Sound Absorbers Using Microperforated Layers

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As a fibre-free absorber, the microperforated plate [1] is increasingly being used in practice. To broaden the effective frequency range, a series of absorption structures employing microperforated layers has been developed using a variety of materials [2, 3]. This paper presents an assessment of the sound absorption properties of some of the structures. Comparisons between calculation and measurement are also made.

THEORY

A main characteristic of microperforated plates is that the acoustic resistance as well as the resistance-to-mass-reactance ratio may be raised tremendously by reducing the perforation to sub-millimeter size. According to Maa [1], for normal incidence the normalised specific acoustic impedance of a microperforated non-metallic plate can be calculated by

\[
Z_s = \frac{R_s + jM_s}{\rho c} = 0.147 \frac{t}{d^2} \left[ \frac{1}{2} \left( 1 + \frac{x^2}{32} \right) + j \omega \frac{0.294 (10^{-1}) \frac{t}{d} (1 + \frac{1}{\sqrt{9 + \frac{x^2}{2}}} + 0.85 \frac{d}{t})}{p} \right]
\]

where \( x = 0.316d/f \), \( \omega = 2\pi f \), \( f \) is the frequency (Hz), \( t \) is the membrane thickness (mm), \( d \) is the aperture diameter (mm), \( b \) is the distance between aperture centres (mm), \( p \) is the aperture ratio (%), \( \rho \) is the density of air, and \( c \) is the sound velocity in air. For square apertures with a side \( l \) (mm), an approximation can be made using the same aperture area [2], namely \( d = 2l/\sqrt{\pi} \).

For multiple microperforated layers, the acoustic impedance can be calculated according to the equivalent circuit. Figure 1 shows such a circuit for two layers of microperforated limp membrane [2]. In Figure 1 the membrane vibration is also considered, which is \( Z_s = (R_s + jM_s)/\rho = r + j\omega m' \). Where \( m' = m'/\rho c \), \( m' \) is the surface density of membrane (kg/m²). In Figure 1 it can be seen that the membrane will play a dominant role if \( Z_s \gg Z_m \), or vice versa. In order to modify the absorption, the acoustic impedance of the whole structure can be adjusted by varying appropriate parameters of the membrane and the apertures. With the same principle, calculation models have been developed for a series of absorbers using microperforated layers. In the models both normal and random sound incidence are considered.

![Figure 1](image_url)

ABSORBERS WITH MICROPERFORATED LAYERS

In Figure 2 are shown the absorption coefficients for one layer and two layers of a microperforated plastic membrane. It can be seen that with two layers the absorption is considerably better than that of a single layer. With \( D_1 + D_2 = 130 \) mm, for example, the absorption coefficient exceeds 0.4 in the range 315-5kHz. It is also shown that the calculations according to the theory give very good agreement with measurements.

The theory is also applicable to open weave textiles [2]. In Figure 3 are shown the absorption coefficients of one layer and two layers of glass fibre textiles. It is noted that the absorption performance of such structures can be high but the parameters must be carefully selected. Again, there is very good agreement between calculation and measurement.

The absorption coefficient of a three layer structure, namely an unperforated limp membrane with two inner layers of microperforated plate, is shown in Figure 4. It can be seen that with this combination the absorption is significantly increased in comparison with any of the three layers alone. The agreement between calculation and measurement is still very good. In the calculation the plate vibration of microperforated layers is not considered.
FIGURE 2. Random incidence absorption coefficients for one layer and two layers of a microperforated membrane with $m'=0.14 \text{kg/m}^2$, $t=0.11 \text{mm}$, $d=0.2 \text{mm}$ and $b=2\text{mm}$.

(1) $D_1=30\text{mm}$ and $D_2=100\text{mm}$: ••••, calculation; ⋆, measurement. (2) $D_1=30\text{mm}$ and $D_2=50\text{mm}$: ••••, calculation; ○, measurement. (3) Calculation of single layer: ---, $D=130\text{mm}$, ......, $D=80\text{mm}$.

To broaden the effective frequency range of a panel absorber, it is useful to introduce a microperforated layer between the panel and the back wall. First, the acoustic resistance of the panel absorber can be significantly increased by the extra acoustic resistance offered by the microperforated layer. Secondly, the acoustic reactance of the panel absorber can be less at relatively high frequencies since the distance behind the panel is decreased from $D_1 + D_2$ to $D_1$. Thirdly, the first zero-point of the acoustic reactance of panel absorber can shift to a lower frequency due to the extra acoustic mass of microperforated layer. Overall, with carefully selected parameters, the bandwidth of a panel absorber can be extended in both low and high frequency directions. In Figure 4 such an example is shown. It is seen that the total increase in bandwidth of the effective range of absorption is more than one octave. The calculation model for this structure is still being developed.

FIGURE 4. Normal incidence absorption coefficient for an unperforated plastic membrane of $m'=0.19 \text{kg/m}^2$ with two inner microperforated layers of $t_1=3\text{mm}$, $d_1=0.4\text{mm}$, $b_1=1.8\text{mm}$, $t_2=3\text{mm}$, $d_2=0.6\text{mm}$, $b_2=6\text{mm}$, $D_1=30\text{mm}$, $D_2=70\text{mm}$ and $D_3=100\text{mm}$: ••••, combination, calculation; ⋆, combination, measurement; ---, only outer membrane with $D_1$, calculation; •••••, only microperforated plate 1 with $D_2$, calculation; ......, only microperforated plate 2 with $D_3$, calculation.

FIGURE 5. Effect of an inserted microperforated layer ($D_1=30\text{mm}$, $D_2=70\text{mm}$, $t=5\text{mm}$, $d=0.55\text{mm}$, $b=6.64\text{mm}$) on the normal incidence absorption coefficient of an aluminium panel absorber of $t=0.1\text{mm}$. ••••, outer panel with an inserted microperforated layer, measurement; ---, only outer panel with $D_1 + D_2$, measurement; ......, only microperforated layer with $D_2$, calculation.

CONCLUSIONS

The above examples show that high performance levels of broadband absorption can be achieved by using strategically designed microperforated layers. The calculation models have been validated by measurements.

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REFERENCES