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COMMISSIONING OF ROCKWOOL'S VERTICAL TRANSMISSION FACILITY ACCORDING TO ISO 10140

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Abstract

In August 2024, construction of Rockwool's Acoustic Laboratory in Hedehusene, Denmark was completed. The laboratory includes a reverberation chamber and vertical, horizontal, and flanking transmission facilities. The vertical transmission facility is being commissioned to comply with the requirements of ISO 10140. This paper presents the commissioning process, interpretation of standard's requirements, and the challenges encountered. In particular, the relationship between reverberation time, diffusivity, and loudspeaker optimization is discussed.

Selected measurement results are presented together with the testing framework used to evaluate the facility. Based on this experience, a proposed sequence of commissioning activities is also outlined for future laboratories or companies planning and commissioning similar facilities.

Keywords: *commissioning, diffusivity, iso 10140, laboratory measurements, loudspeaker qualification*

1. Introduction

In August 2024, the contractor handed over the Rockwool Acoustics Lab (RAL), and commissioning started the same year. The facility was designed and built as a research and development laboratory to support Rockwool's Operational Companies (OpCos) and to perform measurements according to international standards. It includes a reverberation chamber, three horizontal transmission rooms, two vertical transmission rooms, and two flanking transmission rooms. Commissioning began with the two horizontal transmission rooms and the reverberation chamber, while the remaining rooms are still under commissioning.

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RAL is not intended to be an accredited laboratory; instead, it aims to host external accredited laboratories that can perform accredited tests for the OpCos. Therefore, commissioning must follow a formal accreditation process conducted by an accredited external party. Sweco Danmark A/S has been invited to support the commissioning and to certify that the laboratory meets the standards.
The commissioning of Rockwool's vertical transmission facility verifies and documents compliance with the 2021 version of ISO 10140 series [1]. This commissioning process includes specific construction features, controlled reverberation time, satisfactory diffusivity, loss factor of the heavy-weight reference floor, maximum sound reduction index of the laboratory (R'_{max}) and loudspeaker (LS) qualification. Evaluating diffusivity was the first major challenge, and this paper focuses on how this was addressed.

2. Standard's requirements

ISO 10140-5 specifies that both rooms used for airborne sound insulation testing shall have a minimum volume of 50 m3 and satisfy requirements for diffusivity and reverberation time (RT). For diffusivity, the standard states that large variations in sound pressure level (SPL) indicate strong standing waves, and that diffusing elements shall be added until the sound reduction index (R) is not influenced by additional diffusers [1]. For RT, the standard states that it should not be excessively long or short [1]. If, at frequencies higher than 100 Hz, it is greater than 2 s or less than 1 s, the dependence of the measured R on RT shall be evaluated [1].

These statements leave room for interpretation. The main questions are therefore: What constitutes a large variation in SPL? What it means for the R to remain unchanged when diffusers are added? How adjusting the RT of a room affects diffusivity? And how LS qualification affects the assessment of room conditions? These are elaborated below.

The first inquiry is the absence of a numerical limit for allowable spatial SPL differences (spatial ΔSPL). In practice, this leaves two options: define a threshold subjectively or from external literature, or use the approach of adding diffusers until the R is not influenced. The second inquiry is how to determine whether the R has converged after adding diffusers. In this paper, the diffusivity is checked by measuring changes in spatial ΔSPL and in the R when adding diffusers. Here, spatial ΔSPL describe variation within a single room. If adding diffusers reduces the SPL in both rooms, the R should remain unchanged. In theory, additional diffusers should also reduce the spatial ΔSPL and standard deviation (stdev), but in practice this trend occurs only at specific frequencies. A further difficulty is that improving diffusivity at low frequencies is constrained by room size, in this case 80 and 60 m^3 for source and receiving room respectively.
A third inquiry is the ambivalent relation between RT and diffusivity. In a perfectly diffuse field, the SPL is uniformly distributed throughout the room, so no spatial ΔSPLs are expected away from room boundaries. By contrast, when absorption is introduced to the room to control RT, the SPL near the absorber will be lower than at locations without absorption and the sound field less diffuse.
The fourth inquiry concerns LS qualification of Annex D [1]. The procedure states that the suitability of source positions shall be tested so that the selected positions give results as close as possible to the mean value of many equally distributed positions in the room [1]. In practice, several source positions are used, the level differences between rooms (D) and the source room standard deviation (stdev) are measured and calculated, and the statistical criteria (stdev) in the annex are applied to select the most stable and representative positions. This can also be viewed as a way to support low spatial ΔSPL and more stable levels when diffusers are introduced in a room with controlled RT. However, the standard does not specify when, within the commissioning workflow, this should be carried out. If diffusers are added, does one need to reperform the LS qualification every single time a diffuser is added, since the room conditions have changed?
The next section presents the initial and final commissioning framework used to address these inquiries and requirements.

3. Commissioning framework and results

3.1 Initial framework

Several approaches were tested in the search for a diffusivity steady state. For all frameworks, first, the target RT was controlled as stated in [1] and further explained in section 3.2.1 of this document.

3.1.1 Standard deviation of SPL in a room

The first approach was to assess standard deviation of the source room levels, where two criteria were defined: (1) the spatial stdev should be below the requirement of Annex C of ISO 3741:2010 [2], which concerns sound power determination in reverberation chambers (relevant due to the similar assumption of a diffuse sound field); and (2) stdev should decrease and approach a steady state when an additional diffuser is introduced. The stdev was calculated from SPL measurements at six independent locations in the room and two LS positions, yielding 12 independent measurement results. Measurements were performed for seven diffuser configurations (configs.) presented in Table 1. Seven absorbers were present during all measurements (7R).
The small diffusers were rectangular surface diffusers, 0.7–0.8 m wide and 1.2 m long. The large diffusers were made from a 1.5 × 1 m rectangular sheet bent into a semi-frustum of a cone with a depth of 0.4–0.6 m. Both diffuser types were made of 5 mm thick acrylic. A photo of source room config. 9D is shown in Figure 2.
Figure 1 shows that, above the Schroeder frequency of 224–317 Hz for RTs of 1 s and 2 s, respectively, the stdev tends to be lower or close to the ISO 3741 upper limit for configs. with more diffusers, as expected. At frequencies below the Schroeder frequency, none of the diffuser configs. fall below this limit, and no clear convergence is observed. The figure also shows that the stdev depends on frequency. Overall, the results do not show a consistent reduction in stdev across all frequency bands as more diffusers are introduced.

Table 1. Diffuser configs. used during measurements. S- small diffuser; B- big diffuser. Area = one-sided area of diffusers in a diffuser config.

Room 3 (R3) = source room			Room 4 (R4) = receiving room		
Config.	Diffusers	Area [m^2]	Config.	Diffusers	Area [m^2]
0D	0	0	0D	0	0
4D	4xS	3.6	3D	3xS	2.9
5D	4xS +1xB	5.1	4D	3xS +1xB	4.4
6D	4xS +2xB	6.6	5D	3xS +2xB	5.9
7D	4xS +3xB	8.1	7D	5xS +2xB	7.8
8D	4xS +4xB	9.6	-	-	-
9D	4xS +5xB	11.1	-	-	-

3.1.2 In-house ΔSPL threshold

An in-house criterion was then tested, where the ΔSPL between two diffuser configs. in a room should satisfy

$$\Delta SPL = \left|SPL_{(x)D} - SPL_{(x+1)D}\right| \leq 0.5\ dB \qquad (1)$$

where x is the total number of diffusers in a room, $SPL_{(x)D}$ is the SPL in the room for the previous diffuser set, and $SPL_{(x+1)D}$ is the SPL in the room for the newly introduced set. Thus, the last introduced set contains more diffusers than the previous one. Equation 1 implies that the expected difference in the measured R is ≤ 1 dB, which for the authors may be considered an insignificant change in R.

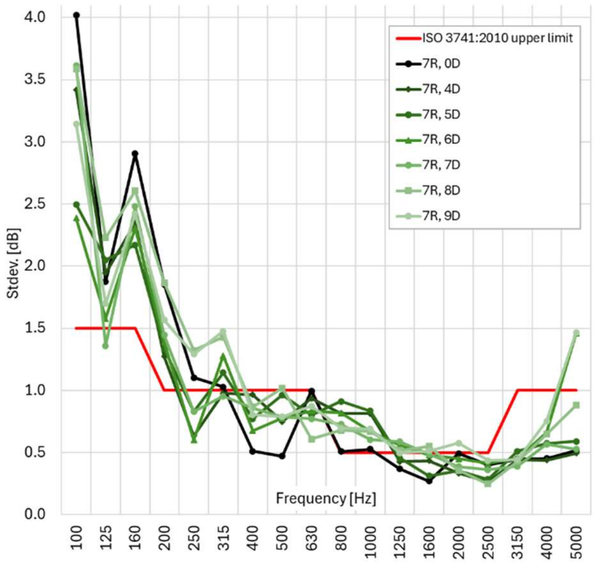

Figure 1. Standard deviation of spatially independent SPL measurements in source room for different diffuser configs.

Figure 3 shows the SPL changes in the source room. Only the changes from 100 to 1000 Hz are plotted, because, as shown in the stdev above the Schroeder frequency is expected to be minimal. The expected trend of the ΔSPL decreasing when adding a diffuser is not observed here, the ΔSPL values are erratic, with no clear trend, especially up to 200 Hz. Above this frequency the ΔSPL values satisfy the criterion. These results show that ΔSPL is frequency dependent. Depending on the frequency band, a decrease in ΔSPL may appear, but adding diffusers may cancel it and instead increase the ΔSPL in another band. Therefore, no clear convergence is observed for any diffuser set, especially at low frequencies.

3.1.3 In-house uncertainty threshold

Another potential criterion was then tested. The sound reduction difference (ΔR) between two diffuser configs. should be smaller than the repeatability standard deviation σ_r according to Table 2 of ISO 12999-1:2020 [3], which deals with the uncertainties of building acoustic measurements:

$$\Delta R = \left|R_{(x)D} - R_{(x+1)D}\right| \leq \sigma_r \qquad (2)$$

The purpose of this criterion was to define a numerical, frequency-dependent threshold, consistent with the behavior observed in the previous approaches. In ISO 12999-1, the upper limit for repeatability standard deviation is larger at lower frequencies, between 0.7 and 1.4 dB, and 0.6 dB at frequencies from 400 Hz and above.

Figure 2. Source room with a lightweight deck in the test opening, showing semi-frustum of a cone diffusers, surface diffusers, tuned absorbers and measurement equipment.

Measurements of R were performed with different diffuser configs. in both rooms. The deck between the rooms consisted of 22 mm plywood mounted on 180 × 120 mm wooden beams. Two aleatory source positions were used for the level measurements, in accordance with Section 4.2.2 of ISO 10140-4. The type of deck used for these measurements was selected with future LS qualification in mind (Annex D of ISO 10140-5), where a test element with low R is required according to Section D.1.4.

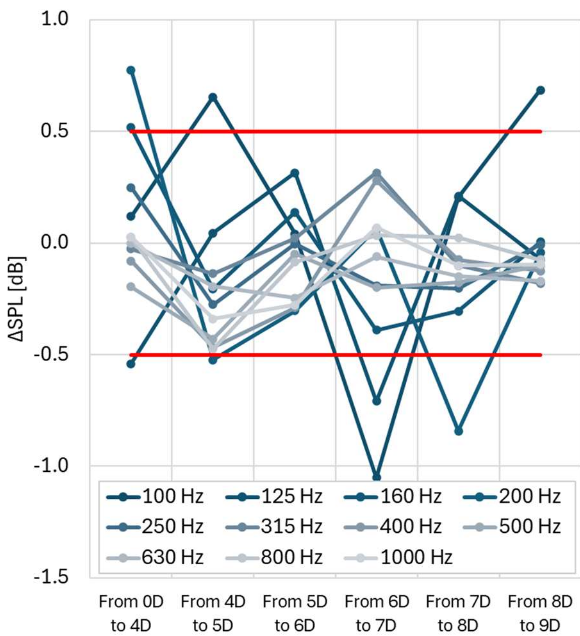

Figure 3. Change in spatial average SPL between different diffuser configs. from 100 to 1000 Hz. Moving microphone boom used in the source room.

Figure 4 green lines show the results obtained for R of the test element with closed gate between the source and receiving rooms. The measurements do not comply with the set requirement of σ_r at low frequencies for any diffuser configuration, reaching ΔR of up to 1.9 dB at frequencies up to 250 Hz. Above 400 Hz, R varies only slightly, regardless of the number of diffusers, and the criterion in Equation 2 is satisfied, with a maximum σ_r of 0.5 dB.

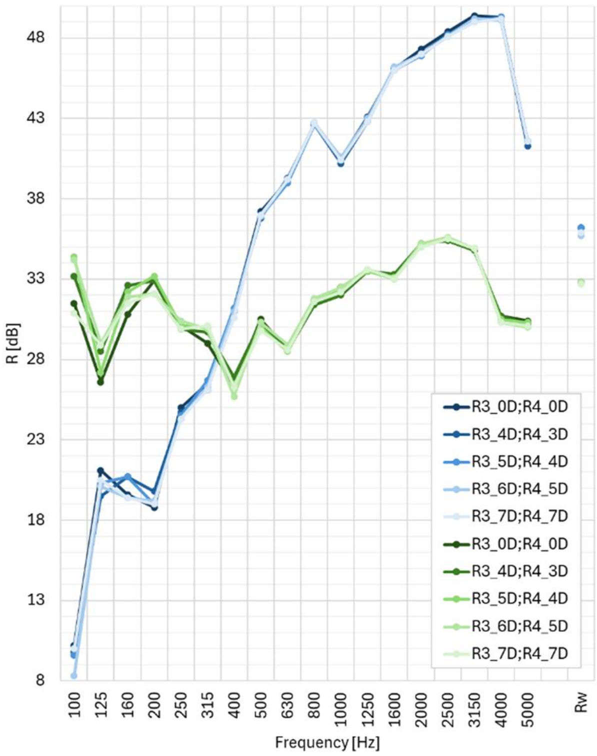

Figure 4. Measured R of two different decks with 5 different diffuser configs. Green lines-measurements with 2 random source positions; blue lines-measurements with 4 best source positions from preliminary LS optimization.

3.2 Final framework

After several unsuccessful attempts to identify a clear trend toward a diffusivity steady state, another framework was proposed and followed. The proposed sequence is: controlled RT (Section 4.2.3 of ISO 10140-5), source spectra equalization (Section 6.1 of ISO 10140-5), preliminary LS qualification (based on Annex D of ISO 10140-5) with no diffusers, diffusivity verification, and final LS qualification (Annex D of ISO 10140-5).

3.2.1 Controlled RT

As with the other approaches, all measurements were performed in a room with controlled RT. The RT was measured using a heavyweight reference floor in the opening. The RT was then verified to fall within the recommended normal range, typically 1–2 s under normal test conditions, to ensure that the measured quantity is not unintentionally biased by an "out-of-range" RT. If RT exceeded 2 s, targeted absorbers were applied on walls.

3.2.2 Source equalization and spectrum verification

Next, the loudspeaker was adjusted so that, on average in the source room, adjacent one-third-octave bands differed by no more than 6 dB. Although not stated in the standard as a specific requirement for diffusion, this step is expected to reduce band-edge sensitivity and masking room-mode or diffusion effects. This improves the robustness of the band averages and reduces bias.

3.2.3 Preliminary loudspeaker qualification

The preliminary loudspeaker qualification was performed in a room with no diffusers to avoid obviously poor source positions, to ensure reasonable excitation of room modes and to yield results close to the "many positions" mean. Four statistically best preliminary qualified loudspeaker positions were chosen for diffusivity verification.

3.2.4 Diffusivity verification

Finally, a diffusivity verification similar to section 3.1.3 was performed with four optimized loudspeaker positions to ensure compliance with the requirement that R should not be affected when additional diffusing elements are installed. This can be evaluated by treating diffusivity verification as a before-and-after comparison under repeatability or reproducibility conditions, using the same measurement conditions with only the diffuser config. changed. The results of this verification are presented in Figure 4 with blue lines. At 250 Hz and above, the variation of R between successive diffuser config. (ΔR) is up to 0.4 dB, and the variation is up to 1.3 dB at lower frequencies when changing from diffuser config. R3_5D;R4_4D to R3_6D;R4_5D. These values are considered marginal and fulfil the requirement of ISO 12999 Table 2. By comparison, as shown in Figure 4 with green lines, when R is measured using two aleatory loudspeaker positions, the ΔR is up to 1.9 dB at frequencies up to 250 Hz and up to 0.5 dB at higher frequencies. As shown in Figure 4, when R is measured with the same diffuser combinations but using four preliminary qualified source positions instead of two aleatory source positions, and equalized source spectra, the ΔR show smaller differences and a more similar frequency spectrum across the different configs., and a change in Rw of up to 0.5 dB. This highlights the importance of the order of activities in the laboratory commissioning process. It also shows that loudspeaker qualification and equalization play a significant role in the assessment of diffusivity and should be performed before diffusivity verification.

3.2.5 Final loudspeaker qualification

Once the final diffuser configuration is chosen, the final ISO 10140-5 Annex D loudspeaker-position qualification was performed with the determined number of diffusers. The final N source positions were recorded and will be used for future measurements.

4. Conclusions

Commissioning a vertical transmission facility requires not only meeting numerical limits but also following a specific framework. In this study, reverberation time, diffusivity, and loudspeaker qualification were treated as linked conditions that influence the stability of sound reduction measurements. The results show that the SPL in the room and diffuser effects are strongly frequency dependent, especially at low frequencies, where convergence is difficult to demonstrate. A structured sequence of controlled reverberation time, source equalization, preliminary loudspeaker qualification, and diffusivity verification provided a practical route to compliance. It was also shown that compliance can be assessed by directly verifying that the sound reduction index is not affected by diffusers, rather than by proving that sound pressure level variations are not large, since the standard does not define numerical limits for such variations. This framework provides a clear basis for commissioning similar laboratories while maintaining a consistent interpretation of ISO 10140.

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