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Uncertainties and repeatability of the Reception Plate Method

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The Reception Plate Method (RPM) as proposed by CEN/TC126/WG7 in prEN 15657-1 estimates the structure borne sound power injected from a (high mobility) vibrating source into a (low mobility) building structure. In the near future, a round-robin test is planned to investigate repeatability and reproducibility issues of the RPM. As a preparation of this round-robin, uncertainties of the RPM are studied using two kinds of structure borne sound sources: the standard ISO tapping machine, placed on a 4 feet table on a reception plate and an industrial washing machine placed on three different bases. The influence of the source position, accelerometer positions and airborne excitation are investigated, together with repeatability tests. Also, differences in injected power between two different brands of the ISO tapping machine are studied.

1 Introduction

The Reception Plate Method (RPM) as proposed by CEN/TC126/WG7 in prEN 15657-1:2008 [1] estimates the structure-borne sound power injected from a (high mobility) vibrating source into a (low mobility) building structure. It first measures the power injected in a standardised reception plate (RP). This power level is then corrected to the power level that would be injected into a virtual infinite reception plate by multiplying it with the ratio of the known constant receiver mobility of the infinite reception plate to the real part of the reception plate mobility averaged over the source contact points. This so-called characteristic reception plate power may finally be used to calculate the in-situ installed power injected in low mobility building structures by measuring or estimating the in-situ receiver mobility. Prediction models in prEN 12354-5:2008 [2], further allow to calculate sound pressure levels due to service equipment in buildings.

In order to calculate the structural power level injected into the RP, the averaged vibration velocity level and the loss factor of the RP need to be measured in third-octave bands from 50 Hz to 5 kHz. This paper will focus on practical aspects and uncertainties related to the measurement of vibration velocity levels.

It must be seen as a preliminary study for a round-robin planned by CEN/TC126/WG7 on repeatability and reproducibility estimates of characteristic reception plate power levels of service equipment by the RPM.

Späh and Fischer already developed some practical guidelines on the number of accelerometer positions, the minimal distance to the vibration source and the minimal distance between accelerometer positions based on numerical simulations [3]. Further analytical considerations on accelerometer spacing and minimal distance to the vibration source can be found in [4]. This paper also aims to check and to further develop these guidelines by practical experience.

2 Reception plate and structure borne sound sources

The RP is a 280 x 200 x 10 cm³ reinforced concrete plate mounted on its edges on thick resilient strips in order to obtain a minimum total loss factor of 8 % up to 100 Hz. Hence, it complies with the specifications given in prEN 15657-1.

Measurements have been made using the following structure borne sound source configurations:

- an ISO tapping machine mounted on a fixed place on a concrete base plate with dimensions of 70x60x4 cm³ (about 35 kg) with four adjustable feet with a plastic bottom (see fig. 1). The vibration levels generated by airborne excitation have been found to be well below (>17 dB) the structure borne vibration levels in all considered third-octave bands (50 Hz – 10 kHz). This has been checked by re-measuring with the source slightly lifted up from the RP.
- an industrial washing machine (160 kg) mounted in three different ways: a) using a heavy-weight (200 kg) concrete base supported by steel feet (case HS); b) using the same concrete base supported by rubber feet (case HR); c) mounted on a MDF plate supported by jacks (case J) (see fig. 2). The different mountings were chosen to vary the source mobility of the washing machine. An eccentric weight of 1.5 kg was attached to the inside of the drum. Four rotating speeds from 720 RPM up to 1080 RPM have been measured, allowing 12 different source configurations.

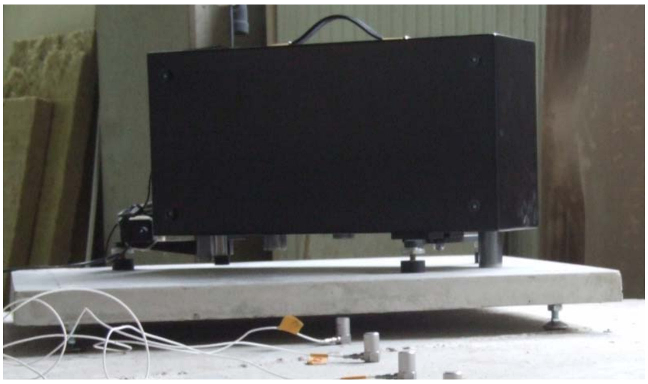

Fig.1 Tapping machine configuration.

Fig.2 Washing machine mounted on heavy concrete base on steel feet on the RP. Also visible are the jacks (supporting the MDF plate) and the rubber replacement feet (on the MDF plate).

3 Accelerometer uncertainties

3.1 Accelerometer mounting

ISO 5348:1998 [5] proposes several methods of mounting the accelerometers to the RP. Two of them are studied here: mounting with a cementing stud (see fig. 3) attached with a two-component glue and mounting with molten beeswax.

The accelerometer's fundamental resonance frequency when mounted with cementing studs is very sensitive to the thickness of the glue, the mounting torque applied and the smoothness of the accelerometer surface and may vary from 4 kHz to 8 kHz.

Mounting with a thin layer of beeswax gives a stable resonance frequency at about 10 kHz, which makes reliable measurements up to 5 kHz possible. When comparing spectra measured with both mounting methods, both curves typically start to diverge from 3150 Hz (see fig. 3). Mounting with beeswax is therefore highly preferred above mounting with cementing studs.

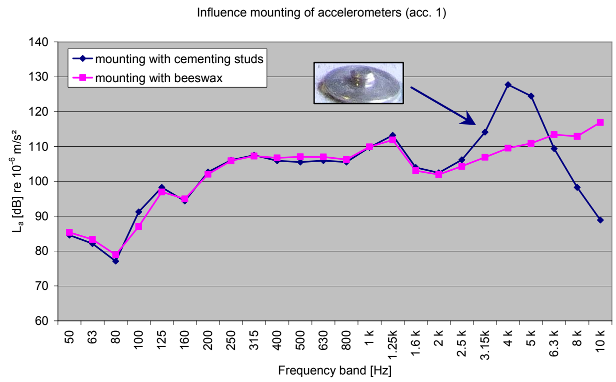

Fig.3 Typical measured acceleration level spectra of the tapping machine configuration when measured by the same accelerometer mounted respectively by cementing studs and by beeswax.

3.2 Accelerometer positioning

In prEN 15657-1, it is specified that the accelerometers shall be positioned as far as possible from the RP edge and from the equipment connection points. To study a possible <u>edge effect</u>, vibration levels were measured at every 10 cm on a line perpendicular to the RP edge (see fig. 4). At low frequencies, the vibration levels are consistent with the mode shapes of the isolated first Eigen modes of the RP. From 250 Hz, only the vibration level of the accelerometer on the RP edge is systematically larger (about 5 dB) than the vibration levels for the other measurement points. It can be concluded that at least 10 cm from the RP edge must be respected.

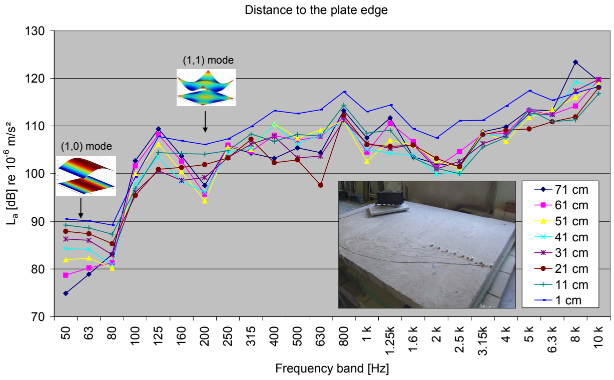

Fig.4 Vibration acceleration levels measured on a line perpendicular to the RP edge.

Similar measurements are made at every 20 cm on a line away from the source. However, no systematic <u>near-field effect</u> can be observed (see fig. 5). It must however be mentioned that the nearest accelerometer position was under the base plate edge, i.e. 20 cm from its feet.

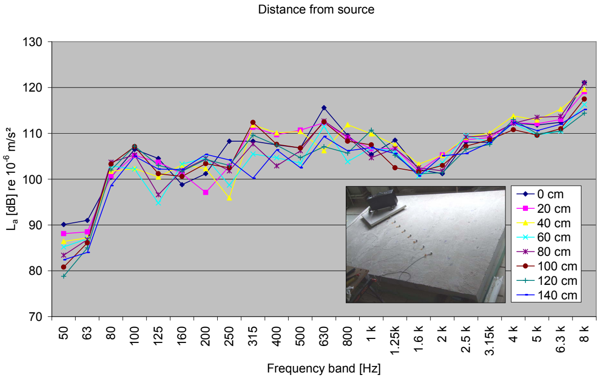

Fig.5 Vibration acceleration levels measured on a line away from the tapping machine source configuration.

There is a large <u>spatial variability of measured vibration levels</u> over the RP that does not decrease when taking more accelerometer positions because it is related to the combination of excited mode shapes (nodes and antinodes) within third-octave bands. By measuring a large number of vibration level standard deviations over 8 accelerometer positions for several vibration sources, we aim at finding a kind of reference standard deviation curve, typical for a RP with comparable dimensions.

Measurements of this standard deviation have been made for the tapping machine configuration (8 source positions, fig. 6) and for the 12 washing machine configurations (4 source positions, fig. 7). We see a large standard deviation at low frequencies because of the low number of Eigen modes per third-octave band (first Eigen mode at 58 Hz). This value gradually decreases with frequency up to 5 kHz, from which it rises again due to the sensitivity of the measured velocity level to the accelerometer's resonance frequency at about 10 kHz (not shown in the graphs). As expected, both source types yield comparable standard deviations decreasing from 5 dB at 50 Hz to 1 dB at 5 kHz.

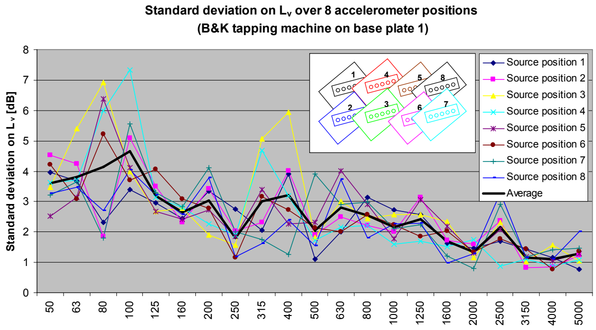

Fig.6 Vibration level standard deviations over the accelerometers for the tapping machine configuration.

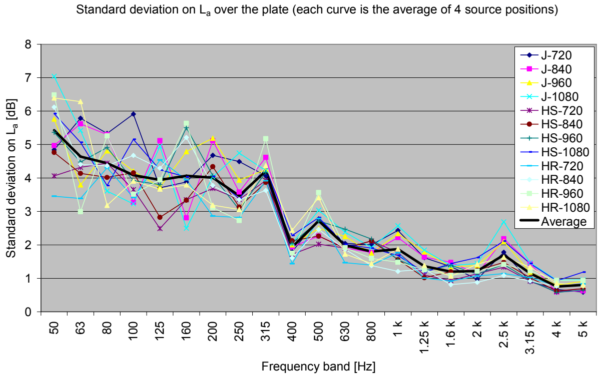

Fig.7 Vibration level standard deviations over the accelerometers for the 12 washing machine configurations.

4 Source uncertainties

4.1 Source mounting

The injected structural power level is sensitive to the way of mounting a source on the RP and also to its position on the RP. In many cases, sources will have to be levelled by adjusting feet. This effect has been studied in detail here. The concrete base with the tapping machine superposed has been re-installed several times at the same position on the RP: 8 times with readjusting the feet and 8 times without levelling. The accelerometer-averaged repeatability limits (2.8 times the standard deviation, see ISO 5725:1994, parts 1 & 6) [6,7] of the RP vibration level are shown in figure 8 for both cases and for the case where no remounting has been done. It can be seen that the repeatability of the RP vibration level, and thus of the estimated injected structural power level, is quite low, and very sensitive to mounting adjustments.

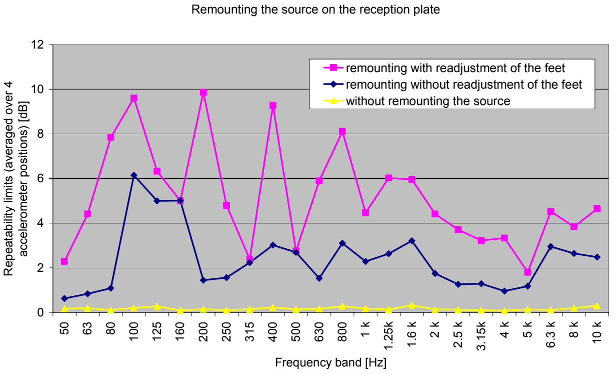

Fig.8 Repeatability limits on the measured vibration levels for the RPM for the case of remounting with and without levelling and for the case without remounting.

4.2 Source positioning

In prEN 15657-1, the source needs to be installed on the RP, according to the instructions of the manufacturer. However, neither the positioning of the source on the RP, nor the number of source positions is specified (unless the 3 plate test rig is used). Therefore the positioning of the source is studied in detail below.

The plate-averaged velocity level for 8 different source positions (see fig. 6) for the tapping machine configuration on the RP is shown in figure 9. For every source position, the following distances for the 8 accelerometers are respected: at least 80 cm from the source's feet, at least 50 cm from the RP edge, at least 30 cm between two accelerometers. It can be seen that the plate-averaged velocity level, and thus the estimated injected structural power level, varies substantially with the source position. These variations cannot be fully justified by the variation of the contact point-averaged RP mobility over the different source positions. Indeed, based on measured RP mobilities in earlier experiments, these contact point-averaged RP mobilities can be considered quasi identical for all eight source positions, seen the size of the base plates, the large number of contact points and the comparable positioning on the RP.

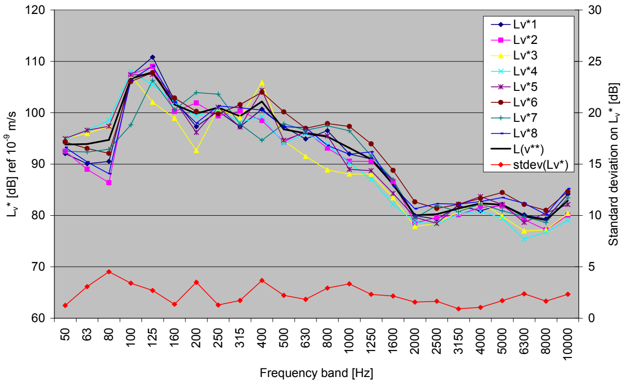

Fig.9 Plate-averaged velocity levels L_v* and standard deviation for 8 different source positions of the tapping machine configuration.

The same procedure has been repeated for the twelve washing machine configurations. Here, the 8 accelerometers were at fixed positions during all measurements. As a consequence, some accelerometers were close to some foot positions and closer to the edge of the RP than in the case above (see fig. 10). The source was installed on 4 positions, one of them at the extreme corner of the RP. Also here, although the RP corners are widely supported by resilient strips, no systematic lower RP vibration levels were seen for this extreme position.

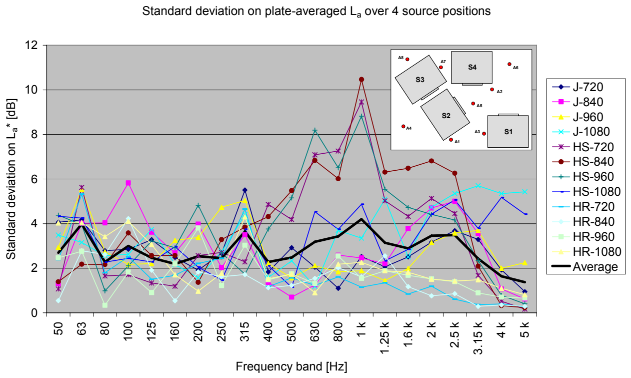

Fig.10 Standard deviations on plate-averaged acceleration levels L_a* for 4 different source positions of the 12 washing machine configurations.

The averaged source-position-related standard deviation on the plate-averaged acceleration levels is of the same order of magnitude as in the case with the tapping machine configuration. The markedly higher values for the cases with the concrete base on steel feet are due to an outlier for source position 2 (probably an unstable mounting). The low values at high frequency for the cases with the concrete base on rubber feet are due to the fact that the signal level dropped down to the background noise level.

Overall, on the assumption of a proper mounting, a good estimate for this source-position-related variation is a standard deviation between 2 and 4 dB for the whole frequency range.

5 Comparison of two ISO tapping machines

For the planned round-robin on the RPM, a suitable reference source has to be found. Because of its known force spectrum and source mobility, the ISO tapping machine is considered initially. In order to avoid having to send the same tapping machine to the different partners, the difference in injected structural power level between two standard tapping machines is studied: Bruël & Kjær Type 3207 and Norsonic Type 211. Both machines have been measured alternately on 8 different source positions on the same base plate (with identical impact point locations). In figure 11, the difference between the RP vibration levels, averaged over 8 source and each time eight accelerometer positions, is displayed. In the RPM frequency range (50 Hz to 5 kHz), the differences are smaller than 2 dB. At higher frequencies, the B&K machine injects substantially more power into the RP. This difference is nevertheless small when compared to the differences that occur when the tapping base plate is replaced by a nominally identical one (slightly different dimensions, weight and feet fixing) (see fig. 11). This indicates that the tapping machine on a concrete base plate as such is not a suitable vibration source for a round-robin on the RPM.

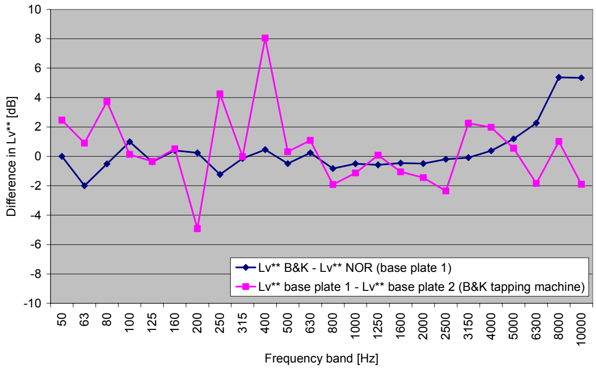

Fig.11 Difference in plate- and source position averaged RP vibration level for both tapping machines on the same base plate and for both base plates with the same tapping machine.

6 Conclusion

Some practical aspects and uncertainties related to the measurement of vibration velocity levels in the frame of the reception plate method (RPM) were studied in detail. It is found that accelerometer mounting with beeswax is to be preferred above mounting with cementing studs. Accelerometers are preferably mounted at least 10 cm from the RP edge and may be mounted close to the vibration source under test. Due to the low number of Eigen modes per third-octave band at low frequencies, standard deviations decreasing from 5 dB at 50 Hz to 1 dB at 5 kHz may be expected for vibration levels measured all over the RP.

The RPM has shown to be very sensitive to the way vibration sources are mounted, in particular the levelling of sources causes the repeatability of the method to be quite poor. The positioning of vibration sources has shown to be not critical: edge and corner positions are possible. On the assumption of a proper mounting, a good estimate for the source-position-related variation is a standard deviation on plate-averaged vibration levels between 2 and 4 dB for the whole frequency range considered.

Acknowledgments

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