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Numerical and Experimental Investigations of Noise Barriers with Helmholtz Resonators

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Noise barriers are known to be an effective instrument to diminish the propagation of traffic noise. In view of required construction heights one seeks to extend the effectiveness of existing or projected noise barriers by means of properly designing the diffraction edge. Here, earlier investigations have demonstrated the potential of integrated Helmholtz resonators within the upper barrier edge. Based on numerical investigations including the indirect boundary element method, procedures have been developed to allow for the optimization of the outer shape and resonator layout of barrier tops. Using this approach, the diffraction edge is dimensioned with respect to given environmental conditions. Experimental investigations are presented in order to verify the computational results. The presented results demonstrate the efficient contribution of appropriate resonator edges to improved, yet moderately high noise barriers.

1 INTRODUCTION

Noise barriers are a widely applied instrument for the protection against traffic noise. Still, one seeks to improve the effectiveness of noise barriers under the restriction of moderate construction heights. The design of the upper edge becomes an increasingly important matter in enhancing noise barriers, because acoustic diffraction is most often the ruling instance for remaining noise impact.

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Earlier investigations about diffraction edges of noise barriers have shown how the integration of Helmholtz resonators into the diffraction edge can improve the shielding effectiveness, comparable to the characteristics of diffraction edges with ideally vanishing surface impedance[1-4]. Yet, the performance of Helmholtz resonators is strongly frequency dependent and therefore subject to an optimization process considering given environmental conditions.

For the sake of comparability, earlier and presented optimizations are conducted for the given environmental geometry as displayed in Figure 1. The two-dimensional model of the sound barrier consists of a vertical plane screen and an (initially) cylindrical diffraction edge on top, with an overall height of 3.7 m. The sound barrier is placed upon the horizontal symmetry plane and subjected to a point source with frequency-invariant source amplitude, exemplarily representing traffic noise in the considered frequency range. The effectiveness of the sound barrier is evaluated by means of the sound power penetrating a vertical plane into the shielded area behind the barrier.

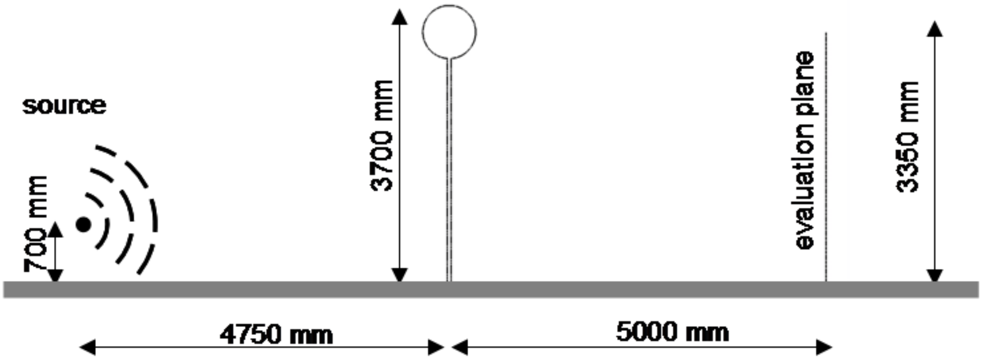

Fig. 1 - Geometry of environmental application condition.

Results of earlier investigations are shown in Figure 2 [5]. The sound power propagation through the evaluation plane is calculated for frequencies from 100 Hz to 2000 Hz, where an acoustically soft edge (surface impedance $Z = 0$) is compared to a rigid edge (impedance $Z \to \infty$). The apparent improvements are desired to be achieved also by resonators that are intended to implement approximately the ideal zero impedance conditions. In Figure 2, the resulting sound power for a layout of resonators is also displayed, where the configuration is focused on the frequency range from 400 Hz to 2000 Hz.

Design and optimization of the resonators integrated in the diffraction edge will be addressed in the present paper. Beforehand, the outer shape of the diffraction edges considered is submitted to a shaping process.

2 SHAPE OPTIMIZATION

For the purpose of resonator placement the shape of the considered diffraction edge is required to provide sufficient installation space within the cross-section. Beyond this demand, it is possible to design the outer shape of the diffraction edge with the objective of further noise

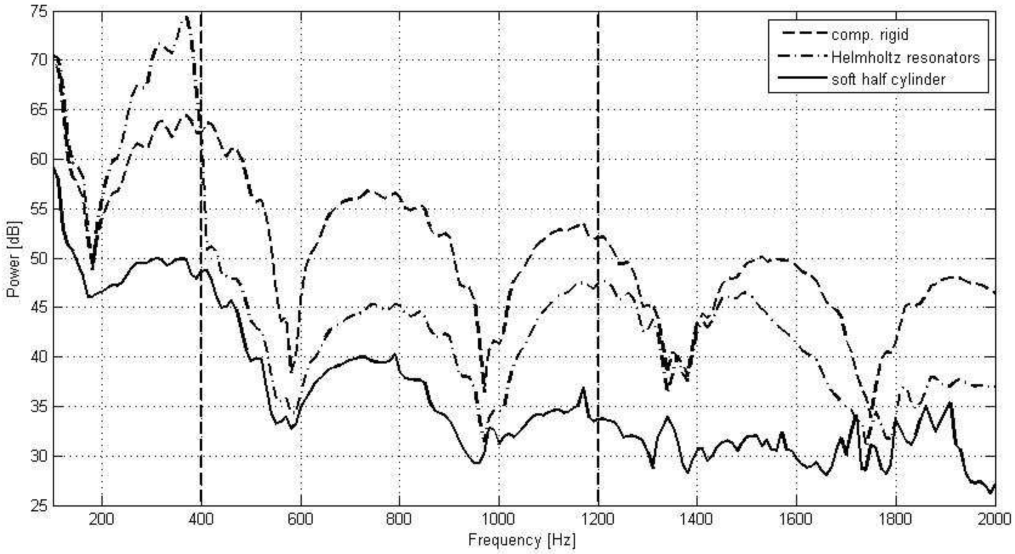

Fig. 2 - Sound power comparison of acoustically rigid and soft diffraction edges and integrated resonators.

reduction. Here, an optimization procedure is applied in order to explore appropriate design guidelines.

The noise barrier to be optimized is modeled as rigid screen ($Z \to \infty$, height 3 m initially) with acoustically soft topping, approximating the ideal effect of Helmholtz resonators (initially cylindrical with 0.7 m diameter), see Figure 3. The shape of the topping is being represented by a set of 26 pivot points. Two of these points link the topping to the screen, the remaining 24 points are distributed at equally spaced angles around a reference point (i.e. initially the center of the circular cross-section). The radial distances R_i of each point can be varied within specified limits (here 0.2 m … 0.75 m), while the angular positions of all points remain fixed. The pivot points are connected by spline curves in order to form a closed shape, ending with horizontal tangents in the links to the screen.

As a matter of course not every possible shape can be described by this parameterization. However, a wide variety of smooth silhouettes are made accessible to the optimization. Finally it should be noted that as a matter of principle self-intersecting shape curves may occur due to variations of the parameters (i.e. radii R_i), indeed the optimization has not been affected hereby.

The optimization of the outer shape is carried using the software tools SYSNOISE[6] and OPTIMUS[7]. Goal function is the average sound power in the frequency range from 400 Hz to 1200 Hz, evaluated at steps of 10 Hz. The resulting optimum shape is displayed in Figure 4.

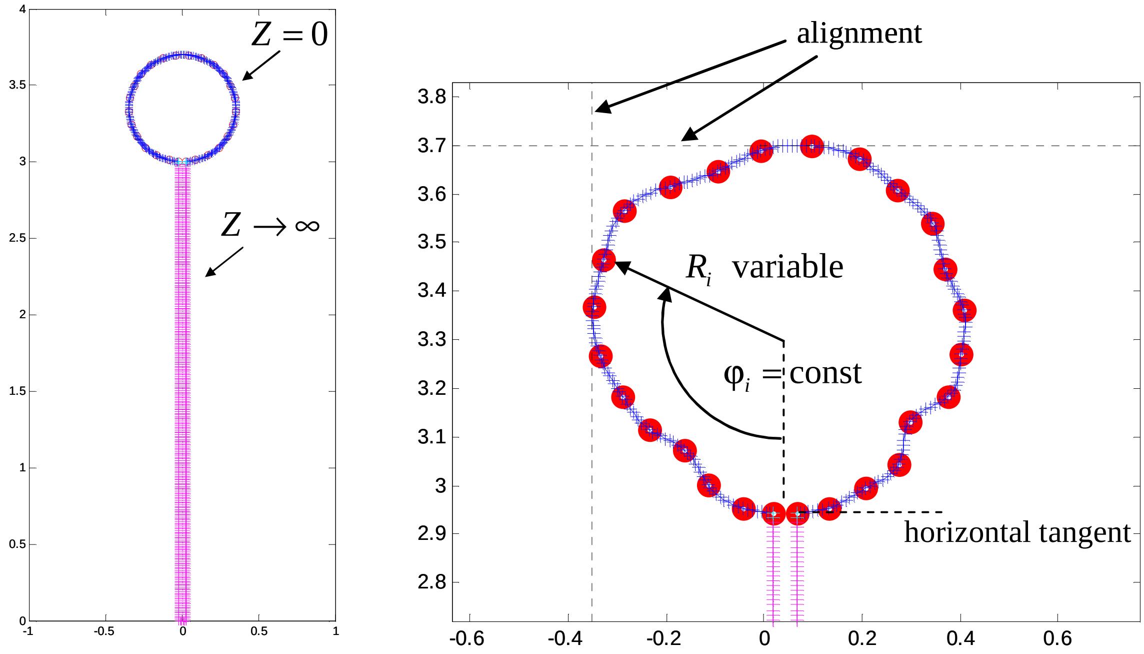

Fig. 3 - Model used in the first step of optimisation.

3 RESONATOR DESIGN AND OPTIMIZATION

An acoustically soft (i.e. impedance $Z = 0$) surface is a key requirement for significant improvements of achievable noise mitigation. Essentially the upper sections of the diffraction edge are required to exhibit vanishing surface impedances. However, appropriate materials complying with this demand are not known. Answer to this problem is the integration of adequately tuned resonators into the diffraction edge that can establish zero impedance conditions on the surface at least for specific frequencies. Here, Helmholtz resonators are treated rather than $\lambda/4$ resonators, because they allow for more shaping freedom.

On the basis of the results of the described shape optimization, a simplified outline contour forming a shape as illustrated in Figure 4. The advantage of a T-shaped topping is exploited while resonator space is provided within the cross-section. Seven resonator chambers are integrated into the cross-section, the angular width of each (with respect to the center of the upper arc) is parameterized by α_i, $i = 1 \ldots 7$. The mouth widths are denoted by angles ε_i, the uniform thickness of the upper shell by w.

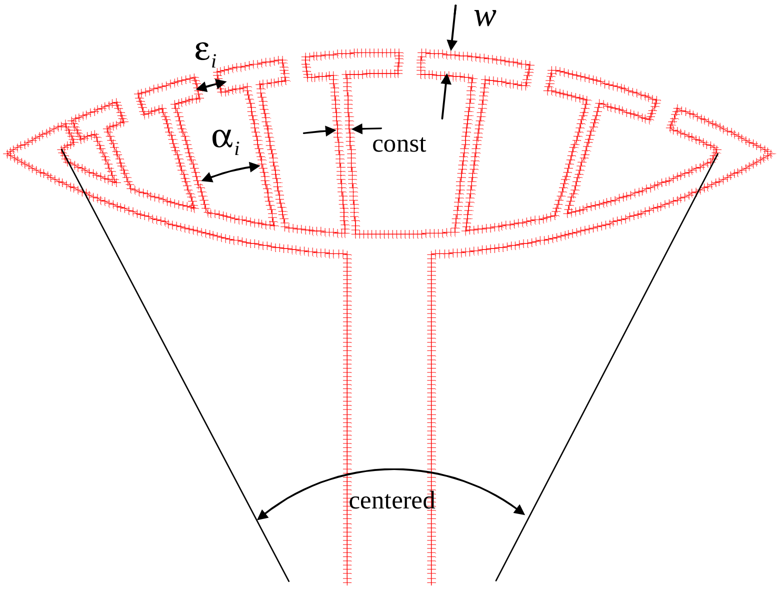

Fig. 4 - Shape and parameterization of the diffraction edge with Helmholtz resonators.

At varying chamber widths α_i occurring during the course of the optimization, the chambers are arranged such that the fillets dividing neighboring chambers remain at constant widths and that the assembly of the chambers is centered within the cross-section. Hereby, the control of the optimization has to ensure that in total all chambers fit into the available space at all instances.

Clearly, the simple vertical screen exhibits the least noise mitigation of the compared models. Considerable improvements are achieved by extending the diffraction edge horizontally. It is to be noted that local minima in the sound power spectra occurring due to interferences are shifted by frequency because of changing geometry of the interfering sound paths.

4 MEASUREMENTS

In order to verify the efficiency of the developed topping the numerical results are compared with results obtained from measurements. In this case a special measurement method was used which allows to reduce the length of the tested noise barrier to only 20 m.

Using a linear array of 21 microphones it is possible to shape a wanted orientation of the overall sensitivity normal to the noise barrier and to reduce the effect of the sound diffraction at the barriers ends down to the negligible level. Two examples of the frequency dependent spatial sensitivity of the used array are shown in Figure 5. It can be seen there, that already for 600 Hz the sensitivity at +/- 13° from the direction normal to the barrier is 13 dB smaller compared to the main sensitivity in the direction normal to the barrier. At 1.5 kHz the same effect is appears already for angels +/- 5° from the direction normal to the barrier. A dodecahedron loudspeaker was used as an acoustic source to generate the white noise excitation.

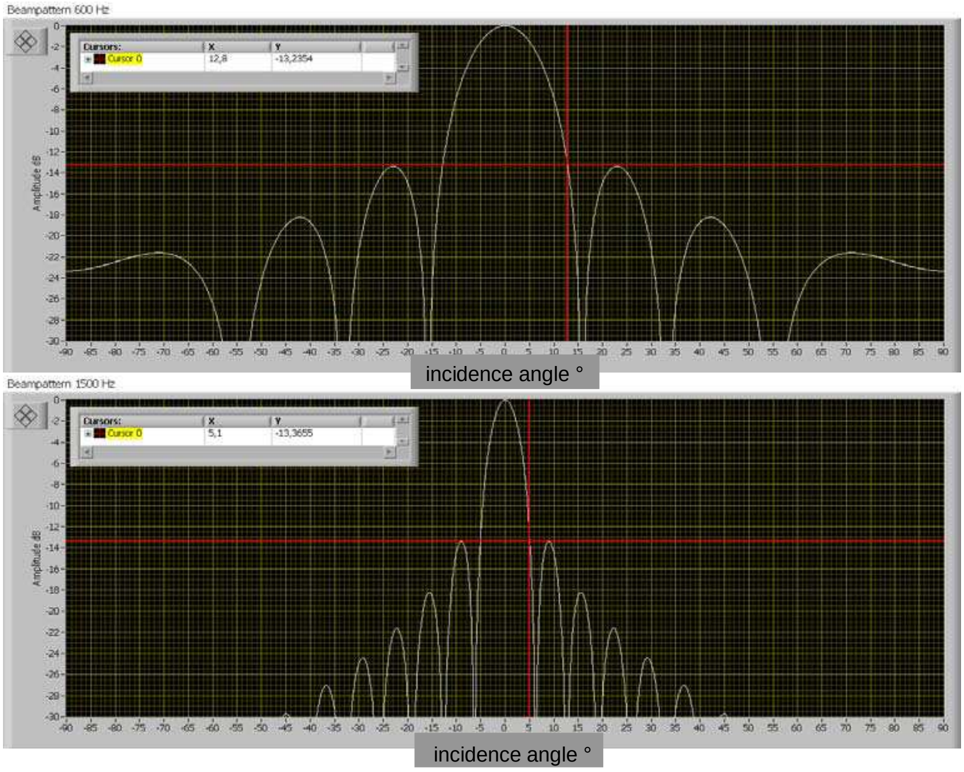

Fig. 5 - Spatial sensitivity of the used array for two representative frequencies.

The topping was divided in 40 sections of 50 cm length. These sections were fixed together to a uniform 20 m long top edge. One segment of 9 topping sections as well as the whole measurement setup is shown in Figure 6.

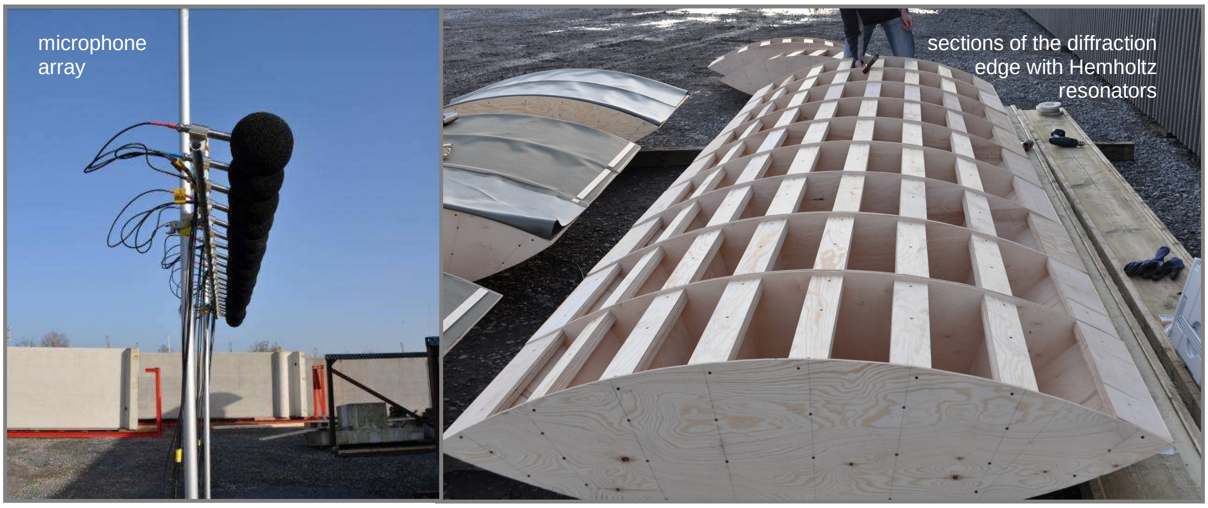

Fig. 6 - The measurement setup.

The achieved results are presented in form of third-octave-spectra of the sound pressure measured with and without the discussed top edge (Figure 7). They confirm that the upper edge of the barrier significantly affects the barrier's performance. The reduction of the sound pressure at the receiver side reaches up to nearly 12 dB. In only three bands the achieved enhancement of the noise protection falls below 3 dB.

It should be mentioned, that the simulation model and the experimentally investigated set-up differ in the barrier dimensions and its surface conditions. The height of the barrier used for measurements was 300 mm bigger than the simulated one. Different to the totally sound-reflecting numerical model, the barrier used for measurements had a highly absorbing covering on the sending side. It is interesting to see, that the developed topping obviously improves the performance of the barrier not only under narrow boundary conditions but helps to reduce the noise exposure also when some differences of the installation situation occurs.

5 CONCLUSIONS

A new design for a diffraction edge of a noise barrier is presented in this paper. The proposed solution combines an optimized shape of the barrier's topping with a series of Helmholtz resonators placed inside its body. The dimensions of the topping and the resonators are developed by means of the numerical acoustics controlled by appropriate optimization algorithms. An experimental examination attests the expected effectiveness. Comprehensive numerical investigations discussed in this paper show that the proposed diffraction edge substantially improves the noise protection of a simple barrier by only relatively small increase of its height.

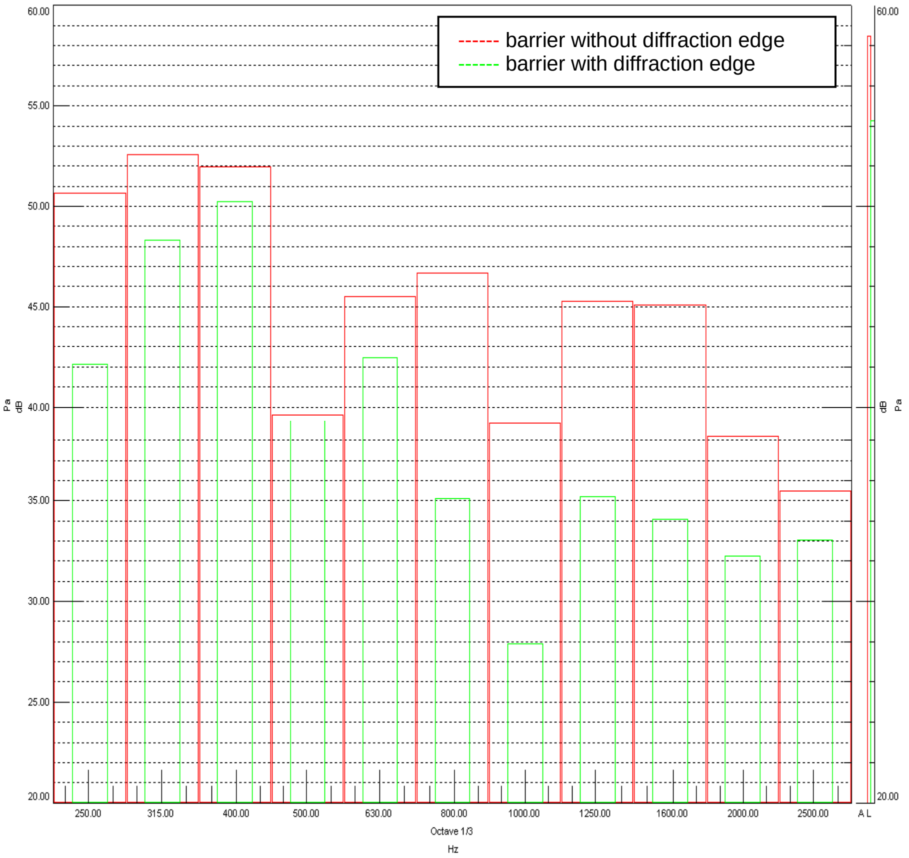

Fig. 7 - Third-octave-spectra of sound pressure measured with and without the diffraction edge.

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