Measurement of structure-borne sound power of mechanical installations

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Introduction

The Standard EN 12354 describes in Part 5 a prediction model for the calculation of sound levels caused by structure-borne sound sources in buildings. The main obstacle to the use of this prediction model is the fact that the input data for structure-borne sound sources such as mechanical installations are not yet available. Airborne sound sources are commonly characterised by the air-borne sound power. The characterisation of structure-borne sound sources is much more difficult. The calculation of the power is possible by considering the mobility of the source and the receiver as well as the free velocity or blocked force of the source. This approach needs a great amount of data. Up to 6 degrees of freedom need to be considered. Additional complexity results if the source, as usual, has more than one connection to the receiver. Not only point, but also transfer terms between the different connections and between the different degrees of freedom have to be taken into account [1]. Therefore this approach is much too complicated and the required effort is too great for a practical laboratory method. To reduce the amount of necessary data a reception plate method is proposed, on which the power of the sources can be determined much more easily. At present, the approach is confined to machines with mobilities higher than the building mobilities (the force source assumption) and therefore applies to massive building constructions rather than lightweight building structures.

Evaluation of the structure-borne sound power

The structure-borne sound power P can be deduced on a reception plate [2] from :

$$P = \tilde{\tilde{v}}^2 \eta \omega m$$

with the spatial- and time averaged velocity v of the reception plate in the far field, the loss factor η, the angular frequency ω and the mass m of the plate. An important aim of the present work is to develop transformation algorithms in order to predict the power into real building elements from the reception plate data. The data can then be used as input data for prediction models like EN 12354 Part 5.

Description of the source

The source considered is a whirlpool bath, where all the necessary equipment is attached to its frame. The bath has 8 feet and 2 pumps, one for air and the other for water. In this paper the regarded excitation of the whirlpool was the water pump operating at maximum power. It pumps water through venturi-valves at the side of the whirlpool into the tub. No air was added to the water jets. The whirlpool and reception plate are shown in figure 1.

The reception plate

The reception plate is of concrete with a length of 2.8 m, a width of 2.0 m and a thickness of 0.1 m. It is supported at the corners by resilient material with a high internal loss factor. The plate thickness allows force source assumption between source and receiver. Practical restrictions limited the area of the reception plate.

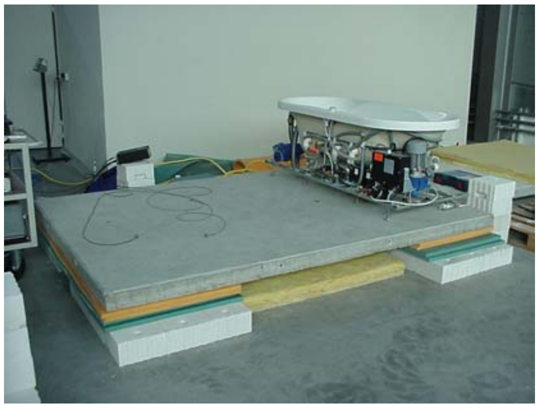

Figure 1: The reception plate and the whirlpool bath.

The resultant modal density is therefore low at low frequencies. To improve the modal characteristics of the plate the loss factor of the plate is of great importance. It is required to be high enough at the low frequencies to ensure a high modal overlap without loosing finite plate characteristics by over damping. Additionally at mid frequencies the loss factor should be comparable to the loss factor in buildings, to make the transfer algorithm of the power as easy as possible. To realise such a loss factor the area of the contact between the reception plate and the resilient material was altered to find optimum conditions. The measured loss factors on the reception plate for different area of contact are shown in figure 2.

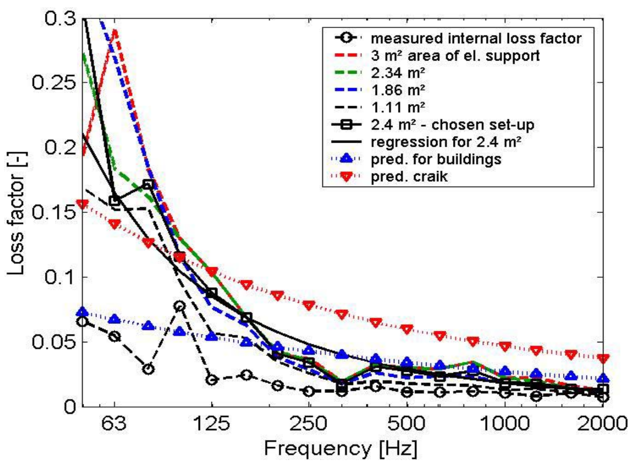

Figure 2: Measured loss factors of the reception plate.

The internal loss factor was measured first with the plate in isolation from the support pads. Measurements were repeated for different areas of contact between plate and pads. Compared to the measured values are the predicted loss factors according to [3,4]. The optimum area of contact between the resilient high-damping material and the reception plate was 4 x 0.75 m x 0.8 m at all 4 corners (with a total of 2.4 m² of contact area). The mass-spring resonance of the system is approximately at 20 Hz. In the mid frequencies, except for 315 Hz, a loss factor close to the one in buildings was achieved. At low frequencies the loss factor increases, due to the high displacement at the corners.

Reference floor

To evaluate the transfer of the data measured on the reception plate to building situations a reference floor was chosen. The floor was of 180 mm concrete in a transmission suite. The size of the floor was 5.37 m x 4.22 m. The floor loss factor, obtained by decay methods, is about half the value expected in buildings (see figure 2). However, mobility measurements indicate a loss factor which approximates the loss factor in buildings. The reasons for the different values, measured by the different methods, needs some more investigation. For the calculation of the power, the loss factor was approximated by the loss factor in buildings.

Power measurements on the reception plate and the reference floor

The whirlpool was placed on the reception plate near to one of the smaller edges, as seen in figure 1. The feet of the whirlpool where rigidly connected to the reception plate using a very stiff and hard glue. The measured power on the reception plate is shown in figure 3. It is compared to the power calculated by the mobility and free velocity approach [1]. For the calculation of the power a 8x8 diagonal matrix was used considering the point mobilities of forces perpendicular to the plate surface. The transfer terms of the mobilities where not included.

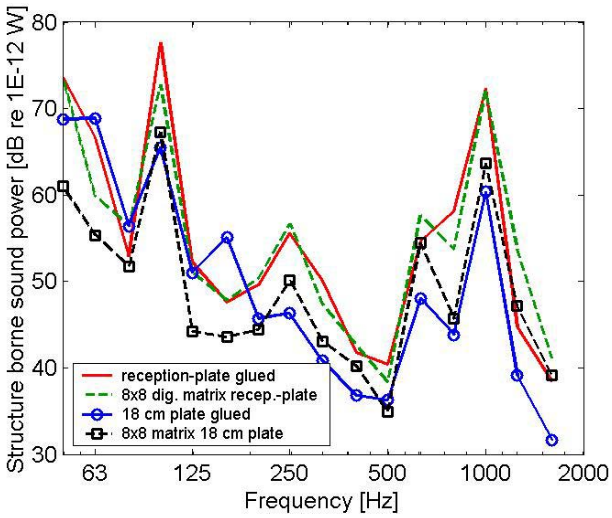

Figure 3: Measured and calculated structure-borne sound power on the reception plate compared to the measured and calculated power deduced at the reference floor plate.

The comparison of the measured power on the reception plate in figure 3 shows some deviations below 80 Hz. At higher frequencies the agreement is good. It seems that an acceptable approximation is obtained by using the 8x8 diagonal matrix, which considers vertical force excitation only. Compared to the results on the reception plate the measured and calculated structure-borne sound power into the reference floor are also shown. For the calculation, 8x8 mobility matrices were used, considering force perpendicular to the plate and all transfer terms between the 8 feet. The measured power at the reference floor shows high values at 160 Hz, which are thought to be due to moment excitation. Because of the position of the whirlpool on the reception plate, moment excitation was not encountered. At higher frequencies the power measured on the reference floor plate is slightly lower then calculated.

Transfer to input data for in situ prediction

The application of the data to the prediction of the in situ power requires the measured data to be transformed to input data for building elements of different density, thickness and size. Because of the unknown boundary conditions and the relative high loss factor in buildings, it seems appropriate to represent the building floors and walls by their characteristic point mobilities. For the reception plate, the characteristic mobility or the spatial and spectral average of the real part of the point mobilities of the contact points can be used. The difference of the reception plate and building element mobility can be utilised for the transfer calculation. In figure 4 the difference of the measured powers at the two plates compared to the differences of the mobilities are shown.

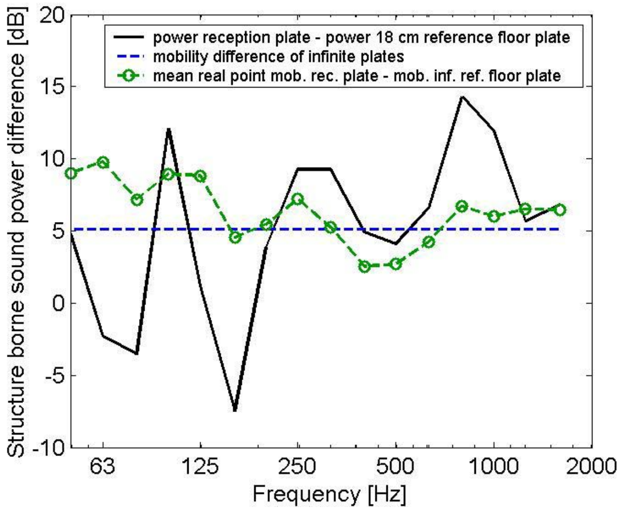

Figure 4: Difference between the measured structure-borne sound power at the reception plate and the reference floor compared to the difference of the infinite plate mobilities and of the mean real point mobility and the infinite plate mobility of the reference floor plate.

The measurements show a great difference at 160 Hz. This is due to the moment excitation of the whirlpool on the reference plate, which does not occur at the reception plate. The large differences at 800 and 1000 Hz might be explained by high force excitation on the reception plate, that doesn't exist at the reference floor plate. The results point to the question, where the source should be placed on the reception plate to best represent a building situation. It is likely, that the used position of the source on the reception plate is not appropriate. Nevertheless the difference between the mean real point mobility and the infinite plate mobility shows a promising way to transform the measured data into input data for prediction models like EN 12354 part 5.

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[3] M. Späh et al.: Verifizierung des Rechenverfahrens für die Luftschalldämmung nach EN 12354-1 für den Massivbau; Teil 1: Eingangsgrößen, DAGA 2001, Hamburg.

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