Laboratory characterization and field prediction of whirlpool bath noise

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Two draft standards on building equipment noise have been sent to CEN/TC126 for enquiry in 2005: one (work item 126 061) about the laboratory characterization of airborne and structure borne noise generated by such equipment (taking whirlpool baths as an example) and the other one (pr EN 12354-5) about the field prediction of equipment noise, the input data being the quantities obtained in laboratory. In this paper, the two draft standards are briefly presented and applied to whirlpool baths. First, the different power quantities generated by a whirlpool bath installed in a laboratory are measured according to the standard but using a reception building structure different from the three plate test rig defined in the standard. In a second phase, the noise levels transmitted to rooms adjoining the test room (where the equipment is installed), are measured and compared to levels estimated using the prediction method. The results obtained show a good coherence between the two draft standards which give a rather satisfying estimation of field sound levels due to whirlpool baths.

1 Introduction

Two draft standards on building equipment noise have been sent to CEN/TC126 for enquiry in 2005: one (work item 126 061, [1]) about the laboratory characterization of airborne and structure borne noise generated by such equipment (taking whirlpool baths as an example) and the other one (pr EN 12354-5, [2]) about the field prediction of equipment noise, the input data being the quantities obtained in laboratory. In this paper, the two draft standards are briefly presented and applied to whirlpool baths. In a first part (section 2), the different power quantities generated by a whirlpool bath installed in a laboratory are measured according to the standard but using a reception building structure different from the three plate test rig defined in the standard. In a second part (section 3), the noise levels transmitted to rooms adjoining the test room (where the equipment is installed), are measured and compared to levels estimated using the prediction method.

2 Laboratory characterization of whirlpool baths

2.1 Principle of the test method

According to draft standard CEN/TC126/WG7/NE22, both the airborne sound radiated by the equipment in the room where it is installed and the structure borne sound transmitted through the receiving building structures into adjoining rooms are characterized.

The airborne sound is characterized by the airborne sound power of the equipment, estimated from the spatially averaged sound level of the room where the equipment is installed, and the reverberation time of the room (this method is well known). In the case of whirlpool baths, these measurements (as well as the measurements of structure borne sound) are performed for 3 operating conditions: blower on full speed, pump on full speed and blower and pump on, both full speed. Figure 1 shows an example of airborne sound power results; it should be noted that the peaks, which correspond to noise generated by the different active units of the whirlpool bath (pump, blower), were found not very reproducible with level differences up to 4 dB obtained for the same operating condition reproduced twice. The highest sound power level in dB(A) is obtained when both the blower and the pump are on full speed.

![Figure 1: Airborne sound power obtained for the operating condition “blower and pump on, both full speed”](image-url)
The structure borne sound is characterized by the structural power injected to each building element (floor and walls) to which the equipment is connected; a whirlpool bath installed in the corner of a room is therefore characterized by three structural power components. Each power component \( L_{W_{s,i}} \) is estimated from the spatially averaged vibration level of the element considered \( L_{v,i} \) and the loss factor \( \eta_i \) of the same element (obtained from its structural reverberation time) according to

\[
L_{W_{s,i}} = L_{v,i} + 10 \log(\eta_i 2\pi f m_i S_i) - 60 \quad (1)
\]

\( m_i \) and \( S_i \) are the mass per unit area and the surface area of the element.

It is important to notice that the estimation given by Equation (1) is only valid if the element considered \( i \) is isolated from the others; in the draft standard, a three plate test rig with plates isolated from each other using resilient material, is proposed.

2.2 The receiving building structure tested

In the measurements presented in this paper, the whirlpool bath is connected to the building structure shown in Figure 2, where walls and floors are not isolated from each other. In this case, the method is only valid if the power injected by the equipment to the building element considered is much higher than the powers transmitted from the other elements.

In order to check this condition, the following vibration level measurements of the receiving elements (also called reception plates) were performed: (i) measurements of the floor and the walls with the bathtub on the floor but disconnected from the walls; (ii) measurements of the floor and the two walls with the bathtub on the floor and connected to one wall at a time. Three measurements have therefore been performed per building element \( i \). An example of the structural power components \( L_{W_{s,i}} \) obtained are shown in Figure 3(a-c). The results show that

- the structural powers injected to the floor are practically the same (differences of the same order as reproducibility), if the bathtub is fixed or not to the walls
- the structural power injected to the 18 cm concrete wall comes from the floor and not directly from the equipment,
- the structural power injected to the 10 cm concrete wall comes from the floor except at low frequencies (50 to 100 Hz) where the structural power comes directly from the equipment.

- Most of the structural energy is below 500 Hz because of the rubber feet the bathtub is resting on.

\[ Y_{\infty,rec}(\Re(Y_{rec,i})) \]

\[
L_{W_{sn},i} = L_{W_{s},i} + 10 \log(Y_{\infty,rec}/\Re(Y_{rec,i})) \quad (2)
\]

so that results can be compared in round robin tests. \( L_{W_{sn},i} \) is the normalized structural power, \( Y_{\infty,rec} \) the reference reception plate mobility (chosen as the mobility of the infinite plate, which is known as the characteristic mobility) and \( \Re(Y_{rec,i}) \) the averaged real part of the input mobility of reception plate \( i \) at the source connection points.
The bathtub is resting on the floor through five feet equipped with rubber vibration isolator and on the lateral walls on a metallic attachment bracket through a resilient layer (3 mm in thickness). This resilient layer is compressed only when the bathtub is filled with water. The connections to the floor and walls are shown in Figure 4.

![Figure 4: Pictures of the bathtub mounting elements: (a) rubber foot on the floor and (b) metallic attachment bracket to the walls.](image)

Figure 5 shows the input mobilities measured at the source connection points to the floor (5 feet positions) as well as the averaged mobility over these five positions. Below 500 Hz (where most of the structural energy is located as seen in Figure 3), the measured mobilities are lower than the characteristic mobility of the floor mainly because the connection points are close to the floor edges and corner (especially point 5).

It should be noted that only normal force mobilities are considered in Equation (2). It has been shown [3] that normal forces are dominant in the connection of a whirlpool bath to a floor; however no study has been conducted on the line connections to the walls where moments might be dominant and the normalization proposed in Equation (2) irrelevant.

The calculation of a single number descriptor for structure borne sound is proposed in the standard by fictively installing the equipment in a reference building and by calculating in dB(A) the sound pressure level transmitted to a room using pr EN
12354-5 (see Section 3 below). A correction for the 
difference in input mobility similar to Equation (2) is 
applied to transform the normalized reception plate 
power components measured in laboratory to the 
structural powers injected to the reference building 
elements (called installed structural power 
components). Once again this transformation might not 
be relevant for the structural power components related 
to the walls.

In pr EN 12354-5, the source strength is expressed by 
the characteristic structure borne sound power level 
$L_{W,sc}$ of the source. The sound pressure level for each 
transmission path $i, j$ is then calculated from the power 
injected to building element $i$ expressed as a sum 
$L_{W,sc} + D_{CJ}$ where $D_{CJ}$ is a coupling term in decibels; 
this sum corresponds to the installed power 
components defined above.

In a second step, a link to EN 12354-1 [4] is proposed 
by estimating the incident airborne sound power 
generating the same vibrational energy in element $i$ as 
the installed power component considered.

In order to check the coherence between the laboratory 
characterization method and the field prediction 
method, the sound pressure level transmitted to the 
room below by the equipment installed in the same 
receiving building structure as before was both 
calculated using pr EN 12354-5 and directly measured. 
The results are given in Figure 6 for the 3 operating 
conditions mentioned in Section 2.1. The global levels 
in dB(A) are also shown in Figure 6.

There is a rather good agreement between calculated 
and measured results, the differences being of the order 
of reproducibility. It should be noted that in the 
configuration studied,

- the contribution of the structural powers injected 
to the walls has been found negligible;
- the direct transmission path through the floor has 
been found dominant;
- pr EN 12354-5 has been modified at low 
frequencies, below the critical frequencies of the 
building elements considered in order to take into 
account the low radiation efficiency of these 
elements;
- the measured and evaluated global sound 
pressure levels are relatively close, except when 
the blower and pump are both on full speed. The 
2 dB(A) difference in this operating condition 
could be associated to the reproducibility 
problem previously mentioned.
- the characteristic mobility of the floor has been 
chosen as upper limit to estimate the installed 
power component related to the floor since the 
mobilities measured at the source connection 
points were all below the characteristic mobility 
(see Figure 5); the higher upper limit proposed in 
the draft standard so that predicted results can be 
on the safe side, might be too pessimistic.

3 Method predicting the structure 
borne sound

In pr EN 12354-5, the source strength is expressed by 
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$L_{W,sc}$ of the source. The sound pressure level for each 
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4 Discussion

The main comments are the following:

- The operating conditions for equipment such as whirlpool baths do not seem to be very reproducible.

- A correction for the difference in input mobility between laboratory reception plate and reference plate, as well as between laboratory reception plate and field receiving building element is proposed respectively in order to normalize the laboratory structural power results and to transform laboratory structural power components into installed (in situ) ones. This correction is only valid for normal force excitation.

- The upper limit proposed in the standard for the (in situ) mobility of building elements seems very pessimistic for equipment mounted close to an edge.

- The prediction method must be carefully used at frequencies below the critical frequency of the building elements considered (radiation efficiency).

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References

[1] Draft standard CEN/TC126/WG7/NE22 (work item 126 061): Laboratory measurement of airborne and structure borne sound from building equipment, taking whirlpool baths as an example. December 2004

