Audio Control Room Optimization Employing BEM

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Abstract

The Boundary Element Method (BEM) is a state-of-the art tool in many engineering and science disciplines. In acoustics, the usage of BEM is increasing, especially for low frequency analysis, since the computational effort for small to medium geometries and long wavelengths is comparatively small. While BEM is well known to give reliable results for correctly programmed room shapes, the poster at hand demonstrates that the BEM model can also respond accurately to inserted absorptive materials, and hence the method is useful for virtually prototyping the efficiency of proposed acoustical modifications ahead of actual construction. Please refer to the full convention paper 9967 [1] for more detailed information.

Introduction

The analytical listening, recording, editing and mixing tasks of a sound engineer in an audio control room demand perfectly neutral listening conditions. For studio planning and design, this is a specifically challenging requirement in the low frequency domain. Two typical effects can occur: strong level differences in the frequency response, and slow decay of sound energy. Both can be explained utilizing the modal sound field which is dominant in the low frequency range.

The space between two reflective, opposing walls can be excited to a resonance with a particular set of frequencies. As commonly known, these are called modal frequencies, natural frequencies, or eigenfrequencies. The eigenfrequencies of a rectangular room can be calculated using the Rayleigh equation 1 [2, p. 230].

$$f_{eigen} = \frac{c}{2}\sqrt{\frac{n_x^2}{l_x^2} + \frac{n_y^2}{l_y^2} + \frac{n_z^2}{l_z^2}} \qquad (1)$$

c is the speed of sound, n_x, n_y, n_z natural numbers (including zero) and l_x, l_y, l_z length, width and height of the room.

Non-parallel, opposing, and reflecting walls also show standing waves, but not as prominently as parallel walls. The BEM is an approach that takes into account the effective spatial geometry, as well as absorption, and the positions of the sources and the receivers.

Said Method is a numerical procedure for solving the wave equation (eq. 2), a partial differential equation.

$$\Delta p - \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2} = 0 \qquad (2)$$

Δ is the three-dimensional laplace operator, c is the speed of sound, and p is the sound pressure. If the problem is now limited to sine-shaped waves, the wave equation can be simplified to the Helmholtz equation (3), which is no longer time-dependent.

$$\Delta p + \frac{\omega^2}{c^2} p = 0 \qquad (3)$$

Δ is the three-dimensional laplace operator, ω the circular frequency, c the speed of sound, and p the sound pressure as a complex amplitude function. The Kirchhoff-Helmholtz integral describes the relationship between the sound velocity and sound pressure on a closed enveloping surface and the complex amplitude function at an arbitrary receptor point to this enveloping surface. With the discretization of the enveloping surface to suitable n partial surfaces and assuming that the sound field sizes within a partial surface remain constant, the problem becomes an equation system with n unknowns. It can be solved satisfyingly accurate with today's computing power for the low frequency range. The BEM software used in the works at hand is ABEC [3].

Own Investigations

Geometry

The room under investigation is an audio control room. There is a clearly measurable notch in the frequency spectrum just below 100 Hz. Figure 1 shows the plan view. The interior dimensions are $6.50m$ x $4.91m$ x $2.64m$ (L x W x H). Length and width are averaged values. The volume is $84m^3$ and the room is built using decoupled drywall construction. The monitors are Barefoot MicroMain 27 on both sides including Barefoot subwoofer expansions.

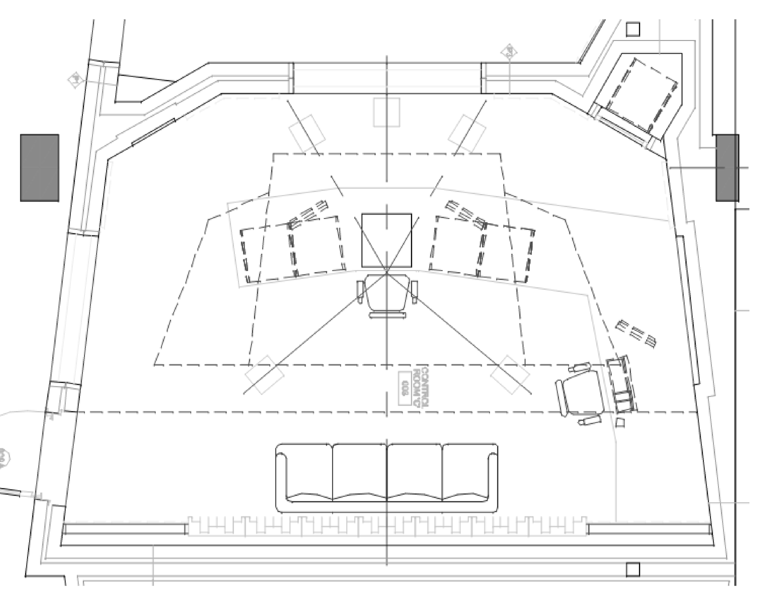

Fig. 1: Plan view of the control room.

Measurements and Simulations

The measured frequency response in figure 3 clearly shows the issue: the dip in the frequency response between 80 and 100 Hz can be observed, which is more than 10 dB lower than the neighboring maxima. Following the measurements, the geometry of the room was modelled in the BEM software. The existing absorbers were inserted with corresponding absorption properties. The values are estimates and are based on previous investigations, see also [4], which have been normalized for this study. The tuning frequency or maximum absorption of the low frequency absorbers, which in both cases is in the 50 Hz range, is of main relevance for this project. The absorbers are marked in figure 2.

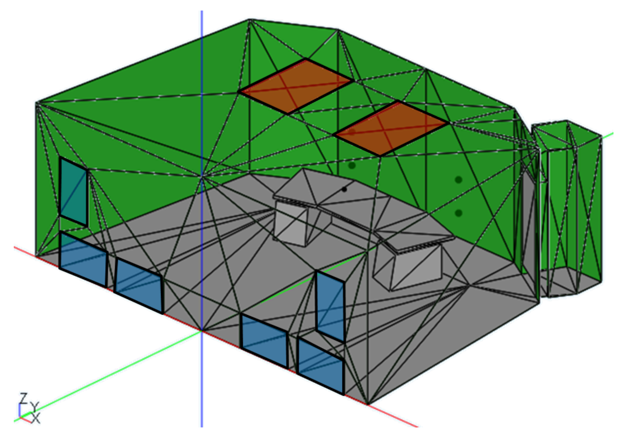

Fig. 2: Existing low frequency absorbers in the BEM model: Pawel absorbers on the rear wall, VPR on the ceiling.

Since the walls and ceiling were built in drywall construction, additional damping was added to the system for the walls and ceiling by absorption of $\alpha = 0.10$, which results in a slight smoothing of the frequency response and is more consistent with the measurement.

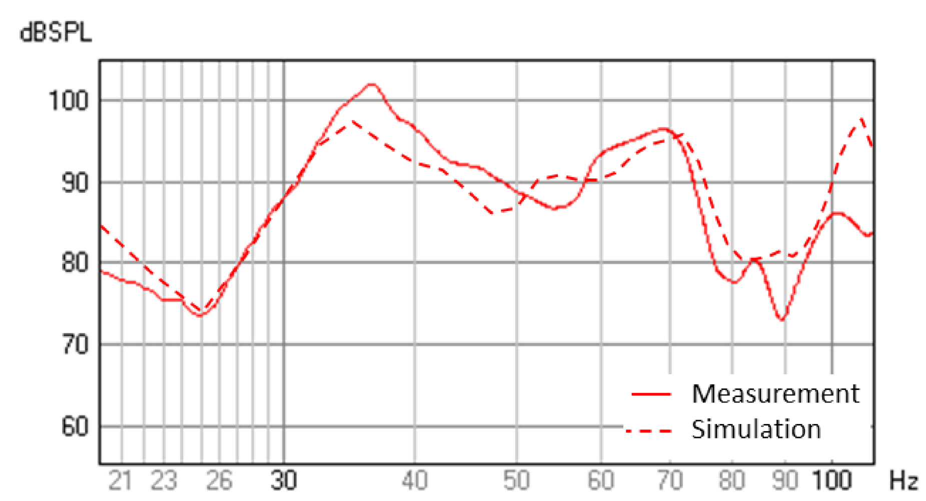

Fig. 3: Frequency response measured (continuous) and simulated (dashed).

Figure 3 shows the measured as well as the simulated frequency response. The simulation of the frequency response matches the measurements very well, especially in the problematic areas (around 70 Hz and around 90 Hz). In the 110 Hz range, the model shows a peak which is not mirrored in the actual measurement.

The matched model can be employed to calculate the pressure distribution in the room on user-defined surfaces. This was done for the most prominent frequencies 70 Hz, and 90 Hz, see figures 4, and 5. Following observations can be made:

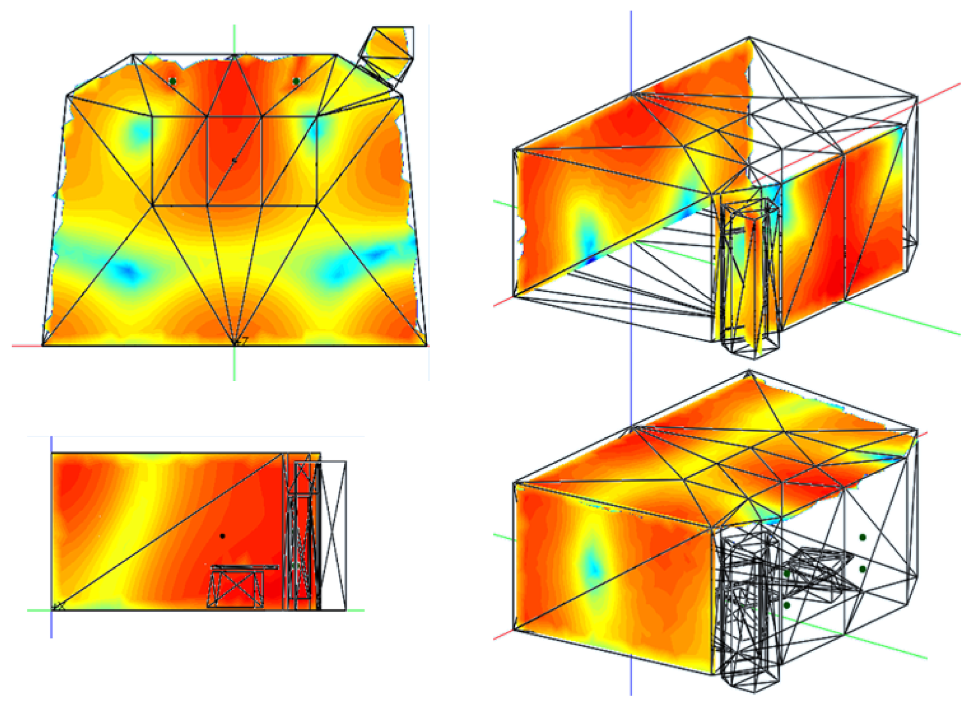

Fig. 4: Pressure distribution for 70 Hz.

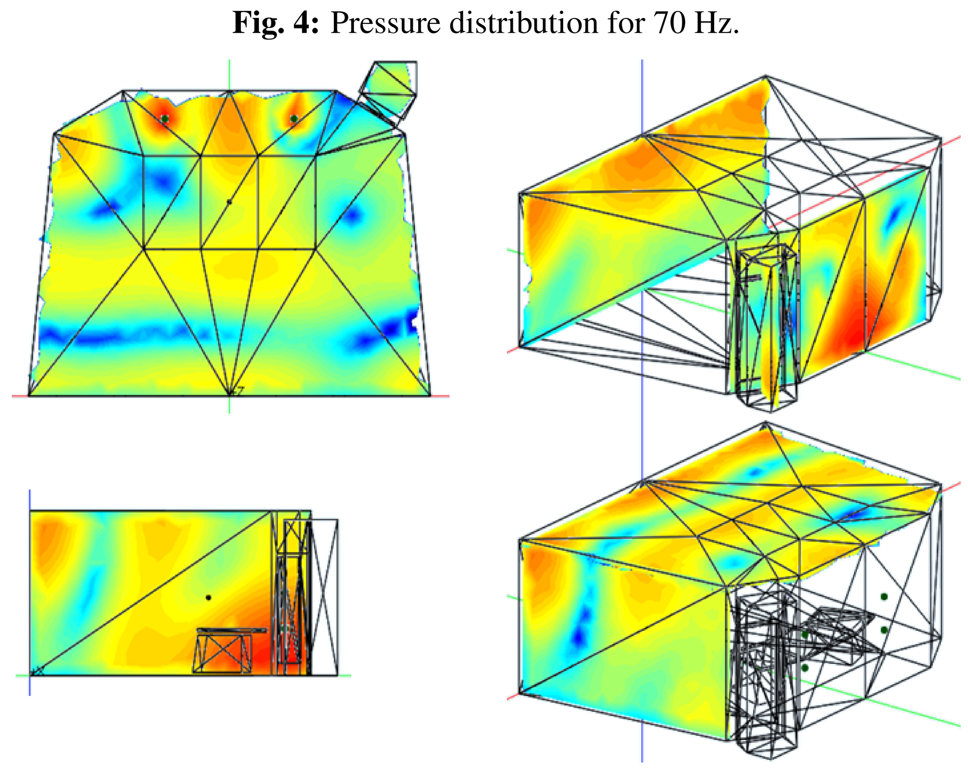

Fig. 5: Pressure distribution for 90 Hz.

35 Hz: Boost in frequency response. The lowest axial mode between the front and rear wall is at 36 Hz.

60 Hz: Relatively high pressure at the listening position in the measurement, less pronounced in the simulation.

70 Hz: Maximum in frequency response. The second axial mode between front and rear wall is at 71 Hz and further eigenfrequencies are close to this frequency. In the pressure distribution (see fig. 4) the node is not exactly visible, but it is obvious that the effect occurs mainly between the front and rear wall.

90 Hz: There is remarkably little pressure in the entire room. The pressure distribution may show high pressure at the listening position, compared to other areas of the room, but with very low sound pressure level. The frequency response confirms the low pressure by showing a dip. It can be assumed that the modal effect involves room modes between the front, lower room edge, and the rear, upper room edge. At 80 Hz (measurement) resp. 82.5 Hz (simulation) there is an additional minimum which is at least partly related to the third axial mode between the side walls. The drop in the frequency response is thus widening.

The minimum at 90 Hz in the frequency response is the most problematic and is therefore prioritized.

Interpretation and Recommendations

Various measures were tested in the simulation for the desired effect. The frequency response depicted in figure 6 shows the result of these iterative BEM simulations.

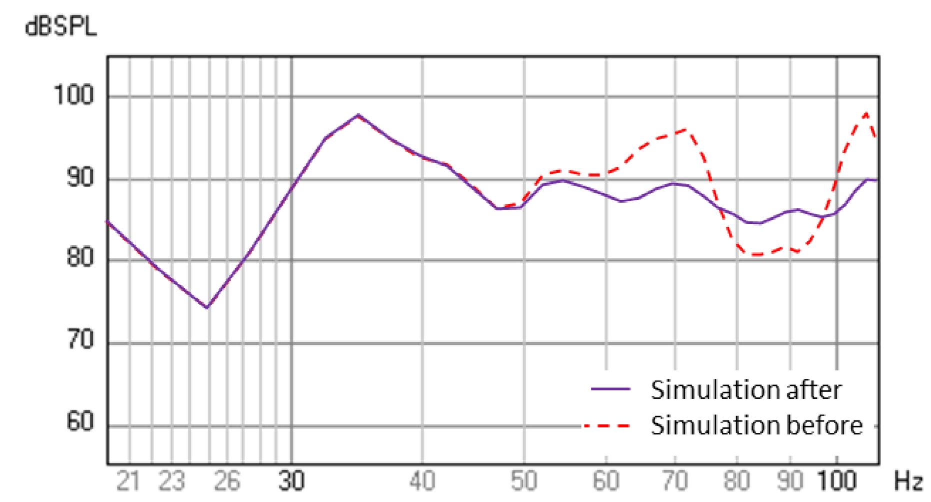

Fig. 6: Frequency response simulation before (dashed) and after (continuous) the measures.

The desired correction of the simulated frequency response was finally achieved with the following measures, arranged according to descending priority, in terms of their effectiveness:

1. Absorption of 90 Hz and the neighboring frequencies at the upper rear wall.
2. Absorption from 60 Hz to 70 Hz between the mixing console and the front wall on the floor. According to the BEM model, absorption of 90 Hz at this position results in a level reduction at 90 Hz in the entire room, which must be avoided.
3. Absorption from 60 Hz to 70 Hz at the front ceiling between the existing VPR absorbers and the front wall.
4. The model also shows an elevation at 105 to 110 Hz, which is why measures are proposed at the front side wall for completeness.
5. The room mode at 35 Hz can be effectively absorbed on the rear or front wall. A reduction by means of an equalizer is considered effective here as well.

Conclusions and Outlook

The influence of position-specific absorption on the sound pressure field in the audio control room was clearly demonstrated and examined in the BEM analysis for the low frequency range. It was confirmed that in order to control low frequencies in small rooms, precisely adapted measures are necessary. It was shown that these can reliably be developed in a BEM analysis.

Uncertainty lies in the absorption data of the used treatment, which is based on estimation and calculation, as well as the entire room envelope (drywall), which was modeled to be slightly absorptive but independent of frequency. The room geometry and surface details have been simplified according to the highest frequency to be simulated and certain pieces of furniture have been omitted.

Further research includes carrying out a BEM analysis with optimization process and to investigate its accuracy for a project with problems in the low frequency range in time domain.

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References

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[2] Everest, F. and Pohlmann, K., *Master Handbook of Acoustics*, McGraw-Hill Education, 2009, ISBN 9780071603331.

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