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HEADPIECES WITH $\lambda/4$ RESONATORS TO IMPROVE SOUND BARRIERS – VARIOUS CONTOURS

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Abstract

In earlier papers about headpieces for noise barriers with finite impedance we discussed several constructions of cylindrical shape with Helmholtz-resonators and rectangular shape with $\lambda/4$ -resonators. Here the influence of the shape was investigated by comparing two different contours of the upper side of a headpiece with $\lambda/4$ -resonators: a circular contour and a flat contour. Comparisons between numerical calculations and measurements were made for the cylindrical contour. The results of the measurements from the flat and circular contoured headpiece were compared. There were differences when comparing the behavior in the frequency domain. Especially in the maxima the circular contour showed a more pronounced behavior in the frequency domain which can be observed in the octave bands of the insertion loss. Over a broader frequency range the results principally were similar. Rectangular constructions of headpieces attached to barriers reduce the sound level behind barriers compared to a single barrier with the same height.

INTRODUCTION

Since 1995 at the Institute of Technical Acoustics the effects of headpieces for noise barriers with finite impedance realized with resonator constructions were investigated [1-5]. Such headpieces attached near the top of an existing noise barrier can improve the sound shielding effect in the shadow region. Also other authors investigated resonator constructions attached on the top of a barrier and obtained similar results [6-9].

In this study we were interested in the influence the contour of the upper side has on the effect of noise shielding. We investigated two different contours.

The theoretical principles were shown in [1,5]. Here $\lambda/4$ -resonators were used to realize the impedance on the surface of the headpiece. The numerical calculations used the geometry of a cylinder attached on a semi-infinite screen. This numerical calculations were compared with measurements from a headpiece attached at the top of a barrier with a circular contour at the upper side of the headpiece. Also measurements with a flat contoured headpiece were made and

compared with the results of the circular contoured to show the different effects by changing the shape of such an headpiece.

EXPERIMENTAL SETUP

The construction of the headpiece used for the measurements contained 522 rectangular tubes. The outer edge length of each tube was 50 mm. All tubes had a length of 200 mm. The tubes were combined in 9 rows creating a length of the headpiece of 3 m. In one case the tubes were fixed at the same height in the rectangular box creating a flat surface of the open tubes (Fig. 1). In the other case the tubes were fixed at different heights creating a surface with the contour from a segment of a circle (Fig. 2, see also next chapter and Fig. 4).

Two series of measurements were taken: one with the open structure so that the effect of the impedance of the open tubes was measured, and as a reference, the hard surfaced headpiece realized by covering the upper side with a heavy foil (5 kg/m²) (see background on Fig. 1). By comparing this two measurement series only the effect of the varying impedance can be shown with identical geometry of the headpiece. This results in the insertion loss as a level difference between the measurement with covering minus the measurement without covering.

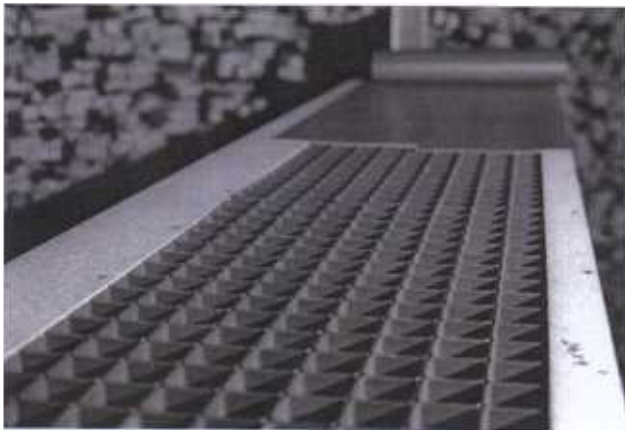


Fig. 1: Headpiece with tubes, flat contour



Fig. 2: circular contour

The barrier with the attached cylindrical headpieces was tested in the anechoic room (14 m long x 9 m wide x 8.5 m high) of the Institute of Technical Acoustics. To avoid energy transport through the barrier it was constructed as a double wall.

The noise screen butts at both ends onto a highly absorbing wall of the anechoic room creating a triangular area. To avoid energy transport at the lower edge of the wall, the supporting grid of the anechoic room on the source side was completely covered with a double floor construction. To reduce reflections from the ground, porous foam (thickness: 50 mm) was laid on the source side. A single loudspeaker was used as source to reduce effects of interference.

The sound level was measured with an FFT-Analyzer at 40 positions up to 3.2 kHz with and without covering the headpiece. This two series were taken for the flat contour and the circular contour of the tubes (Fig. 3).

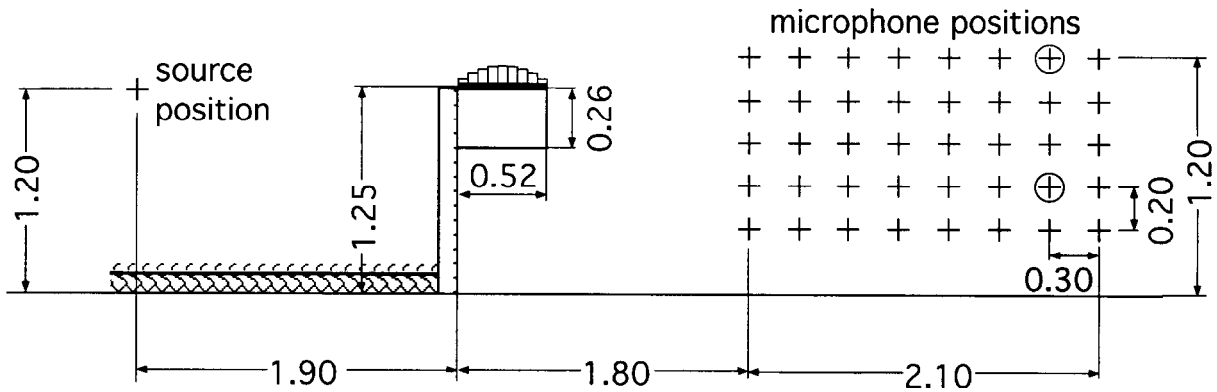


Fig. 3: Side view of the measurement equipment

THEORY

To calculate the insertion loss realized from the impedance effect of the surface of the headpiece a cylinder with a given locally reacting impedance attached to a semi-infinite screen was used. The source was positioned in the far field. The effect of the cylinder with the radius b on the surrounding sound field is then expressed through its impedance

$$Z = - \frac{p(b)}{v_r(b)} \quad (1)$$

where $p(b)$ is the sound pressure on the surface of the cylinder $r = b$ and $v_r(b)$ is the outward radial component of the velocity. Also a local independent impedance $\partial Z / \partial \varphi = 0$ was assumed. Details of the theoretical and numerical methods are described in [1,5]. The radius and the position of the cylinder was chosen in a way that a segment with an angle of 120 degrees agree with the contour of the open sides of the tubes (see Fig. 2, 4). This results in a radius of 265 mm.

30 to 90 points depending on the chosen frequency at equal distances on the surface of the cylinder have to fulfill the boundary condition (Eq. (1)). To obtain the insertion loss from the effect of the impedance two cases were calculated. In one case the impedance of the upper segment with an angle of 120 degrees was given by

$$Z = -j(\rho c / \gamma) \text{ctg}(k_0 a) \quad (2)$$

where γ is the part of the area with the open surface of the tubes to the whole area ($\gamma \approx 0.85$), k_0 is the wave number and a is the length of the tubes. The impedance of the remainder from the cylinder was hard surfaced (i.e. reflective, $Z \rightarrow \infty$). In the other case the complete cylinder was hard surfaced as a reference like the covered headpiece in the measurement series. Similar to the results of the measurements the insertion loss is the calculated level difference between the hard surfaced cylinder and the cylinder with acting open tubes at the upper side.

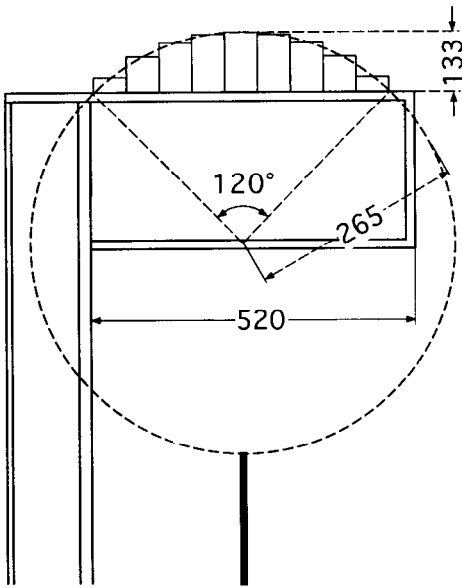


Fig. 4: Geometry for calculations

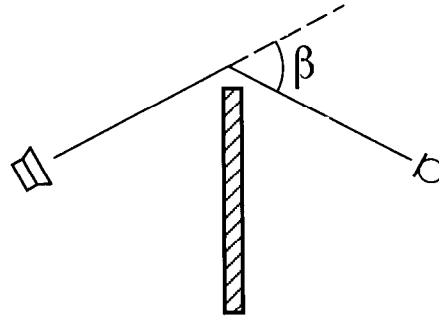


Fig. 5: Definition of the diffraction angle

RESULTS

Results over frequency for two chosen points

Flat contour, measurements and calculations. Fig. 6 and Fig. 7 show the results for the measurements with the circular contour of the tubes (black curves) and the numerical calculations (gray curves) versus the frequency for two chosen receiver points (see indicated positions in Fig. 3).

Fig. 6 shows the upper chosen position and Fig. 7 the lower position. In both cases there is a good agreement between measurement and calculation. The dotted vertical lines indicate the resonance frequencies of the open tubes (i.e. $\lambda/4$; $3\lambda/4$; $5\lambda/4$, ...).

This is a typical behavior of such a resonator construction [5]. Below the fundamental resonance frequency $f_0 \approx 400$ Hz the impedance has stiffness character. In a small range below the resonance frequency up to a critical value of the impedance there are improvements. Below this frequency a negative insertion loss results. Above the resonance frequency the impedance has mass character, so positive insertion loss can be expected. This typical behavior is repeated below the next resonance frequency $f_1 \approx 1200$ Hz because the impedance has stiffness character resulting in a negative insertion loss around 1000 Hz.

Above f_1 the improvements were higher for the measured results. Also it can be noticed that in the frequency range where improvements occur the insertion loss tends to higher values at higher frequencies.

Comparing Fig. 6 with Fig. 7 it is easy to see that the insertion loss at same frequency ranges is higher in the case of the lower receiver point when positive improvements appear. The opposite behavior occurs when considering ranges with a negative insertion loss. In this cases the insertion loss has higher negative values for the chosen lower receiving point (i.e. $f \approx 1000$ or 1800 Hz). So the principle behavior is more pronounced for the lower point i.e. more in the shadow region.

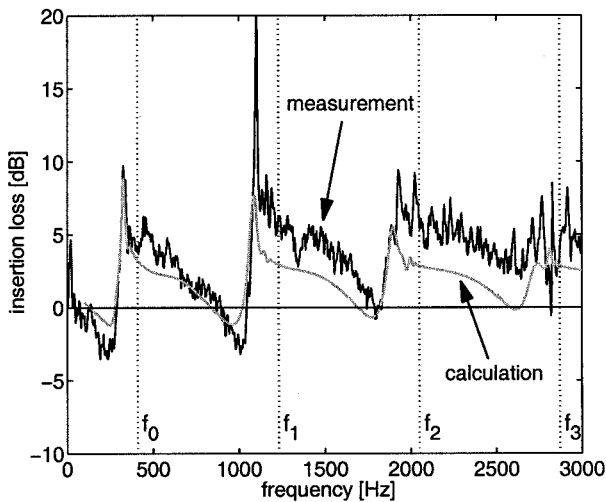


Fig. 6 Upper receiver position

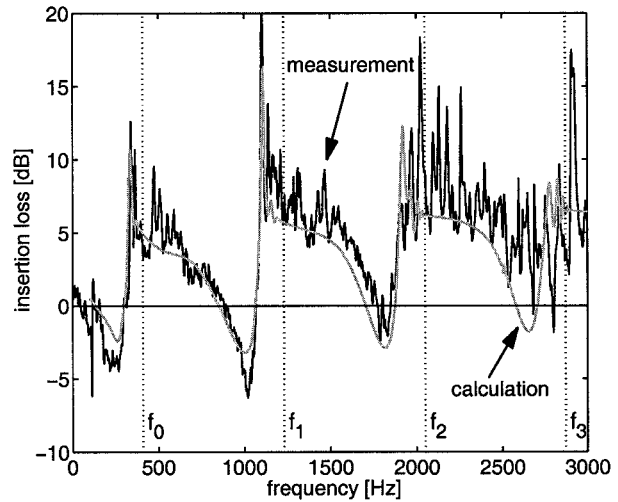


Fig. 7 Lower receiver position

Flat and circular contour, measurements. Fig. 8 and Fig. 9 show the results of the measurement series with the flat and circular contour of the tubes both in one graph (gray curves: flat contour, black curves: circular contour; see also Fig. 1 and Fig. 2). The difference between the results of these two shapes is small, but increases for higher frequencies.

Especially below the resonance frequencies in the ranges of negative insertion losses the circular contour tends to higher negative values (i.e. $f \approx 1000$ or 1800 Hz). In case of the circular contour it can be noticed that the improvements have a wider frequency range because they start at a lower frequency below the third higher resonance frequency ($f_3 \approx 2000$ Hz). At higher frequencies (above 2000 Hz) the circular contour results in higher insertion losses for both receiver points.

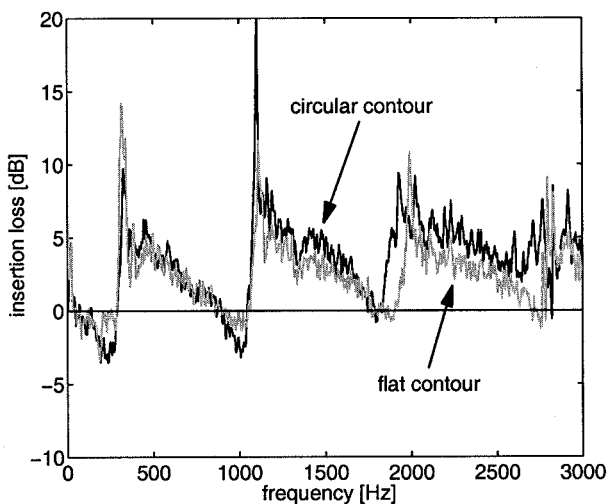


Fig. 8 Upper receiver position

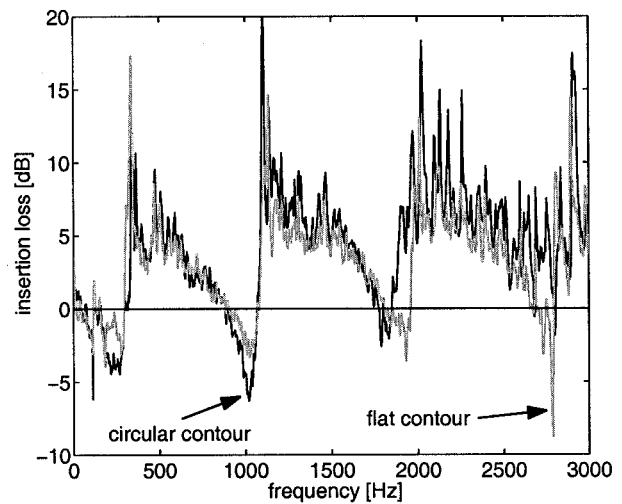


Fig. 9 Lower receiver position

Results over the diffraction angle in octave bands

Fig. 10 to 13 show the results of the measurement series with the flat and circular contour of the tubes for four octave bands over the diffraction angle β (see Fig. 5). The '+'-signs indicate the results for the 40 receiver points from the measurements with the flat contour of the tubes and the 'o'-signs indicate the results from the measurements with the circular contour.

In the lowest octave band ($f_m = 250$ Hz, Fig. 10) which is below the fundamental resonance frequency $f_0 \approx 400$ Hz we expect negative values of the insertion loss because in this frequency band mainly stiffness character of the impedance occurs. Also corresponding to the results by comparing the two chosen receiver points (Fig. 8 and 9) it is expected that this effect is more pronounced in the shadow region so the insertion loss decreases with the diffraction angle for both contours. Another point that can be seen also in Fig. 8 and 9 are the lower insertion losses for the circular contour compared to the flat contour. For the flat contour the insertion loss is between -2 and 1 dB, for the circular contour it is -4 to -1 dB.

In the next octave band ($f_m = 500$ Hz, Fig. 11) which is mainly determined from the positive effects close below f_0 (stiffness character with small amount of the impedance) and above f_0 (mass character) we obtain only positive insertion losses which increase with the diffraction angle for both contours. For the circular contour the results are about 1 dB higher than the results for the flat contour (3 to 5 dB for the flat and 3.5 to 6.5 dB for the circular contour).

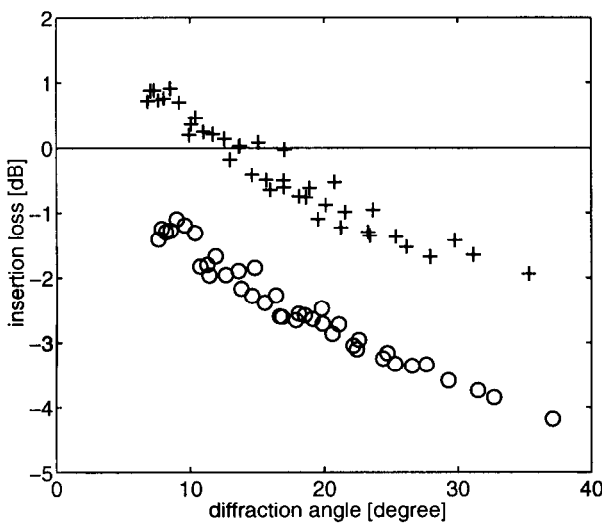


Fig. 10 Octave band, $f_m = 250$ Hz,
+ : flat contour
o : circular contour

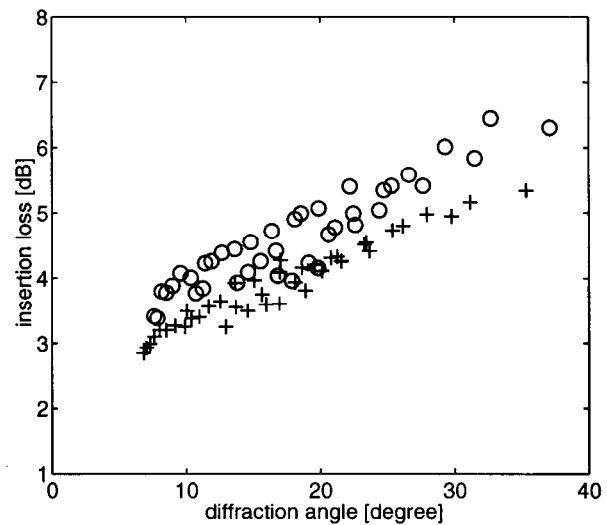


Fig. 11 Octave band, $f_m = 500$ Hz,
+ : flat contour
o : circular contour

The octave band with the center frequency $f_m = 1000$ Hz (Fig. 12) encloses mass and stiffness character of the impedance in this frequency band corresponding with positive and negative insertion losses (see also Fig. 8 and 9). The mean insertion loss is higher for the flat contour (0 to 1.5 dB) compared to the circular contour (-1 to 1.5 dB). Only a slight dependence on the diffraction angle in this band is observed.

In the highest octave band ($f_m = 2000$ Hz, Fig. 12) the insertion loss is positive for both contours and all receiver points. In this octave band also mass and stiffness character of the impedance appears corresponding to a positive and negative insertion loss but the positive insertion loss have overweight in this frequency band. Corresponding to Fig. 8 and 9 the insertion loss is about 1 dB higher for the circular contour. This differences are more pronounced at lower diffraction angles. The insertion loss is between 2.5 and 3.5 dB for the flat contour and between 3.5 and 5 dB for the circular contour.

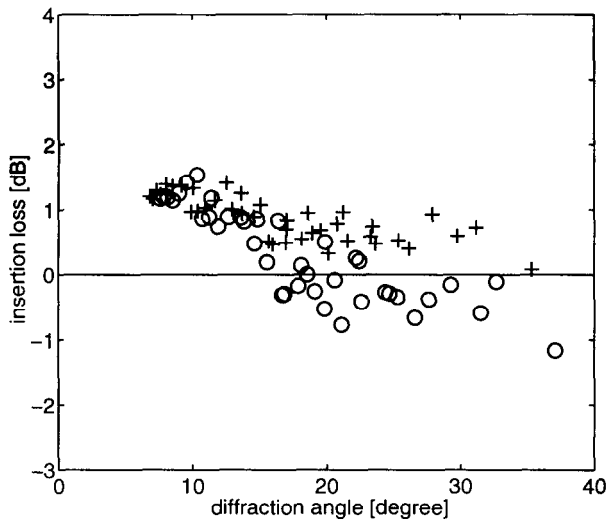


Fig. 12 Octave band, $f_m = 1000$ Hz
 +: flat contour
 o: circular contour

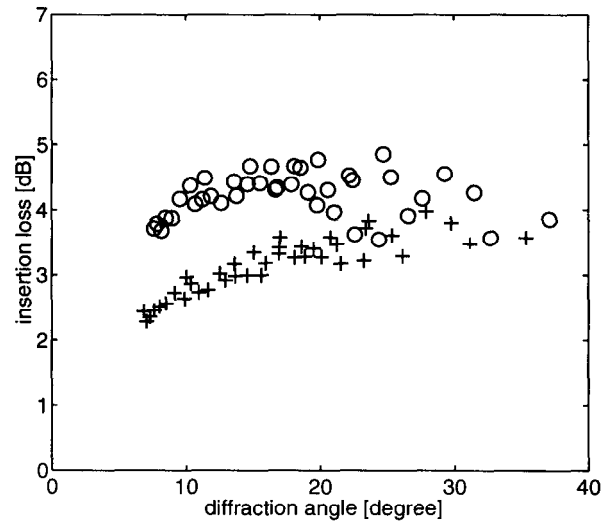


Fig. 13 Octave band, $f_m = 2000$ Hz
 +: flat contour
 o: circular contour

CONCLUSION

In this study the difference between a flat and a circular contour of a finite impedance at the upper side of a headpiece realized by open tubes ($\lambda/4$ -resonators) was shown with measurements and numerical calculation. The numerical calculation of the insertion loss which is the level difference between a hard covered surface and the uncovered open tubes agrees well with the measurements demonstrated at two chosen receiver points .

The principle behavior of a impedance based on a resonator system is the same for both contours as expected. The differences between the two contours are more pronounced in the extremes in the frequency domain. Near frequencies where the insertion loss is most negative (slightly below the resonance frequencies) the insertion loss tends to more negative values for the circular contour. The same behavior occurs in the cases where the insertion loss is most positive (above the resonance frequencies). For this cases the insertion loss is higher for the circular contour. Above 2000 Hz the circular contour shows higher improvements (i.e. higher insertion losses) than the flat contour.

References

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