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An indirect method for the measurement of impact sound insulation

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ABSTRACT

This paper describes a way of measuring impact sound insulation for heavy structures without using the standard tapping machine. Instead, another source of known contact force - e.g. an impact hammer or electrodynamic shaker - is connected to the building element under test. The sound pressure level is measured in the receiving room and then corrected from the difference in force level between the standard tapping machine and the substitution source to obtain the impact sound pressure level. An application of this indirect method is the laboratory determination of the impact sound performance of walls, which can be used as an input for prediction of impact noise of isolated heavy stairs as well as of structure-borne noise from service equipment in situ; the standard tapping machine is indeed not suitable for exciting vertical building elements. In this paper, the indirect method is described, then applied to a floor element and the results are compared to the impact sound pressure level directly determined using the standard tapping machine on the same floor. Several measurements are performed using different numbers of source and microphone positions. The corresponding results are presented and discussed.

Keywords: Impact sound, Measurement, Indirect methods

1. INTRODUCTION

Since 2017, standardization group CEN/TC126/WG1/TG3 is working on a new laboratory measurement method of the impact sound insulation of walls. The practical applications of such measurements may not be straightforward, since the concept of impact sound insulation usually applies to impacts produced on building floors. However, the impact sound insulation performance of walls can be used as input data in predictions of impact sound when the impacts are generated on stairs connected to a heavy structure. Indeed, this quantity is introduced in EN ISO 12354-2 Annex F (1) to define the impact sound reduction ΔL of heavy isolated stair landings and of lightweight stairs connected to heavy walls as follows:

$$\Delta L_{landing/stairs} = L_{n,0,wall} - L_{n,landing/stairs} \tag{1}$$

In equation 1, $L_{n,0,\mathrm{wall}}$ is the normalized impact sound pressure level (in dB ref. 2.10^{-5} Pa) of the wall to which the landing or stairs are connected, while $L_{n,\mathrm{landing/stairs}}$ is the normalized impact sound pressure level when the impacts are produced to the considered isolated landing or lightweight stairs. These quantities are related to the excitation produced by the standard tapping machine, which can only be used on horizontal elements. The determination of $L_{n,0,\mathrm{wall}}$ thus requires a specific measurement method using a different impact source of known applied force.

Previous work also highlighted another possible use of $L_{n,0,\mathrm{wall}}$ in predictions of structure-borne sound from service equipment when a force source assumption can be made (2). Measurements were performed using a special tapping machine adapted to walls that requires to be fixed into the element under test.

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In this paper, a different method using an impact hammer is proposed. Lighter and easily transportable, this impact source however suffers from two major disadvantages in comparison with the tapping machine: its non-calibrated excitation and a limited impact area. The first issue can be easily dealt with by applying a correction to the measured sound pressure level depending on the force level of the excitation – hence the “indirect” character of the proposed method. The second point may require an increased number of source positions in order to reach comparable accuracy, due to modal behavior of the wall.

In this study the method is applied to a concrete floor, so that the results can be compared to those obtained with the standard tapping machine. The experimental protocol is first described in section 2. Results are presented in section 3 and the influence of the number of hammer positions is discussed.

2. EXPERIMENT PROTOCOL

2.1 General principle

The building element under test is an 18 cm thick concrete floor connected to concrete walls. The 54 m^3 room located below is considered as receiving room. The standardized sound pressure level using the tapping machine (noted $L'_{nT,TM}$) is measured in the range 50-5000 Hz following EN ISO 16283-2 (3). The standard uncertainty values given in EN ISO 12999-1 (4) are used.

In addition, a second measurement of the standardized sound pressure level is performed by replacing the tapping machine by a 1.5 kg impact hammer (Kistler type 9728A2000) equipped with a rather hard tip. Repeated impacts are produced to obtain quasi-stationary excitation over averaging periods of 15 s. For each hammer position i, the measured sound pressure level $L_{p,hammer,i}$ (corrected from background noise) is used to determine the sound power to sound pressure transmission function $D_{TF,i}$ as defined in ISO 10848-1 (5).

$$D_{TF,i} = L_{p,hammer,i} - L_{W,hammer,i} \tag{2}$$

In equation 2, $L_{W,hammer,i}$ is the structure-borne sound power level (in dB ref. 10^{-12} W) applied at the ith hammer position.

Applying a power substitution method, the transmission function can be used to calculate the sound pressure level of the tapping machine $L_{p,TM,i}$ as follows:

$$L_{p,TM,i} = L_{W,TM,i} + D_{TF,i} \tag{3}$$

For low-mobility structures, EN 15657 (6) allows to approximate the installed structure-borne sound power level L_W as follows:

$$L_W \approx 10\lg\left(Re\left(Y_{R,eq}\right)\right) + L_{Fb,eq} \tag{4}$$

In equation 3, $Y_{R,eq}$ is the equivalent mobility of the receiver (in m/(N.s)) and $L_{Fb,eq}$ is the equivalent blocked force level (in dB ref. 10^{-6} N) of the source.

These relationships can be simplified as follows:

$$L_{p,TM,i} = 10\lg\left(Re\left(Y_{R,eq}\right)\right) + L_{F,TM,i} + L_{p,hammer,i} - \left(10\lg\left(Re\left(Y_{R,eq}\right)\right) + L_{F,hammer,i}\right) \tag{5}$$

Which further reduces to a simple force level correction:

$$L_{p,TM,i} = L_{p,hammer,i} + L_{F,TM,i} - L_{F,hammer,i} \tag{6}$$

The corrected sound pressure level then needs to be averaged over all hammer positions and corrected from the reverberation time of the receiving room for comparison to the results of the standard measurement.

2.2 Source and microphone positions

For measurements using the tapping machine, 6 source positions are considered. As specified in EN ISO 16283-2, this allows for only one measurement for each source position. One microphone position is considered and made different for each source position.

For measurements using the impact hammer, the same 6 source positions are considered. Additional measurements are then performed by adding other source positions up to a total of 15.

3. RESULTS

3.1 Excitation

The force levels measured by the impact hammer for the 15 source positions are represented in Figure 1. The force level of the tapping machine, considered as independent from its location on the floor, is also represented for comparison. These values are obtained from calculations according to the analytical model described in (7).

These results show that the force level of the impact hammer is well repeatable except for one source position (no. 4), due to weaker operator action. The force level of the impact hammer drops at 800 Hz and higher frequencies, whereas the force level of the tapping machine continues to increase. Nevertheless, it remains well above background noise for all source positions.

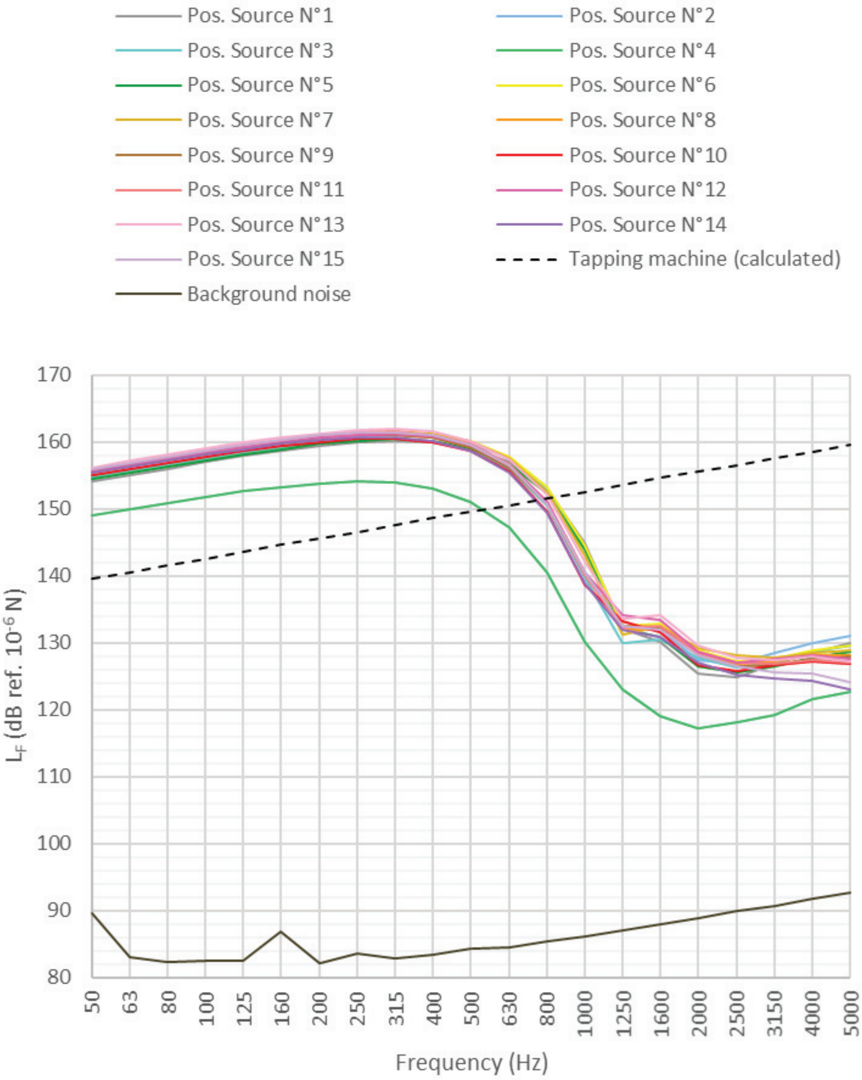

Figure 1 – Force levels of the impact hammer and of the tapping machine

3.2 Impact sound pressure level

The corrected sound pressure level of the impact hammer is represented in Figure 2 as a function of the number of source positions considered. The corresponding single-number ratings calculated according to ISO 717-2 (8) are given in Table 1.

From these results, it can be seen that the corrected sound pressure level may vary slightly depending on the number of positions considered. With an increasing number of positions considered in the average calculation, the corrected sound pressure level rapidly reaches a stable value. The maximum difference between the stabilized values (15 positions considered) and the results for only one position considered is approximately 5 dB at 200 Hz. As of 9 positions considered, the differences with 15 positions considered are less than 1 dB for all frequency bands except at 63 Hz (1.2 dB).

When considering the single-number ratings, all results are within a 1-dB range. From 7 positions considered, the values remain constant.

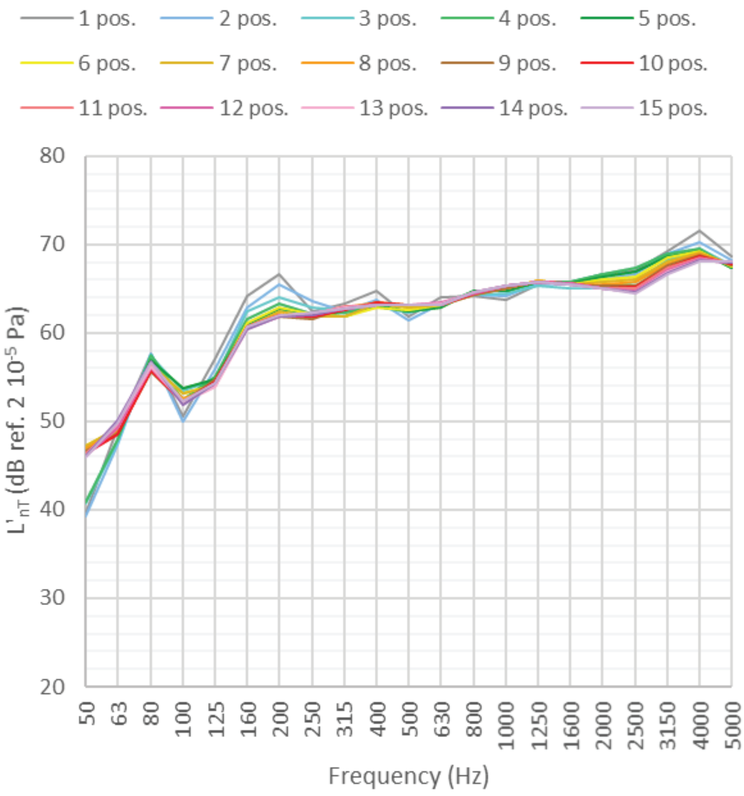

Figure 2 – Impact sound pressure level as a function of the number of hammer positions

Table 1 – Single-number ratings calculated according to ISO 717-2

Number of positions	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
$L'_{nT,w}$ (dB)	73	73	72	73	73	73	72	72	72	72	72	72	72	72	72
$C_{I,100\text{-}2500}$ (dB)	-12	-12	-12	-12	-13	-13	-12	-12	-12	-12	-12	-12	-12	-12	-12
$C_{I,50\text{-}2500}$ (dB)	-12	-12	-12	-12	-12	-13	-12	-12	-12	-12	-12	-12	-12	-12	-12

The corrected sound pressure levels measured using 6, 10 and 15 positions of the impact hammer and the sound pressure level for 6 positions of the tapping machine (considered as reference) are represented in Figure 3. Standard uncertainty limits according to ISO 12999-1 are also given for the measurement using the tapping machine. The single-number ratings calculated according to ISO 717-2 (6) are available in Table 2.

These results show that the corrected sound pressure level of the impact hammer and the sound pressure level of the tapping machine are very similar. Approximately half of the values of the impact hammer corrected level (15 pos.) are within uncertainty limits of the tapping machine measurement result. The other half are less than 1 dB from these limits, except at 100 Hz (1.2 dB gap), 4000 Hz (1.6 dB gap) and 5000 Hz (4.8 dB gap). Similar observations can be made for 6 and 10 impact hammer positions considered, with results really close to those obtained for 15 positions considered.

Considering the single-number ratings, the stabilized L’$_{nT,w}$ value obtained with the impact hammer is 1 dB lower than the result obtained with the tapping machine, while the same values are obtained for the spectrum adaptation terms.

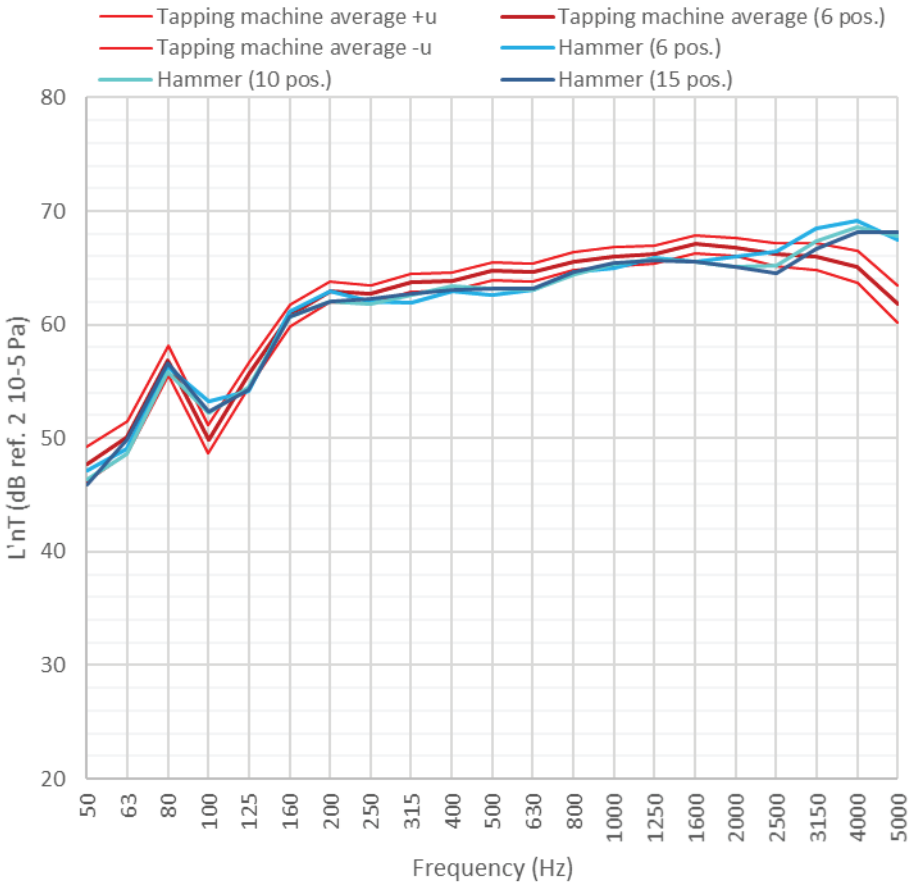

Figure 3 – Impact sound pressure level measured with the impact hammer and with the tapping machine

Table 2 – Single-number ratings calculated according to ISO 717-2

Number of positions	Tapping machine: average	Hammer (6 Pos.)	Hammer (10 Pos.)	Hammer (15 Pos.)
L'$_{nT,w}$ (dB)	73	73	72	72
C$_{I,100\text{-}2500}$ (dB)	-12	-13	-12	-12
C$_{I,50\text{-}2500}$ (dB)	-12	-13	-12	-12

4. CONCLUSIONS

The purpose of this study was to propose a measurement method of the impact sound insulation of walls. To this aim, the standard tapping machine being inapplicable on vertical elements, an impact hammer is used as an impact source and the impact sound pressure level is estimated with an indirect method: the sound pressure level measured in the receiving room is corrected from the difference in force level between the hammer excitation and the tapping machine. In order to validate the principle of this simplified power substitution method, it was experimented on a concrete floor, where the standard tapping machine can also be used and considered as reference case.

The results obtained with both methods are very similar, with slight variations depending on the number of hammer positions considered. Sufficient signal-to-noise ratio was obtained with the impact hammer, even though problems could have been expected at high frequencies.

From these results, it seems possible to measure the impact sound insulation performance of walls with the proposed method using an impact hammer. Due to a limited impact area, it may be necessary to slightly increase the number of source positions in comparison to measurements with the standard tapping machine. A minimum number of 10 positions seems a reasonable compromise.

ACKNOWLEDGEMENTS

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