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CONSIDERATION OF VIBRATION SOURCES IN BUILDINGS ON A POWER BASIS

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Abstract

Vibration sources like pumps, motors, sanitary installations, etc., in addition to being airborne sound sources, are also structure-borne sound sources and in many cases, the sound levels in adjacent rooms are mostly dominated by the structure-borne components. A proposal to predict the structure-borne sound transmissions in buildings is given in Part 5 of the new standard series EN 12354. The source data for this prediction model is required to be on a power basis. Recently, a test procedure has been developed based on the reception plate method. The principle of the method is that the total structure-borne power from the source under test can be obtained indirectly, as a reception plate power, through measurement of the spatial average velocity of a plate attached to the source. It also has been demonstrated that a prediction of the resultant sound pressure level in buildings is possible using the reception plate power as input data. This paper considers the practical application of this method for a wide range of sources, including heating boilers, water-hammers, and footfalls on lightweight staircases. It is shown that although the present method is confined to heavyweight building elements of low receiver mobility, it is appropriate for many mechanical installations.

INTRODUCTION

Vibration sources like pumps, motors, sanitary installations, etc., in addition of being airborne sound sources, are also structure-borne sound sources and in many cases, the sound levels in adjacent rooms are mostly dominated by the structure-borne components. Therefore, attempts have been made, in previous years, to characterize structure-borne sound sources. 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. Taking the complexity of the interaction of the source and the receiving structure, transfer terms between different connections and all possible degrees of freedom into account, it is obvious that the mobility approach, although it is precise, is complicated and the required effort often is too great for a practical laboratory method.

Since the proposal to predict the structure-borne sound transmissions in buildings, given in Part 5 of the new standard series EN 12354, requires source data on a power basis, a test procedure has recently been developed, based on the reception plate method [6]. The principle of this method is that the total structure-borne power from the source under test can be obtained indirectly, as a reception plate power, through measurement of the spatial average velocity of a plate attached to the source. So far, the method has application to heavyweight buildings such that the source mobility is much greater than the receiver mobility. Nevertheless it is shown that the method is appropriate for many mechanical installations and a wide range of installations. It also has been demonstrated that a prediction of the resultant sound pressure level in heavyweight buildings is possible using the reception plate power as input data.

THREE DIMENSIONAL RECEPTION PLATE TEST RIG

The sources considered in this paper, include heating boilers, water-hammers, and footfalls on lightweight staircases. All were investigated within different research projects conducted at the University of Applied Sciences Stuttgart using the reception plate test rig. The three-dimensional plate system consists of three structurally isolated mutually perpendicular concrete plates which allow consideration of sources which are connected to more than one building element. The set-up is shown in figure 1 and is described in detail in [6].

Figure 1 – Photograph of the reception plate test rig

All sources investigated at the new laboratory were mounted to the reception plates and operated as in real situations. The measurements gave up to three spectra of structure-borne sound power for a source exciting three building elements.

RECEPTION PLATE POWER

The three plates are regarded as independent reception plates and the structure-borne sound power into each plate is obtained indirectly through measurement of the spatial average velocity $\bar{\tilde{v}}^2$ of the plate according to [1]:

$$P = \bar{\tilde{v}}^2 \eta \, \omega \, m \qquad [W] \tag{1}$$

with η the total loss factor, ω the angular frequency and m the plate mass. In order to obtain laboratory independent input data for prediction models, the reception plate power is corrected for the modal behaviour of the plate. This gives the so-called characteristic plate power $P_{characteristic}$, which represents the power into an infinite plate with the same thickness and material and is calculated by:

$$P_{characteristic} = P_{reception\ plate} \frac{Y_{c,\ reception\ plate}}{\mathrm{Re}\left(\overline{Y_{contacts}}\right)} \qquad [W] \tag{2}$$

with the reception plate power $P_{reception\ plate}$, the characteristic mobility of the plate $Y_{c,\ reception\ plate}$ and the real part of the mean of the mobilities at the contacts $\mathrm{Re}\left(\overline{Y_{contacts}}\right)$. The characteristic plate power can be used to compare data obtained at different laboratories and for studies related to acoustical improvements of sources. This characteristic power can be transformed into input data for prediction models like EN 12354 Part 5 [4] by the ratio of the characteristic mobilities of the real building plate and the reception plate.

$$P_{Building} = P_{characteristic} \frac{Y_{c,\ Building}}{Y_{c,reception\ plate}} \qquad [W] \tag{3}$$

A definite calculation of the mobility of the building plate at the contacts is usually impossible, because the boundary conditions as well as the placement of the source in real buildings are not known. Thus the characteristic mobility of the building plate $Y_{c,Building}$ is used in equation (3) although it does not take the modal characteristic of the finite building plate into account.

CONSIDERED SOURCES

The above outlined test procedure has been developed by Späh using a whirlpool bath as exciting structure-borne sound source [7]. Based on this work the following sources were investigated at the new reception plate laboratory.

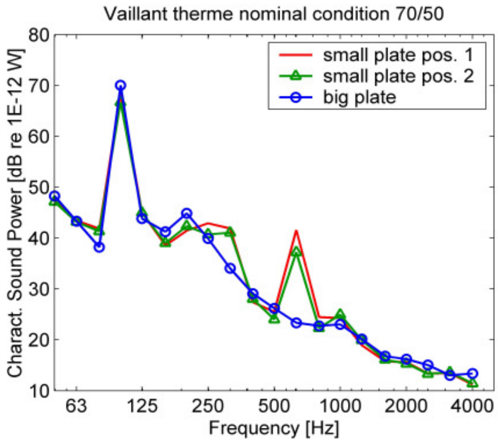
Heating Boilers

A pilot project investigated the possibility of characterising heating appliances at the reception plate test rig. Sources under test for this project were a wall-mounted gas powered therme and a floor-standing oil powered burner unit (see figure 2). These sources produce a stationary noise with tonal components.

Figure 2 – Photographs of the tested heating appliances; Left picture: Gas powered therme; Right picture: Oil powered burner unit

Gas powered therme units

These units are of particular interest since they are often installed inside dwellings. For this study, the therme with a nominal power of 23 kW was consecutively mounted to the vertical reception plates as in real situation and operated with 70/50°C outgoing- and return temperature. The characteristic structure-borne sound power was determined for each reception plate. The results in the left graph of figure 3 indicate the reproducibility of these measurements. The maximum at 100 Hz is presumably caused by the internal pump of the heating circuit. Above this frequency the structure-borne sound power decreases continuously. Both measurements at the small reception plate, obtained measuring the velocity at different points, show good agreement. However there is a small difference at 315 Hz as well as a distinct peak at 630 Hz which does not appear at the large reception plate. It is assumed, that due to the conversion from one plate to the other, the mounting conditions and/or the flow conditions changed. In general the method gives reproducible results applicable for this source.



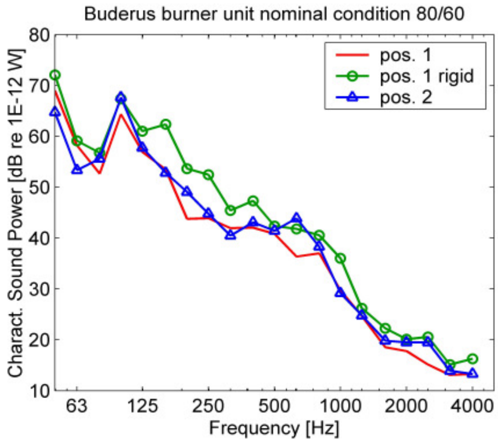


Figure 3 – Characteristic structure-borne sound power of the gas powered therme (left) and the oil powered burner unit (right)

Oil powered burner units

The unit was a low temperature cast iron heating boiler with an internal fan burner and a nominal power of 21 kW. The source was positioned on the horizontal reception plate and operated with nominal 80/60°C outgoing- and return temperature. For cooling, an external recuperator with fresh water was used, as with the gas therme. To investigate the reproducibility of the measurements the burner unit was installed at two different positions on the reception plate. Furthermore the influence of the plastic covered feet was tested at position 1 by replacing the standard feet with rigid screws. The determined characteristic structure-borne sound powers of the oil powered burner unit are shown in the right graph of figure 3. The structure-borne sound power has a peak at 100 Hz with a continuous decrease above this frequency. The measurement results for the different positions of the source are very similar and indicate acceptable reproducibility. As expected, the structure-borne sound power through rigid contacts is greater than for standard feet, especially in the mid-frequency range. Results indicate that although the unit is a heavy and rigid structure-borne sound source the reception plate method still applies and leads to reliable and reproducible source data.

Water-Hammer noise

Water hammers arises due to the rapid closing of a water armature because the water flow comes to an abrupt standstill. In work conducted at the University of Applied Sciences Stuttgart [5] the structure-borne sound power generated by water-hammers was investigated. Pipes of different material were mounted to the large vertical reception plate with eight standard pipe clamps (see figure 4). A bathtub armature was used which closed the armature automatically with a closing time of 100 ms (see left of figure 5). Although water-hammers are impulsive sources, it is still possible to obtain the structure-borne sound power using the reception plate method. According to the time response of the flow pressure fluctuations a time domain was defined in which the resulting velocity of the plate was measured.

Figure 4 – Photograph of vertical reception plate with the attached plastic pipe

The characteristic structure-borne sound powers of water-hammers in pipes of different material are shown in the right graph of figure 5. The structure-borne sound powers of copper- and composite pipes are similar in the low- and mid frequency range. Above 1000 Hz the composite pipe tends to give a slightly higher structure-borne sound power than the copper pipe. The induced structure-borne sound power from water-hammers within a plastic pipe is less than for other pipes. This is because of the large impedance change between the plastic pipe and the metal clamps. This study on water-hammers showed that there is the possibility to investigate this exceptional kind of structure-borne sound sources with its impulse signal characteristics at the reception plate laboratory and hence to obtain input data for prediction models.

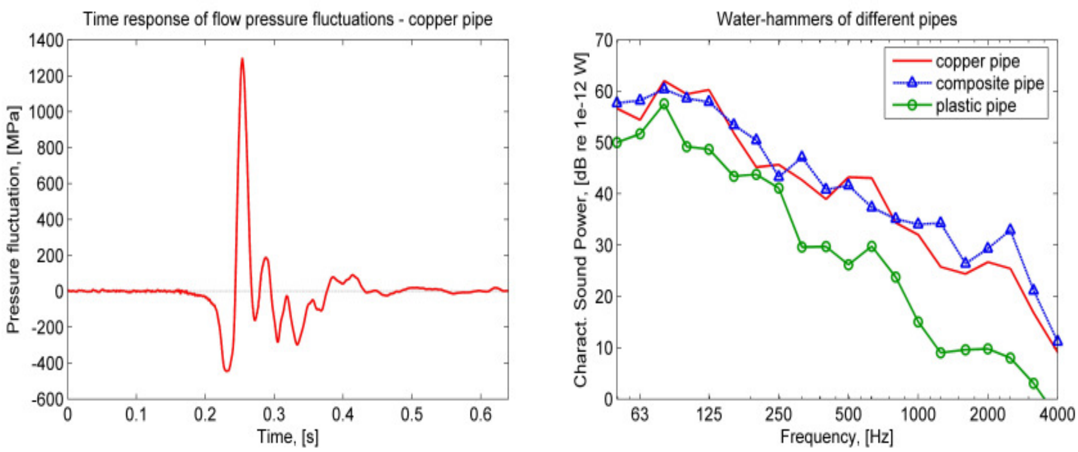


Figure 5 – Time response of flow pressure fluctuations in copper pipe (left) and structure-borne sound power of water-hammers in pipes of different material (right)

Lightweight stairs

Timber stairs, which are directly attached to walls separating dwellings, can cause severe acoustical problems [2]. One type of stair system considered, consisted of 14 solid timber steps, each supported by the handrail and individually fixed, at the other end, to the wall with a pair of steel bolts (see left of figure 6).

Figure 6 – Mounting detail (left) and step fixed on reception plate (right)

Initial measurements showed that the excitation of one step as part of the complete staircase and the excitation of one step isolated from other steps produces almost the same impact sound pressure level in the receiving room. Therefore, only one step was attached to the reception plate [3] (see right of figure 6). Both a standard tapping machine and a rubber ball (according to ISO/CD 140-11) were used. The characteristic plate powers are shown in figure 7.

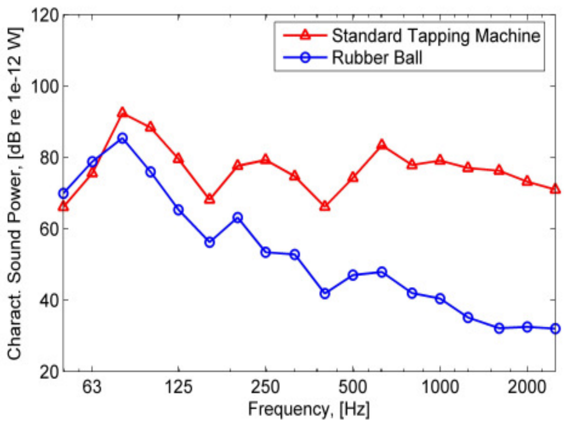


Figure 7 – Characteristic plate power of step with standard tapping machine- and rubber ball excitation

The installed power (see equation 3) also was calculated and compared with the measured structure-borne sound power of the whole staircase installed in the test facility at Stuttgart. This comparison is shown in figure 8 for the two different types of excitation. Although there is experimental uncertainty, there is generally agreement between predicted and measured values. This indicates, that the reception plate method is appropriate to characterise steps of this particular wooden staircase.

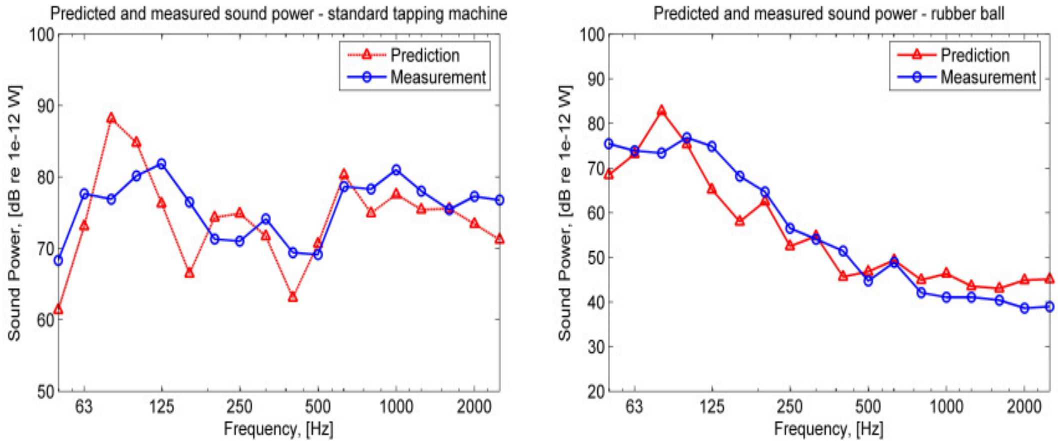


Figure 8 – Comparison between predicted and measured structure-borne sound power for excitation with standard tapping machine (left) and rubber ball (right)

CONCLUDING REMARKS

The practical application of the reception plate method, as developed at Stuttgart, has been described. It has been shown that the method provides repeatable and reproducible values of structure-borne sound power from a wide range of mechanical installations in buildings. Both steady-state and transient sources can be treated. The source data can be simply transformed to the characteristic plate power which allows comparison of sources and comparison of the results of different laboratories. A further simple transformation of the data yields input data for the building propagation models of EN12354.

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