Room acoustics, sound insulation design and supervision for a multimodal measuring laboratory

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Introduction

For analysing sound design in acoustics measuring labs have become essential. However, the integration of acoustic equipment in existing laboratory rooms and the build-up of acoustic labs still remain challenging. The IAS as part of the TU Dresden set up a new laboratory for measurements and subjective assessment of **multimodal stimuli**. The laboratory rooms had to be integrated into an existing faculty building. The demands to the acoustic quality in terms of reverberation time and absence of noise were remarkably high since the intended experiments required that presentations of acoustic stimuli as well as vibrations were included. Both had to be connected with optical information on a projection screen.

Acoustic quality demands

Sound insulation

To minimize acoustical disturbances during the intended experiments, a low background noise level is essential for the laboratory operation. Therefore a noise limit according to GK 10 was set (defined in DIN 15996 [1], see Figure 1).

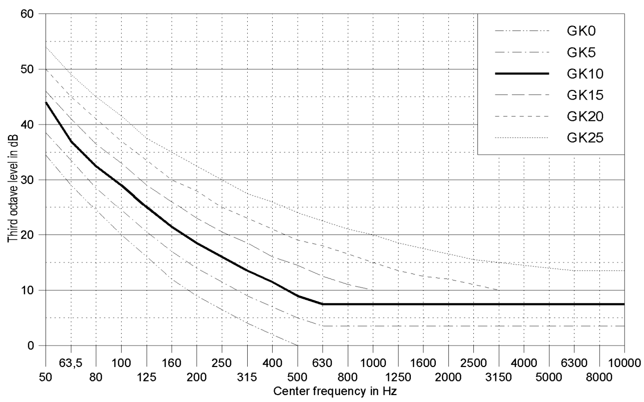

Figure 1: Spectral limit values for third-octave background noise levels (DIN 15996, GK 10)

Noise levels to be expected in neighbour rooms of the laboratory were widely unknown. ,Thus aim values for sound insulation were defined according to OIRT-recommendation R 53 for broadcast studios:

-weighted apparent sound reduction index $R'_w > 70$ dB (for walls, ceiling, floor)

-weighted normalised impact sound level $L'_{n,w} < 48$ dB

-weighted apparent sound reduction index $R'_w > 50$ dB (for windows).

Room acoustics

The optimum reverberation time value depends on the volume of the laboratory room and is also defined in DIN 15996 [1]. For the room size of 77 m^3, the reverberation time value should be between 0.22 s and 0.37 s with a frequency response according to DIN 15996 [1]. Furthermore, acoustic disturbances like flutter-echoes and sound concentrations are to be avoided.

Design concept

Background

Besides the measuring laboratory itself, rooms for the preparation of test persons, the control of experiments and the technical equipment are to be provided (see Figure 2).

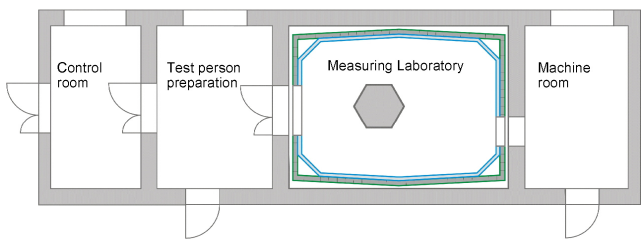

Figure 2: Overview of lab room arrangement

Sound insulation

The lab rooms are part of a faculty building erected in the 1950s. Earlier investigations showed poor sound insulation for the existing building structure. Most of all, the impact noise level remarkably exceeded the thresholds set by quality demands for studio rooms. The reason is the stone ceiling construction (ACKERMANN ceilings) without floating floors. Improvements in sound insulation in a range of 20 dB required a room-in-room construction with solid inner shell. Existing window openings received fillings of masonry. After removing the old floor of the lab room, a new ferro-concrete floor was installed at a lower level, serving both for better sound insulation and more room height (see Figure 3 and Figure 4). Mineral fibre is filling the space between old masonry and inner shell of the room-in-room system. This shell is formed by U- and double-T beams bricked up with 11.5 cm wide lime sandstones. The ceiling of the inner shell was closed with 8 layers of gypsum plaster board inserted between the double-T beams. A chipboard layer served as permanent shuttering for the floor screed with a thickness of 8 cm. Both floor and walls are supported by longitudinal beddings for elastic decoupling.

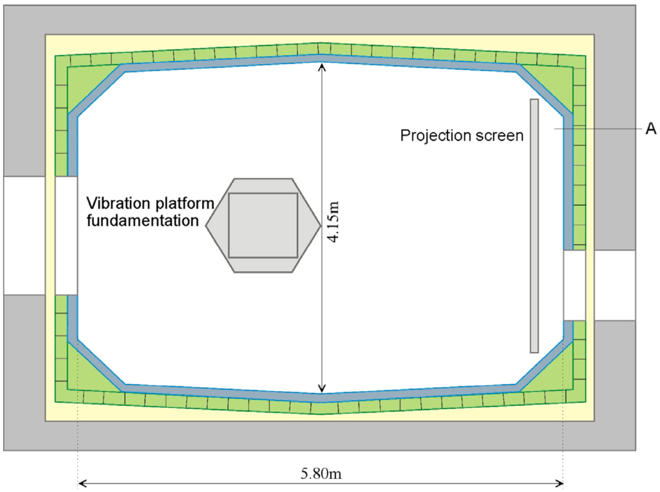

Figure 3: Ground plan of laboratory room with:

A: wall structure from right to left: masonry (old), mineral fibre 10 cm, steel skeleton with 11.5 cm lime sandstone, mineral fibre 15 cm, perforated metal sheets

One major problem was to find a compromise between the floor's static stability and a low resonance frequency not exceeding a value of about 20 Hz. Finally, beddings with relatively low stiffness were combined with deflection limiters. An accessible raised floor with a spacing of 27 cm is provided for cable installations as well as for air supply. For that purpose, some of the raised floor plates are perforated. The air exhaust opening is situated in the wall/ceiling edge next to the preparation room. The machinery of the AC system could be placed below preparation and control room in a chamber that does not own common walls with the lab room itself. AC machines obtained separate elastic foundations for vibration protection. For air supply and exhaust ducts, various silencers were designed to fulfill the demands of a very low background level.

The vibration platform obtained an independent ferro-concrete foundation separated from the ferro-concrete floor plate. The gap between fundamentation and floor plate is filled with dampening mineral fibres preventing sound transmission from below to the laboratory (see Figure 4).

For doors and windows, systems with sufficient sound insulation needed to be chosen. The most critical doors in the inner shell of the lab room were designed with a rated sound reduction index of 47 dB at minimum.

Room acoustics

To meet the narrow tolerance range of reverberation time, room surfaces have to be covered with spectrally matched absorber materials. In the design process, a three-dimensional room model was created using the self-programmed acoustic simulation software PAULA. This tool was used to optimize the absorber distribution in order to achieve a possibly even frequency response of reverberation time. Impulse response computations gave indications to possible problems with the temporal structure of the sound field (e. g. echoes). To prevent the lab room from flutter-echoes side walls were inclined by about 3° to avoid parallelism.

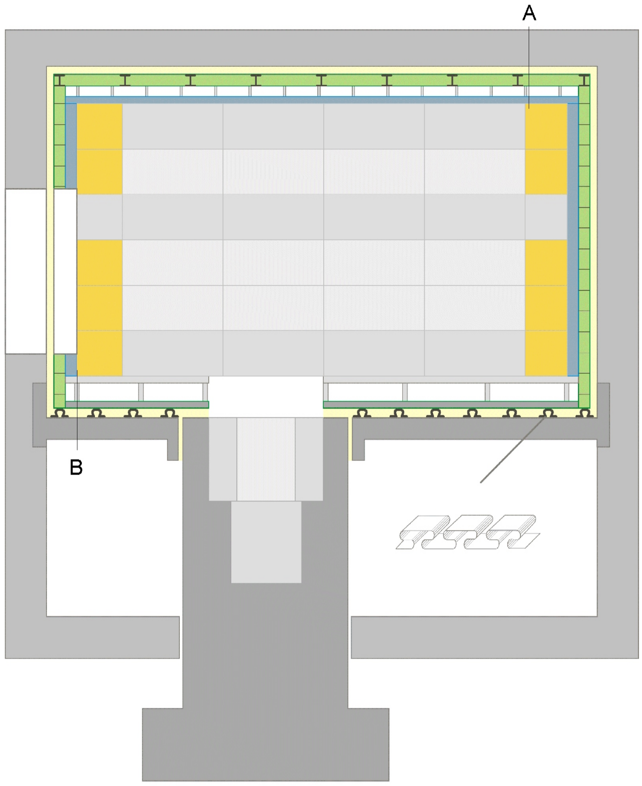

Figure 4: Lab section with

A: ceiling structure (from above: stone ceiling 34.5cm, mineral fibre 10cm, steel profiles with 8 gypsum board layers (10cm total), air spacing 10 cm, mineral fibre 3cm, perforated metal sheets

B: Floor layer structure (from below): ferro-concrete 25cm, mineral fibre 10cm with longitudinal beddings, fibreboard 2cm, screed 8cm, air spacing 27cm, raised floor 4cm, dampening felt lining

For choosing the right absorber surface several alternatives were evaluated. A uniform visual appearance of the surface is important since the attention of test persons shall not be attracted by the room but by the experimental stimuli presented in the laboratory.

In the end an absorber system with perforated metal sheets was chosen. The raster of the sheet elements at the wall is visualised in Figure 4. All elements covering walls and ceiling were given the same color (light grey) and the same perforation with an open area of 20 %. Variable absorbing coefficients could be realised using different types of inlays (mineral fibre only, additional plastic foil, additional imperforated metal sheets). One horizontal band of absorber elements was designed for later integration of a Wave Field Synthesis (WFS) loudspeaker system.

In the room edges, adjustable Helmholtz resonators were provided for low frequency absorption and room-mode dampening.

Supervision experiences

The building process was very complicated since the surrounding faculty rooms were in normal operation. Thus, one task of supervision was mediation between building labour and faculty staff displeased about noise and other disturbances. Due to the high quality demands and the difficult working conditions, the project took about 8 months from the start to taking over by the user.

Obviously, permanent supervision was absolutely necessary to achieve the high demands to acoustic quality. Our experience showed, even construction companies specialized in acoustics do not always act very sensible with respect to the results of their work on acoustic quality. Therefore every single work step both structural works and finishings had to be checked and, if necessary, corrected. A choice of inaccuracies is for instance: untight construction of the inner shell, untight door frames, leaky lead-throughs of air ducts and cables, material joints between vibrationally decoupled elements, rattling metal sheets. During supervision, noise and vibration measurements delivered valuable indications for necessary construction changes.

Results

The successful realisation of the acoustic design concept is indicated by measurement results for sound insulation and room acoustics. A selection of results for sound insulation is given in the following:

- weighted apparent sound reduction index:

R'_w = 74 dB (wall from corridor to lab room)

R'_w = 72 dB (ceiling of lab room)

R'_w = 48 dB (door to lab room)

- weighted normalised impact sound level :

$L'_{n,w}$ = 32 dB (ceiling of lab room)

$L'_{n,w}$ = 32 dB (corridor floor to lab room).

These results indicate a high standard in sound insulation. The threshold for the background noise according to DIN 15996, GK 10 can be kept even with the AC system at maximum power (see Figure 5).

Room acoustic quality is mainly indicated by the spectral response of reverberation time. After fine tuning of the Helmholtz resonators reverberation time was measured in the lab room using the method of pulse response backward integration. Figure 6 is indicating mean values of a total of 8 measurements. The curve is very uniform above 100 Hz and is generally situated at the lower end of the tolerance regions. One should notice that a certain partition of broadband absorbers will be removed if the lab is completed with the WFS loudspeaker system. The reverberation time curve will fit even better in the tolerance range after implementation of the WFS system.

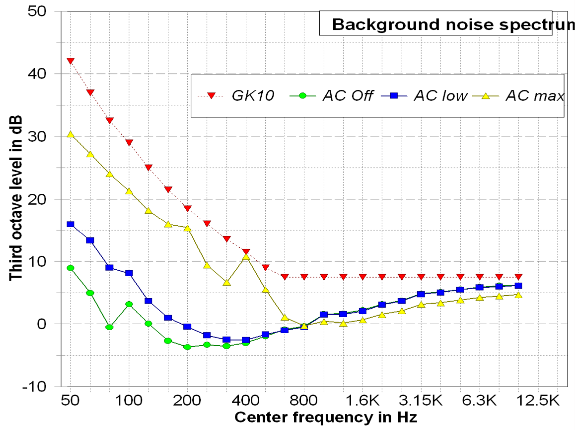

Figure 5: Measured background noise spectrum in the laboratory room with different settings of the AC system

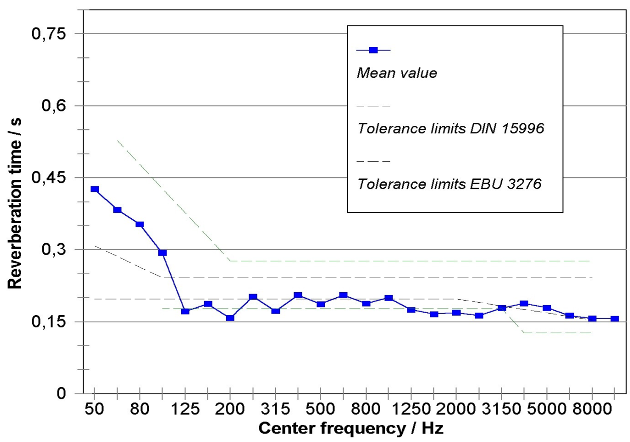

Figure 6: Measured mean values of reverberation time as a function of frequency in the completed laboratory room

References

[1] DIN 15996: Image and sound production in film and video studios and radio stations- Principles and provisions for a work station, Deutsches Institut für Normung, February 2006

[2] EBU Tech. 3276: Listening conditions for the assessment of sound programme material - monophonic and two-channel stereophonic, European Broadcasting Union, May 1998