight timber frame building elements. In the frequency range from 300 to 4000 Hz, differences in the weighted sound reduction index R_W as large as 10 dB were measured, suggesting that the method of fastening can have a large impact on the acoustic performance of building elements. Using the measured vibrational responses of the element, its acoustic radiation efficiency was computed numerically by means of a Rayleigh integral. The increased radiation efficiency partly explains the reduced sound reduction index. Loosening the screws, or reducing the number of screws, lowers the radiation efficiency, and significantly increases the sound reduction index of the partition.

1. Introduction

Lightweight construction building elements, e.g. timber frame partitions, show a large variation of sound insulation properties [1,2] although many of them differ only in a few subtle details. The rather complex interactions around the element details require careful investigation, in particular to respond to the need for reliable prediction models. Several studies (e.g. [3–7]) have shown that workmanship has significant influence on the sound insulation characteristics of this kind of building elements. The used method to fasten (e.g. with screws or staples) the panel (e.g. gypsum boards, gypsum fiber boards or chipboards) to the studs has a considerable influence on the sound insulation characteristics, and thus on the single values that are commonly used for rating the acoustic insulation performance. Since element-related variations of the single numbers often exceed the range of typical sound insulation categories of proposed sound insulation classification schemes (i.e. [8,9]), these uncertainties need to be quantified and indicated, together with the reported values.

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In the literature, numerous studies have been carried out on the sound transmission through double leaf wall systems. In Ref. [10] it was found that structural connections greatly reduce the sound transmission loss, especially for wooden studs (and, to a lesser extent, for lightweight steel studs). The effect of nail spacing in wood-studded plasterboard double panels was also studied by Craik and Smith [11]. Decreasing the nail spacing produces systematically higher values of the sound reduction index, which was explained by the fact that when the nails are acoustically far apart (i.e. larger than half the bending wavelength of waves on the panel) then they can be considered as individual point connections whereas when they are close together the joint should be considered as a line connection. This was also verified in a study by Schoenwald [12] who used scanning laser vibrometry for that purpose. Similarly, Mayr and Gibbs [13] conclude that the point mobility of panels that are point-connected to frames, strongly depend upon the distance between the drive point considered and the nearest fixing points. When this distance is less than 0.2 times the bending wavelength of waves on the panel, the point mobility is determined by the framing elements. When this distance is larger, the frame fixings have minimal effect and the panels can be considered an infinite, unstiffened plate. Also Ref. [14] reports that the stiffness (or type) of the stud, and the spacing of the screws between the panel and the stud are crucial parameters. Finally, in Ref. [15] the effect of screw spacing was investigated for steel frame studs, considering two screw spacings of 300 and 600 mm.

In this paper, the workmanship related sound insulation uncertainties of a basic timber frame partition were investigated in detail. In particular, the effect of the number of screws, and how firmly the panel is fastened to the studs, on the sound reduction index *R* of the lightweight building element was studied experimentally. Seven different configurations of a lightweight timber frame building element were considered, varying the screw spacings from 1230 mm down to 307.5 mm, the screws being firmly fixed and subsequently loosened half a turn. Standardized sound insulation measurements according to ISO 10140 [16] were carried out and supported by scanning laser Doppler vibrometer (LDV) measurements.

The physical mechanisms involved were investigated with the aim to enhance the understanding of the interactions in the zones around the screws. Advanced data processing of the LDV measurement results was carried out, obtaining operational deflection shapes of the building element, the radiated sound power, and radiation efficiencies of the building element. With these findings the influence of the fastening details on the sound transmission index are explained from a physical point of view. This insight provides input to the development of prediction model details regarding the influence of crucial building element details on the sound insulation properties and their range of variation.

The paper is structured as follows. Section 2 describes the methods used, i.e. the measurement methods according to the standard, and the LDV measurement approach employed in this work. This section also discusses the way the LDV measurement data are processed. Section 3 elaborates on the measurement test set-ups and the lightweight timber framed building element under test. Section 4 presents the measurement results obtained by the measurements according to the standard (Section 4.1) and the results obtained by the LDV measurements (Section 4.2). In Section 5 conclusions are drawn.

2. Methods

2.1. Measurement and analysis method according to ISO standards

Sound transmission measurements were performed on a timber frame partition according to the standard ISO 10140 [16]. The sound pressure level of a diffuse sound field in the source room and in the receiving room was measured in one-third octave bands from 50 Hz up to 5000 Hz. A spatial average of the sound pressure levels was determined in source and receiving room by calculating the average across 2 microphone boom positions in each room, with an averaging period of 32 s at each boom position. During the averaging period of 32 s, the boom completed one turn. The reverberation time of the receiving room (necessary for the calculation of the room compensation term and in calculation of the sound reduction index *R*) was measured as prescribed by the standard. Measurements were performed on 2 rotating microphone boom positions in each room.

Based on the one-third octave band sound insulation values, the weighted sound reduction index R_W, as a single number quantity, is determined according to ISO 717-1 [17].

2.2. Vibrometry based operational deflection shape analysis, sound power analysis and radiation efficiency analysis

In the performed LDV measurements, the vibrational response of a timber frame partition due to a structure borne excitation, using a shaker connected to the panel, is measured as a function of position along the panel surface. A structure borne point excitation was employed in this measurement because, in principle, there is a relationship between airborne sound insulation and impact sound pressure level provided by partitions (see for instance [18–20]). This principle is valid both above and below the coincidence frequency, as was pointed out by Vér [19] and Beranek [21]. A more in-depth discussion on the measurement results as obtained by structure borne excitation and airborne excitation can be found in Section 4.2.5.

In addition, compared to excitation by an airborne incident acoustic wave, excitation by means of a shaker gives a better measurement quality for a number of reasons. Firstly because of the use of an impedance head between the shaker and the test wall, the acceleration at the point of excitation and the exciting force are measured, which both can be used as well defined reference signals. Secondly, the structure is excited in a deterministic manner at a single point, as opposed to a randomly distributed acoustic excitation. This approach allows the study of the vibration pattern of the panel surface and