inter.noise 21-24 AUGUST SCOTTISH EVENT CAMPUS GLASGOW 2022

Uncertainty of structure-borne sound source quantities and the installed power from interlaboratory test results according to EN 15657

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ABSTRACT

Structure-borne sound sources affect the acoustic quality inside buildings. Based on many years of research, methods have been standardised to characterise structure-borne sound sources in the laboratory (EN 15657) and to predict the sound transmission from these sources when installed in buildings (EN 12354-5). This contribution is about the uncertainty of the source descriptors used in EN 15657 and the predicted installed sound power which is the input quantity for EN 12354-5. Recently an interlaboratory test with 7 participating laboratories has been performed. The task was to measure the blocked force, free velocity and mobility of an artificial source and the blocked force of the ISO tapping machine. From the evaluation of the measurement results estimates for the uncertainties of the source quantities and the installed power could be deduced.

1. INTRODUCTION

Structure-borne sound in buildings is generated by vibrating sources, which inject vibrations through the contacts with building elements. The vibrations propagate throughout the building and radiate sound into rooms. The structure-borne sound generated in buildings depends on the source and the building structures involved in the transmission and the quantity to express the amount of sound emitted by the source is the installed power (structural power transmitted to the receiving building element). The installed power is not a characteristic of the source only but also depends on the receiver. Methods for the characterization of structure-borne sound sources for all installation conditions are standardized in EN 15657:2017 [1]. These source quantities serve as input data for the prediction of the sound transmission using prEN 12354-5:2021(E) [2], when the source is installed in a building. This paper summarizes shortly the results of an interlaboratory test on the methods given in EN 15657:2017 [1]. A detailed documentation is published in [3].

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2. SOURCE INPUT QUANTITIES FOR PREDICTION

The input quantity for prediction using EN 12354-5 is in the general case the installed power [2], which can be determined from the source and receiver properties using the approximation of (1).

$$L_{\mathrm{Ws,i}} \approx 10\lg\left(\frac{\mathrm{Re}\left(Y_{\mathrm{R,eq,i}}\right)Y_0}{\left|Y_{\mathrm{S,eq}}\right|^2+\left|Y_{\mathrm{R,eq,i}}\right|^2}\right)\ \mathrm{dB} + L_{\mathrm{vf,eq}} - 60\ \mathrm{dB} \tag{1}$$

where $\left|Y_{\mathrm{S,eq}}\right|$ is the equipment single equivalent mobility magnitude, $\mathrm{Re}\left(Y_{\mathrm{R,eq},i}\right)$ and $\left|Y_{\mathrm{R,eq},i}\right|$ are respectively the single equivalent mobility real part and magnitude of receiving element *i* and $L_{\mathrm{vf,eq}}$ is the equipment single equivalent free velocity level in dB ref. 10^{-9} m/s. A similar expression of the installed power in the general case can be written as a function of the blocked force level $L_{\mathrm{Fb,eq}}$. If the receiver mobility is significantly lower than the source mobility, which is the case with the low mobility reception plate used in EN 15657, the installed power is approximated by (2):

$$L_{\mathrm{Ws,i}} \approx 10\lg\left(\frac{\mathrm{Re}\left(Y_{\mathrm{R,eq,i}}\right)}{Y_0}\right)\ \mathrm{dB} + L_{\mathrm{Fb,eq}} \tag{2}$$

3. INTERLABORATORY TEST

3.1. Sources

The same source as in [4] was used again for this new interlaboratory test with slight modifications. It consists of an aluminium plate mounted on three feet which is excited by an inertial shaker driven with pink noise and connected to the aluminium plate in line with a force transducer (Figure 1, left). Instructions for the operation and mounting of the Round Robin Reference Source (RRRS) were given to the participants. As an additional source an electromagnetic standard tapping machine, a SINUS TM 50 (Figure 2, right) was provided which is designated as Reference Tapping Machine (RTM). Additionally, the labs were asked to perform measurements with their own laboratory tapping machines (LTM).

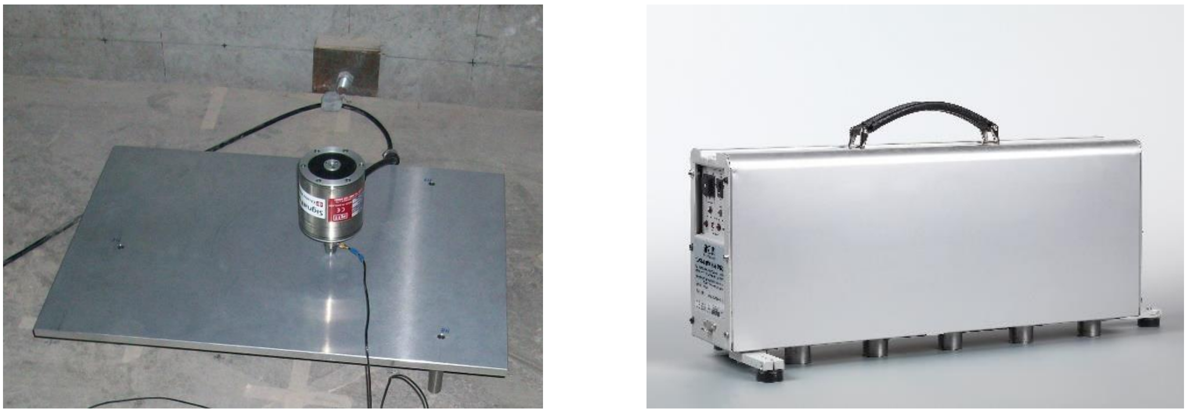

Figure 1: RRRS (Round robin reference source) on a low mobility reception plate (left); Reference Tapping Machine RTM (right); from [3].

3.2. Participating laboratories and performed measurements

Within the interlaboratory test, measurements were performed by Empa (Switzerland), CSTB (France), IBP (Germany), Geberit (Switzerland), PTB (Germany), HFT Stuttgart (Germany) and TH Rosenheim (Germany). The task was to determine the single equivalent blocked force, the single equivalent free velocity and the single equivalent mobility of the RRRS according to [1]. For both tapping machines, only the single equivalent blocked force was to be measured using a low mobility reception plate. One laboratory reported results with an isolated and a non-isolated low mobility reception plate. These two results are considered to be independent. A high mobility reception plate was applied only by one laboratory.

3.3. Properties of the reception plates

All low mobility reception plates are concrete plates. Four isolated plates are used with surface masses of 190 kg/m², 240 kg/m², 250 kg/m² and 250 kg/m² and surface areas of 5.6 m², 5.6 m², 5.7 m² and 10.4 m². Such data is not required for non-isolated plates as they were calibrated using a known input power. Nevertheless, for two of the non-isolated plates it is known that the surface mass is 350 kg/m² and the surface area is about 20 m². This corresponds to reference floors for the measurement of impact noise reduction according to ISO 10140-5 [5].

4. MEASUREMENT RESULTS

4.1. Results with tapping machines

Measured single equivalent blocked force levels (Figure 2, left) are mainly within the theoretically expected limits from [6]. The majority of the results is closer to the upper limit, indicating an elastic impact. For some isolated plates the results are closer to the lower limit, indicating a plastic impact. In one laboratory, an overload of the accelerometers was detected after the sources were sent to the next laboratory. It occurred only with the measurement of the RTM. When these overload cases are omitted, the standard deviation of reproducibility of the single equivalent blocked force level is almost identical for RTM and LTM (Figure 2, right). It is about 4 dB in the lowest bands and about 2 dB between 400 Hz and 3.15 kHz.

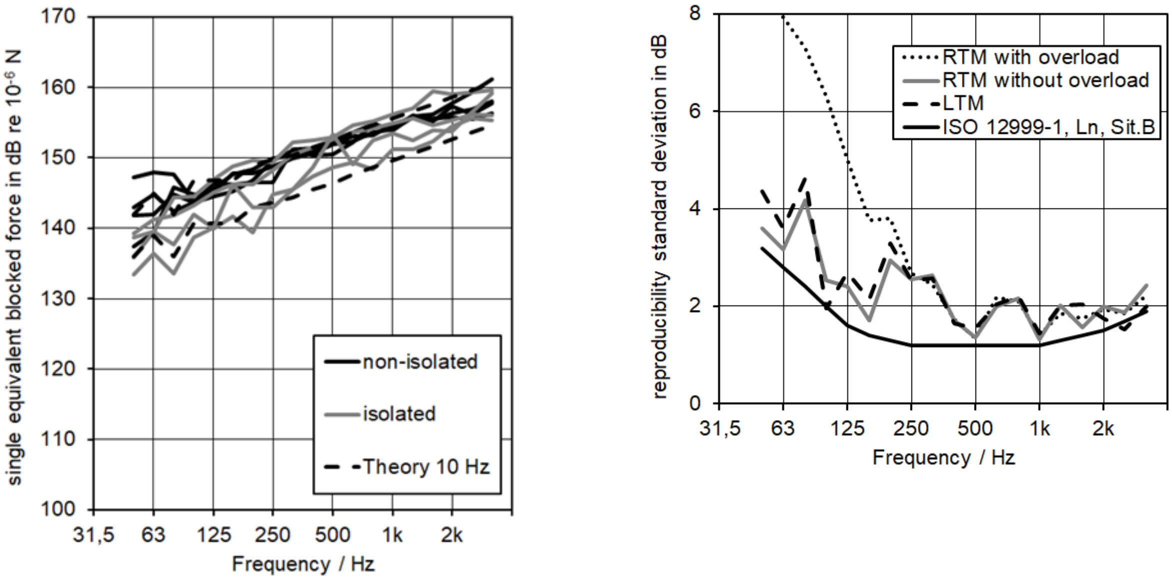

Figure 2: Single equivalent blocked force levels for the laboratory tapping machines LTM measured on isolated and non-isolated reception plates in comparison to the theoretical results for elastic and plastic impacts (left);
Standard deviation of reproducibility for the single equivalent blocked force for the round robin tapping machine RTM and the laboratory tapping machine LTM (right); from [3].

4.2. Results with round robin reference source

The results of the blocked force show a spectral pattern with peaks and troughs (Figure 3, left). One result from an isolated reception plate clearly stands out. The reason for the discrepancy could not be identified. Therefore, this result was omitted from further processing of the reproducibility that is presented with and without correction to the shaker internal force sensor (Figure 3, right). The standard deviation of reproducibility reflects the spectral shape of the measured single equivalent blocked force levels. Smoothing out the peaks and troughs in this curve, a very rough estimate is about 3 dB for all frequencies.

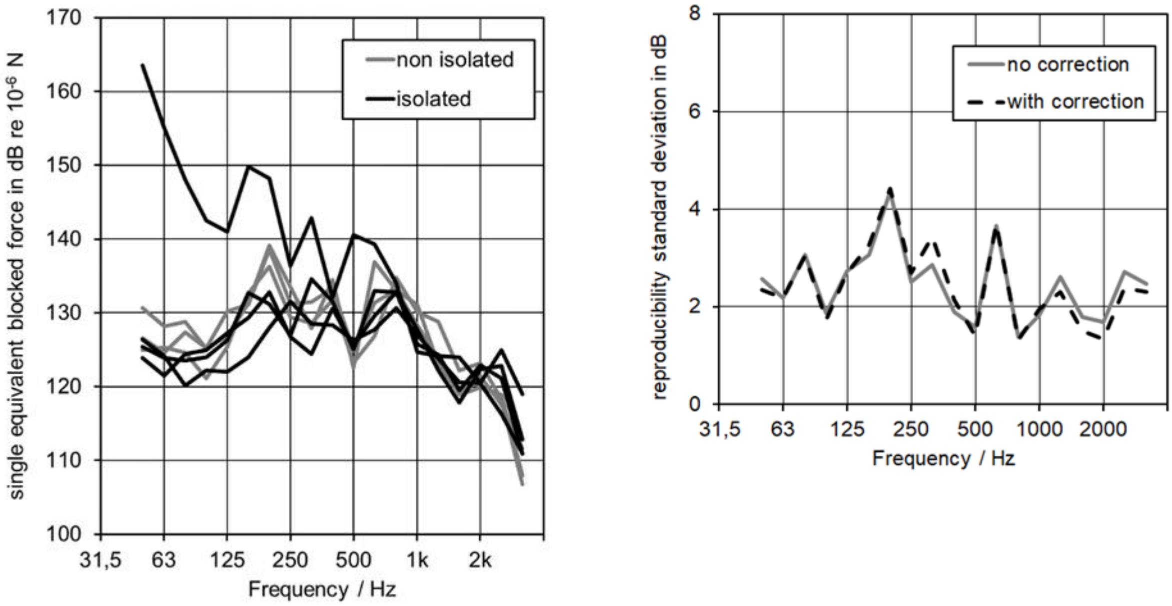

Figure 3: Measured single equivalent blocked force levels for the round robin reference source (left); Reproducibility standard deviation of the single equivalent blocked force level (right); from [3].

The spectral shape of the single equivalent free velocity levels (Figure 4, left) exhibits some similarities to the shape of the single equivalent blocked force level. Peaks and troughs are clearly visible. The standard deviation of reproducibility for the single equivalent free velocity level as a frequency average is about 4 dB (Figure 4, right).

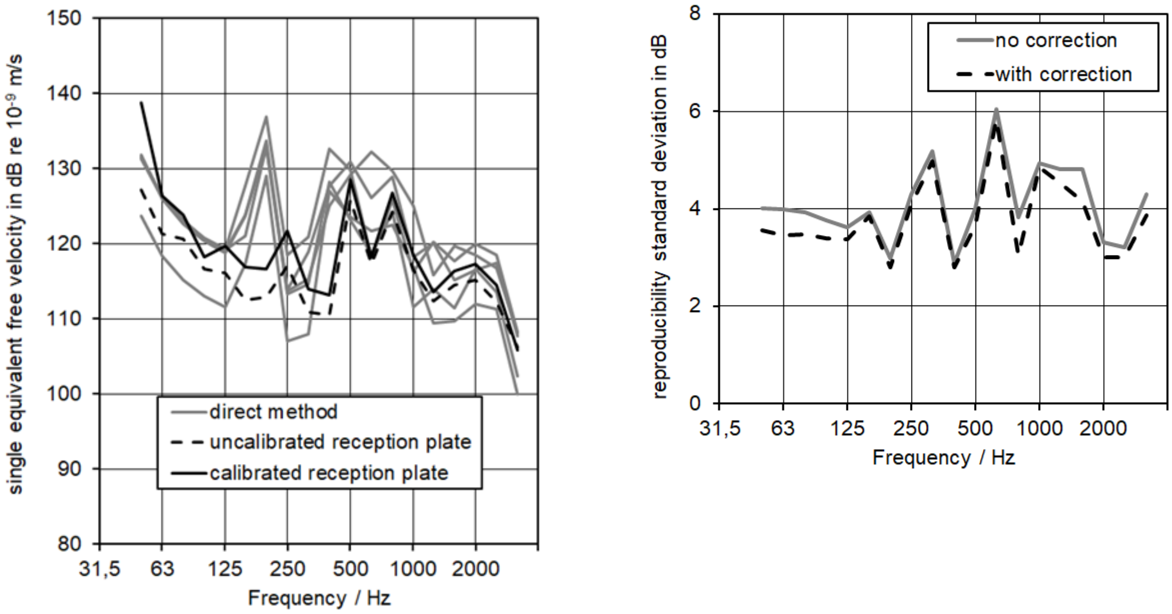

Figure 4: Measured single equivalent free velocity levels for the round robin reference source (left); Reproducibility standard deviation of the single equivalent free velocity level (right); from [3].

Measurement results of the single equivalent source mobility obtained by the participants are in excellent agreement (Figure 5, left). The standard deviation of reproducibility (Figure 5, right) exhibits some variation with frequency which is attributed to the source properties. Therefore, an estimate of 1 dB is considered to be an appropriate estimate for all frequencies.

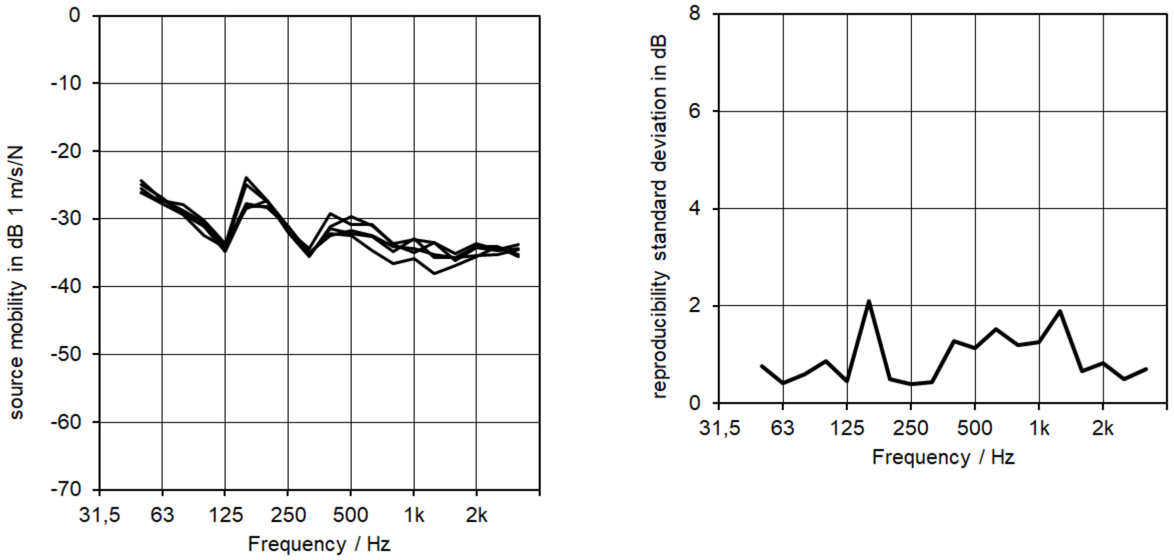

Figure 5: Measured single equivalent source mobility magnitude levels for the round robin reference source (left);
Reproducibility standard deviation of the single equivalent source mobility level (right); from [3].

5. UNCERTAINTY OF INSTALLED POWER

For the calculation of the uncertainty of the installed power equation (1) was rearranged to:

$$L_{\mathrm{W,inst}} \approx L_{\mathrm{Fb,eq}} + L_{\mathrm{Re}(YR)} - 10\,\lg\left(1 + 10^{0.2\,L_{(\mathrm{YR/YS})}/\mathrm{dB}}\right)\mathrm{dB} \tag{3}$$

The underlying assumption for this calculation is that the three quantities single equivalent blocked force level $L_{\mathrm{Fb,eq}}$, the level of the real part of the receiver mobility $L_{\mathrm{Re(YR)}}$ and the level of the mobility ratio $L_{(\mathrm{YR/YS})}$ are independent quantities (3).
As a conclusive example, the installed sound power level of the round robin reference source and its uncertainty is calculated for the two cases that it is connected to a low mobility infinite plate with $Y = 10^{-5}$ m/(s N) and a high mobility infinite plate with $Y = 10^{-2}$ m/(s N) (Figure 6). The resulting 68% confidence intervals for the installed sound power level differ by about 30 dB which is caused by the second term of equation (3).

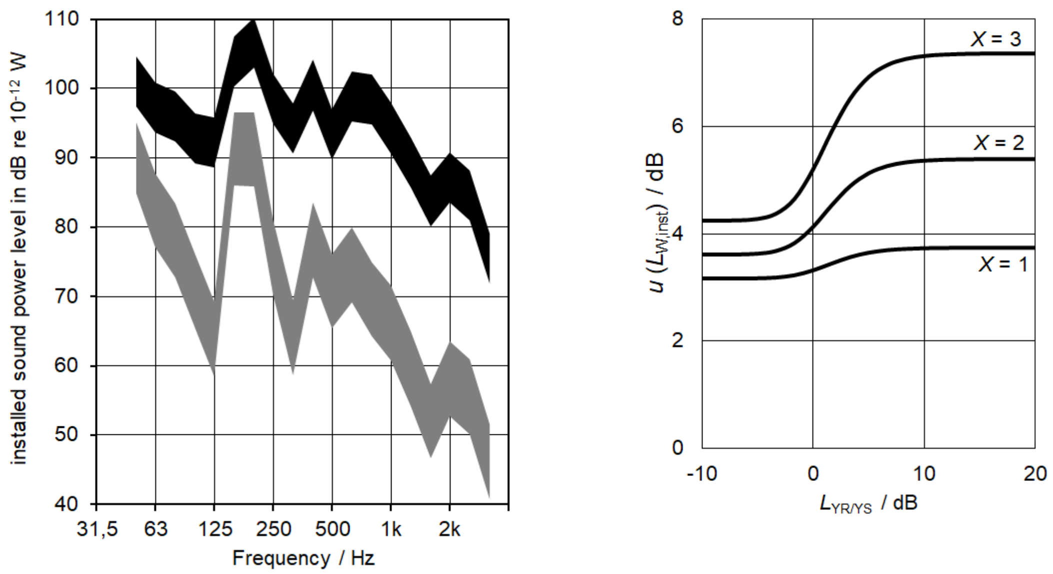

Figure 6: 68% confidence intervals of the predicted installed sound power level of the round robin reference source when it is connected to a low mobility receiver ($Y = 10^{-5}$ m/(s N), black) and a high

mobility receiver ($Y = 10^{-2}$ m/(s N), grey) under the assumption $u\left(L_{\mathrm{Re}(Y\mathrm{R})}\right) = u\left(L_{(Y\mathrm{R}/Y\mathrm{S})}\right) = 2.0$ dB (left);
Uncertainty of the installed sound power level with assumed uncertainties $u\left(L_{\mathrm{Re(YR)}}\right) = u\left(L_{(\mathrm{YR/YS})}\right) = X$ dB (right); from [3].

6. CONCLUSIONS

An interlaboratory test has been performed with a structure-borne sound source. Source quantities were measured according to EN 15657:2017 [1]. From these measurement results, the uncertainties in one-third octave bands from 50 Hz to 3.15 kHz are estimated to be:

$$u\left(L_{\mathrm{Fb,eq}}\right) \approx 3 \text{ dB}; \; u\left(L_{\mathrm{vf,eq}}\right) \approx 4 \text{ dB}; \; u\left(L_{|YS|}\right) \approx 1 \text{ dB} \tag{4}$$

From these uncertainties, the uncertainty of the installed sound power level was estimated. When the receiver mobility is much smaller than the source mobility (force source situation), the uncertainty of the installed sound power level is about 3 dB to 4 dB. In the opposite case, when the receiver mobility is much larger than the source mobility (velocity source situation) much larger uncertainties of up to 7 dB are yielded

$$u\left(L_{w,\mathrm{inst}}\right) \approx \begin{cases} 3 \dots 4 \text{ dB} & \text{for } Y_\mathrm{R}/Y_\mathrm{S} \ll 1 \\ 4 \dots 7 \text{ dB} & \text{for } Y_\mathrm{R}/Y_\mathrm{S} \gg 1 \end{cases} \tag{5}$$

Furthermore, the single equivalent blocked force level of two tapping machines: one provided within the interlaboratory test, the other selected by each laboratory has been determined by the participating laboratories, also according to EN 15657:2017 [1]. Measured single equivalent blocked force levels are well within the theoretically predicted range.

7. ACKNOWLEDGEMENTS

The contribution of all participating laboratories and CEN/TC 126/WG 7 is gratefully acknowledged. Special thanks to Simon Bailhache, Joachim Förster, Lukas Moy, Sven Öhler, Stefan Schoenwald, and Fabian Schöpfer.

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