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EXTENDING THE BANDWIDTH OF PROFILED SOUND ABSORBERS

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ABSTRACT

Schroeder diffusers were originally designed for enhanced scattering, but poorly structured samples can display significant sound absorption, including the frequency range below the design frequency. This has been used as inspiration towards designing a new absorber with extended bass response. This project investigated the mechanism of the high absorption coefficient below the lower limit of design frequency by employing perforated plates in some of the wells of the diffuser. A theory for the enhanced absorption is presented. A numerical optimization was performed to obtain the best absorption by adjusting the positions of the perforations in the wells and the depths of the wells in one period. The results clearly show that this type of profiled optimized absorber extends the absorption at low & high frequencies, and becomes a considerably better wideband simple profiled absorber

1 - INTRODUCTION

The profiled diffuser, invented by M.R.Schroeder [1] in 1970's, has been widely used in concert halls, theatres, and studio control rooms. However, there is evidence of significant absorption [2], when the diffusers are poorly designed. Kuttruff [3] and Mechel [4] investigated the mechanism of the absorption. It was found [5] that the strong coupling between the wells is responsible for the high absorption, and a new type of profiled absorber has been developed. Also there is evidence that poorly structured QRDs can produce high absorption below the design frequency [2]. This inspires the idea that using perforated plates in the wells can extend the absorption to lower frequencies as well as higher frequencies.

Perforated panels have been developed and used for some years, and their ability to produce high absorption performance at low frequencies is well known. Normally, they are fixed on the top of air cavity with porous materials to build resonant absorbers.

In this paper, the effect of varying the position of perforated plate in the well has been investigated. The constant depth structure with perforated plates in the wells has been optimized to result in better absorption without any resistive layer on the top. However, as we will see later, the constant depth structure can not provide a wider absorption band alone. The different depth sequence is essential to extend absorption frequency bands to the lower frequency as well as higher frequency. A numerical optimization is performed to obtain the better absorption by adjusting the position of the perforated plates in the well and the depths of the wells in one period. The results clearly show the improvements offered by this kind of absorber when compared to profiled absorbers without perforated plate.

2 - THE PERFORATED PANEL

2.1 - The impedance of perforated panel

The perforated plates can be considered as a lattice of short tubes, with the distance between adjacent tubes being small when compared with wavelength of the propagating sound, but larger than the hole diameter. Assuming that when sound flows through the holes, there is no motion in plate itself, and the hole radius ($\geq$1 mm) is larger than the boundary layer thickness, then the specific acoustic impedance of perforated plate is [6]:

$$
\begin{aligned}
z_p &= r_m + j\omega m \\
r_m &= \frac{1}{\varepsilon}\sqrt{8\eta\omega\rho}\left(1+\frac{t}{2a}\right) \\
m &\approx \frac{\rho}{\varepsilon}\left(t+2\delta a\right)
\end{aligned}
\tag{1}
$$

Where, δ is the air density, ω is the angular frequency of propagating sound, ε is porosity of the plate, t is the thickness of the plate, a is the radius of the holes, * is the end correction factor (=0.85), and η is the kinemetric viscosity of the air ($\approx$15x10^{-6}m^2/s).

2.2 - The impedance of the entrance of a well with perforated plate

Considering a well length l_n, a perforated plate is fixed in the well at a distance l_{n1} from the opening. The impedance of the entrance of the well can be derived as:

$$
z_w = \frac{\rho c z_1 \coth\left(jk_t l_{n1}\right) + \left(\rho c\right)^2}{z_1 + \rho c \coth\left(jk_t l_{n1}\right)}
\tag{2}
$$

where z_1 is the total impedance at l_{n1} of the perforated plate and the air cavity covered, length $(l_n - l_{n1})$

$$
z_1 = r_m + j\left(\omega m - \rho c \cot\left(k_t\left(l_n - l_{n1}\right)\right)\right)
\tag{3}
$$

k_t is the propagation number in the well, taking the losses caused by viscous and thermal conduction into account, k_t becomes [5]:

$$
k_t \approx k + \frac{k}{2b}\left(1-j\right)\left[d_v + \left(\gamma-1\right)d_h\right]\ ;\ d_v \approx 0.21\frac{1}{\sqrt{f}}\ ;\ d_h \approx 0.25\frac{1}{\sqrt{f}}
\tag{4}
$$

where $k = \omega/c$, $f = \omega/2\pi$, c is the speed of sound, b is the width of well, γ is the ratio of specific heat ($\approx$1.4 for air), d_v, d_h are the thickness of the viscous and thermal boundary layers respectively [7].

2.3 - Effect of varying the position of the perforated plate in the well

As can be seen in Eq (2) and (3), the position of the perforated plate in a well can affect the resonant frequency. Changing the position of perforated plate from the bottom to the opening of the well, the first resonant frequency of the well is gradually decreased. This gives us a possibility to tune the wells by adjusting the positions of the perforated plates in the wells.

3 - CONSTANT LENGTH ABSORBER AND DISCUSSION

The analysis method used to calculate the absorption on the surface of a profiled absorber in Ref [5] is still valid in this case. As mentioned before, a well can be tuned by moving the perforated plate in the well. In this section, a numerical method, the downhill simplex method [8], will be used to tune the wells. A constant length absorber with perforated plates in the wells will be optimized by adjusting the position of the plates to provide better absorption. Because of the strong coupling between the wells, the parameters of the plate should be chosen carefully.

For normal incident sound, the absorption coefficient and impedance on the surface were calculated for two cases, eq. (1): perforated plate on the top of the structure, and eq. (2): optimized structure with perforated plates at different positions in each well. The parameters are: 7 wells in one period, well width 6 mm, separated wall 1 mm, and well length l_n=10 cm; for perforated plate, ε=5 %, a=1.0 mm, t=5 mm. The results are shown in Fig. 1.

From Fig. 1a, it is clearly shown that the absorption of the optimized structure is higher than the structure with a perforated plate on the top for the whole frequency range, and particularly at low frequency, where the absorption coefficient is nearly 1. Looking at the impedance graph Fig. 1b, the optimized structure created a non-uniform surface impedance that scattered sound. The scattering enhances the coupling between the wells, which provides very high resistance when compared with case 1. Although the absorption at low frequency is high in case 2, elsewhere it is low. This indicates that, in order to widen the frequency band, a variable depth sequence is necessary to provide better coupling in whole frequency range of interest.

4 - WIDEBAND ABSORBER AND DISCUSSION

In the above section, high absorption at the frequency range lower than first resonant frequency of well has been obtained. However, the frequency band is narrow. Changing some wells with the constant depth to variable depth can solve this, see Fig. 2. By optimizing the positions of perforated plates in

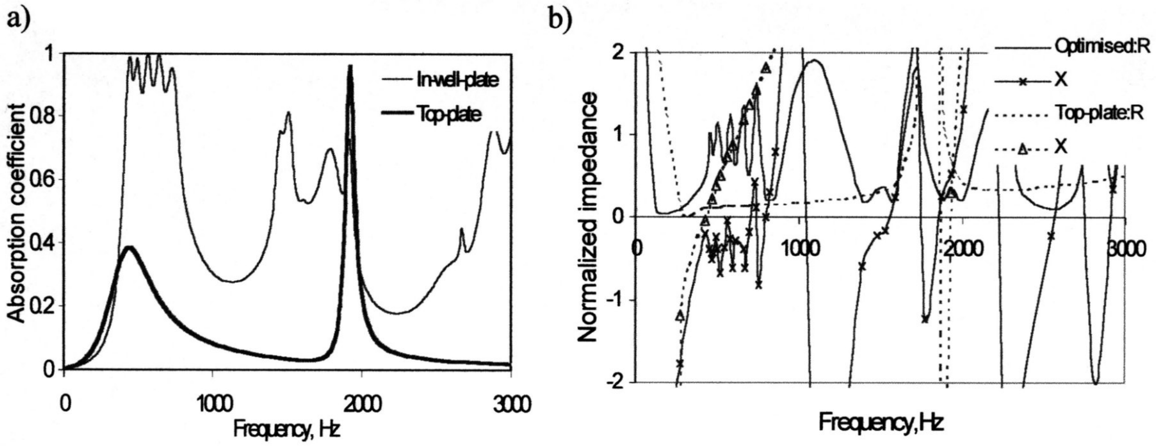

Figure 1: Comparison between the optimized structure and general absorber, a) absorption coefficient; b) impedance: R-real part; X-imaginary part.

the constant depth wells and the depth sequence of variable depth wells, well-tuned and well-distributed resonant frequencies can be obtained. Great effort is needed to balance the number of constant wells and the number of variable wells in order to get better coupling at low & high frequencies. Again, applying a resistive layer smoothes the peaks and troughs seen in Fig. 1a, and the perforated plate parameters should be chosen carefully to avoid even stronger coupling at low frequency.

In the optimization process, the length of wells is restricted in 10 cm, Fig. 2 is the illustration of optimized structure. Fig. 3 shows the comparison between the optimized structures. It clearly shows the high absorption extending to the low frequencies, as well as high frequencies, when perforated plates are used.

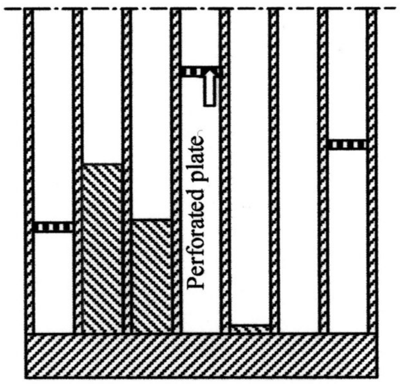

Figure 2: Sketch of one period of optimized structure.

5 - CONCLUSION

The above study has shown the effectiveness of the perforations in the wells. The optimized constant depth concept employing perforated plates can produce better absorption than the ordinary absorber with perforated plate fixed at the top of cavity. However, the frequency band is still narrow. The new optimized structure consisted of a variable depth sequence and perforated plates, which extends the absorption to lower frequencies as well as higher frequencies, and becomes a considerably better wideband absorber.

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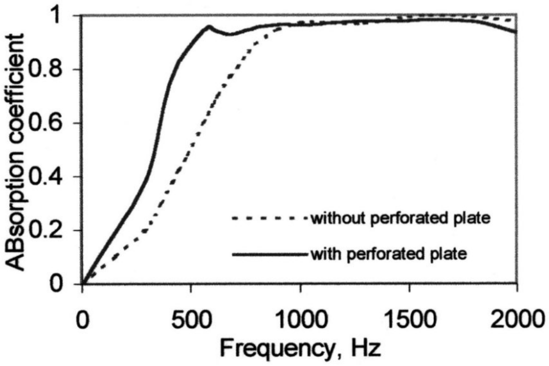

Figure 3: Comparison between the new structure and the structure without perforated plate.

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