New Laboratory for Measurement of Structure-Borne Sound Power of Sanitary Installations

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Introduction

In previous years, attempts have been made to characterize structure-borne sound sources. The complexity of the interaction of the source and receiving structure makes analysis and prediction difficult and time consuming. To calculate the power introduced into a receiving structure one has to consider the mobility both of the source and the receiver as well as the free velocity or blocked force of the source. There are up to 6 degrees of freedom of motion, at each contact, and none can be neglected a priori. The problem is further complicated since the source nearly always has more than one connection to the receiver. Not only point, but also transfer terms between the different connections and the different degrees of freedom have to be taken into account [1]. Therefore, although the mobility approach is precise and also offers insights into the transmission process, it requires large amounts of data and processing time. The approach is too complicated and the required effort is too great for a practical laboratory method. Within the framework of the standard EN 12354, a new part (Part 5) is proposed, giving a prediction model for the calculation of sound pressure levels caused by structure-borne sound sources in buildings. The standard requires an accurate and practical laboratory method to generate input data appropriate for the prediction model. This is readily achievable for airborne sound sources, which are characterised by the airborne sound power. In a similar way, it is proposed that structure-borne sources can be characterised on a power basis in order to provide input data for the prediction model. Therefore a laboratory set-up was developed, based on the reception plate method, on which the power of sources, which act as force sources, can be determined quite easily. The force source approach restricts the application of the data to heavyweight building constructions and is not applicable to lightweight building structures at present.

3-dimensional reception plate system

The 3-dimensional plate system consists of three structurally isolated mutually perpendicular concrete plates, which simulate a corner of a room. This allows consideration of sources which are connected to more than one building element, for example, corner baths. The set-up is shown in Figure 1. The thickness of the plates was 100 mm in order to ensure that the source mobilities were greater than the receiver mobilities and thus a force source assumption is allowed. The plate sizes, which vary between 1.95 m x 2.74 m and 2.21 m x 3.1 m, were chosen for reasons of practicality. The plates are decoupled from each other and connected to the supporting structure via resilient material with a high internal loss factor. The vertical plates are given a static load by 6 pressure plates, which are disconnected from the plates by resilient layers. The construction for the vertical plates provides a static load for the resilient layer between the plate and the supporting structure, equivalent to the weight load of the horizontal plate. The construction ensures a relatively high and similar loss factor for all three plates.

Figure 1: Photograph of the 3-D Laboratory.

Loss factors of the plates

The loss factors of the three plates were obtained from the mean structural reverberation time, using a MLS signal, to enable the measurement of short reverberation times. The loss factors of all plates are shown in figure 2, compared to the predicted loss factors in buildings according to [2] and [3]. The loss factors are high, at the low frequencies, in order to increase the modal overlap without losing finite plate characteristics. In general, the values correspond to those found in buildings [2].

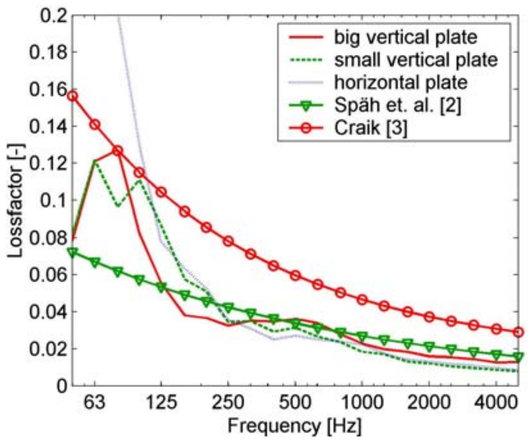

Figure 2: Measured loss factors of the 3-D Laboratory plates.

Vibration level difference between plates

To test the independence of the three plates the velocity level difference between the plates was measured when the floor plate was excited by a standard tapping machine or a wall plate was excited by a hammer. A minimum level difference of 20 dB was achieved, displayed in figure 3.

Structure-borne sound power

The three plates are regarded as independent reception plates. The power into each plate is obtained from the spatial- and time averaged velocity v of the plate according to [4]:

$$P = \tilde{\tilde{v}}^2 \eta \omega m \,, \qquad (1)$$

for loss factor η, angular frequency ω and plate mass m. The reception plate power then is corrected to compensate for the modal behaviour of the plate, to give the power into an infinite plate of the same thickness and material. This can be called the characteristic plate power. The correction is in the form of the spatial and spectral average of the real part of the point mobilities at the contacts. The characteristic plate power can be used to compare results from different laboratories and also can be transformed into an installed power for real floors and walls. This then is the input data for prediction models like EN 12354 Part 5. A comparison of the structure-borne power of a whirlpool bath, measured by the reception plate method and the mobility/free velocity prediction, is given in [5].

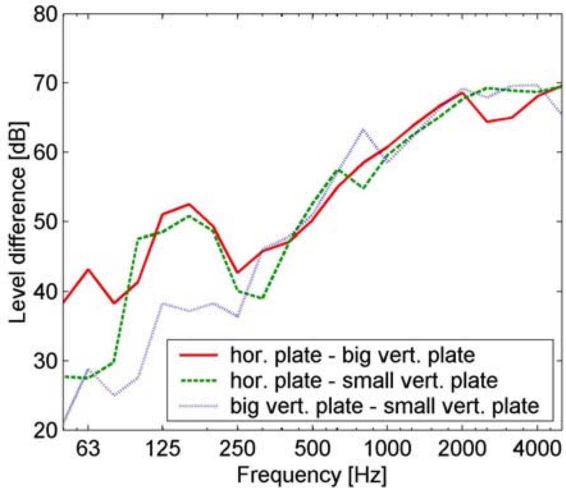

Figure 3: Level difference between the three plates.

Prediction of sound pressure level in buildings

To evaluate the applicability of the data from the 3-plate system a comparison of the predicted and measured normalized sound pressure levels was conducted for a diagonal transmission path. A vertical sectional view of the transmission suite is shown in figure 4. The source was a whirlpool bath, described in detail in [5]. The reception plate power was corrected to give the characteristic plate power, as described above. This then was transformed into the predicted installed power by means of the ratio of the characteristic mobilities of the reception plate and the real floor. This provides the input data for EN 12354-5, which was employed to calculate the sound transmission of the two paths across the cross-junction, shown in figure 4. For the prediction, measured data of the K_{ij} and the loss factors of the building elements was applied. These input data also influences the accuracy of the prediction model and might need adjustment for a most accurate prediction model.

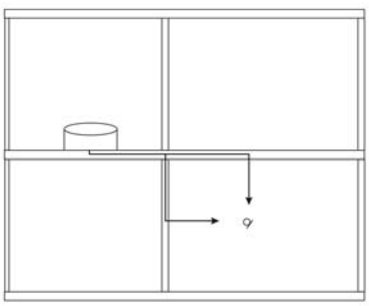

Figure 4: Sectional view of the diagonal transmission path in the transmission suite.

The sum of both paths gives the normalised sound pressure level in the room in the middle lower part of the transmission suite. The same source was then placed on the floor plate in the left upper part of the transmission suite and the normalised sound pressure level was measured in the same room in the middle lower part of the transmission suite. The results are shown in figure 5.

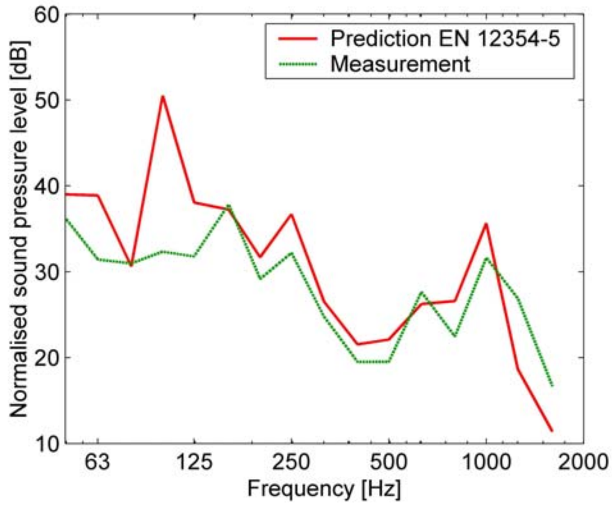

Figure 5: Comparison of the measured and predicted sound pressure levels for a diagonal transmission path in a vertical transmission suite.

Between 160 Hz and 1 kHz the prediction overestimates sound pressure level by 2-3 dB but both curves have a similar signature in this frequency range. At low frequencies the predicted levels are distinctively higher. This may be the result of incorrect compensation for the modal characteristics of the floor, in the transmission suite, which had been expressed simply in terms of the characteristic (infinite plate) mobility. A refinement is being investigated where an upper limit to the floor mobility is calculated in order to predict the likely variation in values at low frequencies.

Conclusions

A new laboratory for the characterisation of structure-borne sound sources is presented. It is relatively small and the sources can be situated and operated as in real situations. The measurements are easy to handle, giving up to three spectra of structure-borne sound power for a source exciting three building elements. For sources with force source characteristics at the laboratory the measured structure-borne sound power can be transformed to other force source situations and used as input data for prediction models. It has been demonstrated that a prediction of the resultant sound pressure level in buildings is possible, using the reception plate power as input data.

[1] M. Späh et al.: Characterisation of mechanical installations in buildings as structure-borne sound sources. ICSV 10 Congress 2003, Stockholm.
[2] M. Späh et al.: Verifizierung des Rechenverfahrens für die Luftschalldämmung nach EN 12354-1 für den Massivbau; Teil 1: Eingangsgrößen, DAGA 2001, Hamburg.
[3] R.J.M. Craik: Sound transmission through buildings using statistical energy analysis. Gower Publishing Limited UK, 1996.
[4] L. Cremer, M. Heckl: Körperschall. Springer Verlag Berlin, 1996.
[5] M. Späh et al: Measurement of Structure-Borne Sound Power of Mechanical Installations, DAGA 2004, Straßburg.

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