Micro-perforated sound absorbers in stretched materials

Christian Nocke (1), Catja Hilge (1) and Jean-Marc Scherrer (2)

(1) Akustikbüro Oldenburg, Oldenburg, Germany – www.akustikbuero-oldenburg.de
(2) BARRISOL S.A.S, Kembs, France – www.barrisol.com

ABSTRACT

The theory of micro-perforated panel sound-absorbing constructions has been introduced by D.-Y. Maa in 1975. Since then many variations of micro-perforated sound absorbing devices and materials have been introduced. Materials that have been used to be micro-perforated have been metal, wood, plastics and many others. In 2001 a nearly invisible micro-perforation has been introduced to the stretched material making it highly sound absorptive. In this contribution measured sound absorption coefficients of various set-ups with micro-perforated stretched foils and different other acoustic materials will be presented. Finally applications will be shown.

INTRODUCTION

Micro-perforated panel absorbers (MPA) were first described by D.-Y. Maa in 1975 (Maa, 1975). Further developments of the theory and applications are presented in various other papers (Maa, 1983, 1984, 1985, 1987, 1988, 1997). The potential of MPA is shown in a publication (Maa, 1998) together with some possible applications. The calculation and measurement of MPA in so-called random incidence of diffuse sound fields has been investigated in two publications (Liu, 2000, Nocke, 2000). Other aspects and further investigations on micro-perforated structures are described for example in (Maa, 2000 and 2001) or (Zha, 1998).

Stretched membrane ceilings have been introduced around fourty years ago. The stretched ceiling consists of a special flexible sheet, which is mounted in-situ by clamping it to a frame construction. The sheet is heated before mounting, and the membrane acquires its final tension after cooling. Nearly any shape might be built by this technique.

Over the last 40 years this kind of ceiling and wall covering has become a popular product with regard to modern architecture and design. Until 10 years ago optical and other aspects of the product were of general interest. After first experiences with a micro-perforated polycarbonate foil (Zha, 1998) micro-perforation of the sheet used for the stretched ceiling was seen as an innovative feature. This acoustic property may open another range of applications for stretched ceilings. In November 1999, the first micro-perforation of a stretched ceiling has been introduced and successfully been applied for room acoustic purposes.

The measured results of the sound absorption coefficients of this new micro-perforated sound absorber from laboratory will be presented for different set-ups.

The last part of paper briefly deals with applications of micro-perforated stretched ceilings. Two examples of room acoustic projects will be described in which the micro-perforated stretched ceiling has been successfully applied to reduce reverberation.

UNDERLYING THEORY

The theory of the micro-perforated panel absorber as initially presented in (Maa, 1975) is based on the classical treatment of sound propagation in short tubes. The derivation by Maa (Maa, 1975) first delivers an approximation for the specific acoustic impedance ZMPP for a micro-perforated panel of thickness t with holes of diameter d spaced at a distance b apart in front of an air cavity with a depth D, see Figure 1 for principal set-up.

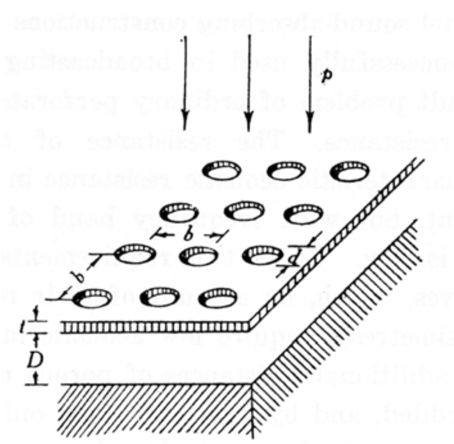

Figure 1. Sketch of micro-perforated panel absorber (MPA) from (Maa, 1975) with
d diameter of orifice,
b spacing between orifices,
t thickness of panel and
D air cavity depth D between panel and backing wall.

From the angle-dependent impedance Z_{MPP} the sound absorption coefficient for normal and random incidence of sound on the micro-perforated sound absorber can be easily calculated using well-known principles (Maa, 1975) (Nocke, 2000).

The derivation by Maa first delivers an approximation for the specific acoustic impedance Z_{MPP} for a micro-perforated panel of thickness t as

$$Z_{MPP} = r + j\,\omega\, m \quad (1)$$

The corrected formulae for r and m are given as follows (Nocke, 2000)

$$r = \frac{32\eta t}{p\rho c_0 d^2}\left(\sqrt{1+\frac{k^2}{32}} + \sqrt{2}\frac{k\,d}{32\,t}\right) \quad (2)$$

$$\omega m = \frac{\omega t}{p c_0}\left(\frac{1}{\sqrt{9+k^2/2}} + 0.85\frac{d}{t}\right) \quad (3)$$

Herein the parameter k is proportional to the ratio of the radius d/2 of the orifice and the thickness of the viscous boundary layer in the orifice, see (Nocke, 2000) for all details and quantities.

A micro-perforated panel in front of an air cavity forms a resonant system. The impedance of this system made of the micro-perforated panel and the air cavity can be calculated using the impedance ZAIR(θ) of the air cavity of depth D at an angle θ to the normal of the surface given by

$$Z_{AIR}(\theta) = -j\cot(\omega D / c_0 \cos\theta) \quad (4)$$

With this the impedance $Z_{MPA}(\theta)$ the impedance of the micro-perforated panel absorber (MPA) can easily be calculated according to

$$Z_{MPA}(\theta) = Z_{MPP}\cos\theta + Z_{AIR}(\theta) \quad (5)$$

With this impedance $Z_{MPA}(\theta)$ the absorption coefficient α(θ) for a plane wave incident at a certain angle θ can be calculated according to

$$\alpha(\theta) = \frac{4\,\mathrm{Re}\{Z_{MPA}(\theta)\}}{[1+\mathrm{Re}\{Z_{MPA}(\theta)\}]^2 + [\mathrm{Im}\{Z_{MPA}(\theta)\}]^2}\,. \quad (6)$$

This equation for α(θ) can now be used for the calculation of the so-called statistical or random incidence sound absorption coefficient according to the well-known Paris' formula

$$\alpha_{stat} = \int_{0^\circ}^{90^\circ} \alpha(\theta)\sin 2\theta\, d\theta \quad (7)$$

RESULTS FROM LABORATORY

In the following part results for different set-ups of micro-perforated stretched materials are presented. First set-ups with only micro-perforated material will be investigated, secondly combinations of micro-perforated and porous materials will be discussed. Finally, results of combinations of unperforated and micro-perforated streteched materials are shown that can be applied as light ceilings.

Figure 2 represents a sketch of a classical stretched ceiling as set-up for reverberation chamber measurements according to (Maa 1975) (Documentation rechnique). The foil is stretched on a frame constrcution with a certain distance between foil and backing wall or ceiling. Usually the wall or ceiling is acoustically hard. The distance between foil and acoustically reflecting backing is between a few centimeters and more than a meter. The sides are closed, the air volume has no connection to the outside.

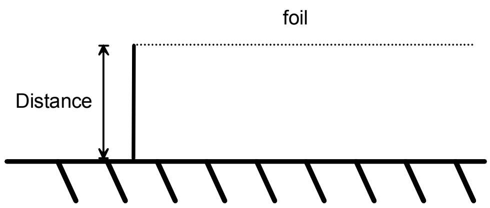

Figure 2. Principal sketch of set-up of the stretched ceiling / foil.

In Figure 3 the frequency-dependent sound absorption coefficient according to (ISO 354, 2003) for the non-perforated and the micro-perforated stretched foil is depicted. It can clearly be seen that the non-perforated foil shows hardly any sound absorption. The maximum value of 0.12 is reached at 400 Hz. The NRC-value according to ASTM C 423-01 (2001) is NRC = 0.05, the SAA-value is SAA = 0.07 for the non-perforated material. The micro-perforated stretched foil shows a maximum sound absorption of 0.69 at 800 Hz and 1000 Hz with an decrease towards low frequencies. At frequencies higher than 1000 Hz the sound absorption coefficient stays above 0.4. The NRC-value for the micro-perforated foil is NRC = 0.45 as well as the SAA-value, e.g. SAA = 0.45.

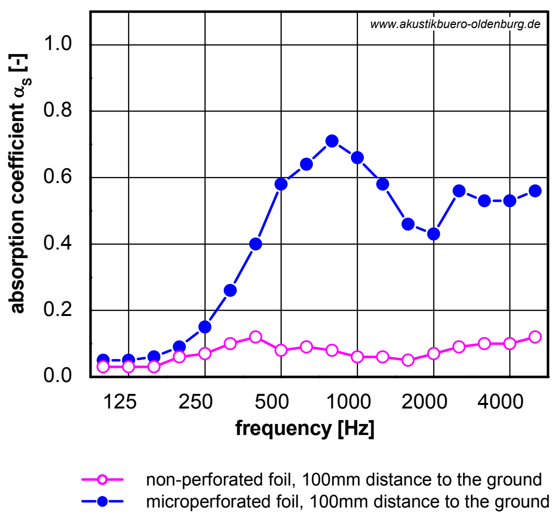

Figure 3. Measured result for sound absorption coefficient according to (ISO 354, 2003) for non-perforated and micro-foerated foil.

As shown in (Nocke, 2000) the agreement between calculations according to Maa's theory for diffuse incidence and measurements in the reverberation chamber is very high. According to Maa's theory only the geometrical conditions as depicted in Figure 1 determine the sound absorption.

The derivation according to equations (1) to (7) ist straight forward and considers angle and frequency depedent impedance values $Z_{MPA}(\theta)$. This is the reason why there is very close agreement between measurements in diffuse field condtions and corresponding calculations, see figure 4.

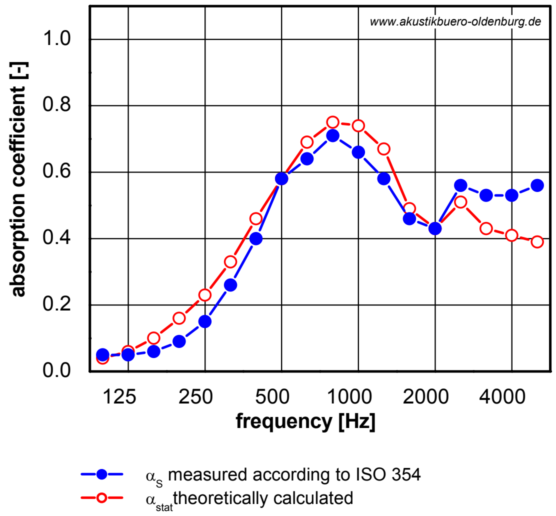

Figure 4. Measured and calculated result for sound absorption coefficient of the micro-perforated stretched foil.

One common concern is whether the stretching conditions will influence the acoustic absorption of the streteched set-up. Figure 5 shows pictures of two set-ups in a reverberation chamber. In part a) one single sheet of dimension 3 m x 4 m is stretched on a frame an set-up with 100 mm distance to the backing floor. In part b) the same area is divided into for pieces each stretched on a separate frame.

Figure 6 shows the results of measurements according to (ISO 354, 2003).

Figure 5. Experimental set-up of the stretched ceiling / foil.
Left: one single sheet of 12 m²
Right: four sheets of 3 m² each.

The comparison of the measured sound absorption coefficients for the single and the divided sheet shows that there is hardly any difference, see fgure 6. Only at very high frequencies, above 4000 Hz, a deviation larger than 0.05 for the sound absorption occurs. This allows the conclusion that the stretching conditions as well as the size of the panel do not influence the acoustic properties of a micro-perforated stretched ceiling.

Furthermore it can be reported that the stretching process or tension in the sheet does not influence the absorption coefficient. In real life application the sheet is produced at a size that is 7-10% smaller than the actual size when installed (Documentation technique). By theoretical calculation according to the equation (1) to (7) it can be shown that the change in absorption resulting from this small change in geometry is far smaller than the measurement accuracy.

Another possibilitiy to improve the sound absorption of a micro-perforated panel absorber is the addition of porous material in the air cavity between the micro-perforated sheet and the backing.

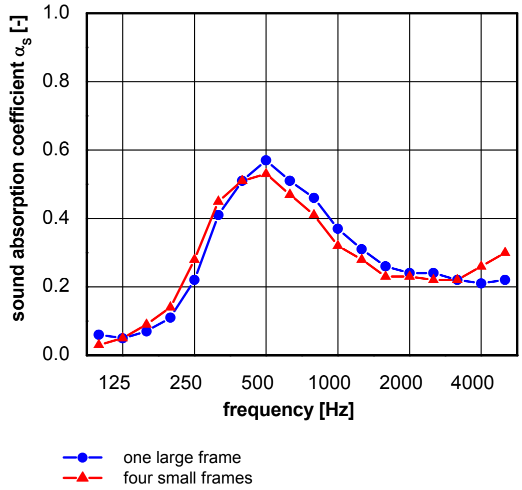

Figure 6. Measured results for sound absorption coefficient of the micro-perforated stretched foil with different panel sizes as shown in figure 5.

Figure 7 shows a sketch of the set-up used for the measurement with a porous material in the backing air cavity. From experiments it can be noted that the actual material is not very important. Tests have been carried out with mineral wool, stone wool, acoustic foam and other materials with different flow resistivities.

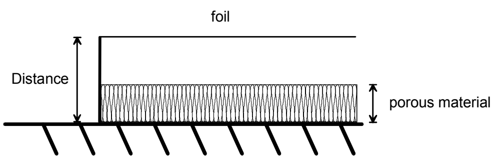

Figure 7. Principal sketch of set-up of the stretched foil.

The porous material results in an increase of the sound absorption coefficient for all frequencies, see figure 8. The maximum is reached at 400 Hz with a value of 1,02 according to ISO 354. For frequencies higher than 200 Hz the sound absorption is higher than 0.6. The single number ratings according to ASTM C 423 yield values of NRC = 0.80 and SAA = 0.78.

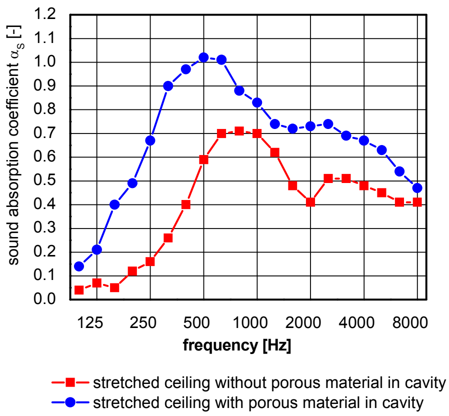

Figure 8. Measured results for sound absorption coefficient according to (ISO 354, 2003) for micro-foerated foil with and without mineral fibre (40 mm thick) in the air cavity. Overal height of set-up: 100 mm

Many more variations using micro-perforated stretched ceilings with and without different porous materials (mineral wool, foam, cloth etc.) have systematically been investigated. Several other aspects as double layered micro-perforated sound absorber, open and closed side walls, positioning of the porous material have been tested. Results of the tests are available from the authors.

APPLICATIONS OF MICRO-PERFORATED STRETCHED CEILINGS

In this section the result of a project is presented where micro-perforated stretched foils have been used to decrease and smooth the reverberation time in a restaurant room.

In the following figure 9 the reverberation before and after installation of a micro-perforated sheet is show. The ceiling was covered with a 30 mm set-up; 20 mm thick mineral woll has been used in the cavity. Reverberation time has decreased from values around 0.75 s to 0.30 s in the frequency range of speech between 250

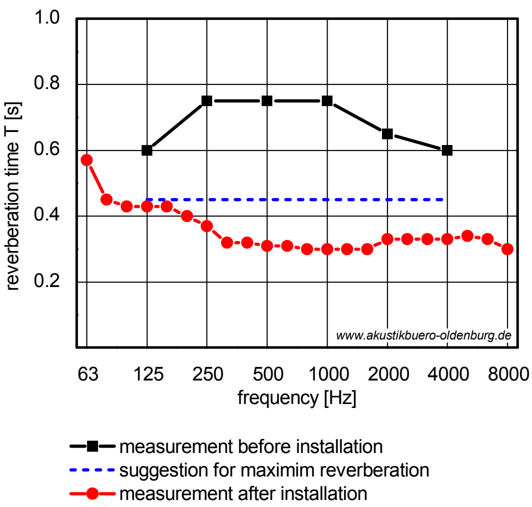

Figure 9. Measured reverberation time in restaurant before and after installation of micro-perforated ceiling.

The following figure 10 shows a view of the restaurant with the stretched ceiling with micro-perforation. Spot lights are included with special mountings. Furthermore a printed sheet with micro-perforation showing the logo of the restaurant is included. This sheet is also translucent and some light has been installed behind.

Figure 10. View of restaurant room with highly absorptive micro-perforated ceiling.

CONCLUSION

The classical theory of micro-perforated sound absorbers according to D.-Y. Maa has been reported. The agreement between predictions and simulations for standard set-ups assembled with micro-perforated stretched ceilings can be confirmed. In general the influence of the stretching process (increase of linear dimensions about 7%) is smaller than the measurement precision. Other investigations in laboratory on freely stretched assemblies and combinations with porous materials also show typical or even better acoustic properties than classical micro-perforated sound absorber set-ups.

Keeping all well-known and much appreciated properties of the stretched foil while adding new acoustic functionality by using micro-perforation offers new perspectives for the application and design of micro-perforated panel absorbers.

ACKNOWLEDGEMENTS

This work has kindly been supported by BARRISOL S.A.S, F–68680 Kembs, the manufacturer of BARRISOL® and the micro-perforated BARRISOL® Acoustics® stretched ceiling.

REFERENCES

ASTM C 423 2001, Standard Test Method for Sound Absorption and Sound Absorption Coefficients by the Reverberation Room Method.

DIN EN ISO 354 2003, Acoustics, Measurement of sound absorption in a reverberation chamber

Documentation technique, BARRISOL® Normalu, F-68680 Kembs, www.barrisol.com

Liu, K., Nocke, C., Maa 2000, D.-Y. Experimental investigation on sound absorption characteristics of micropperforated panel in diffuse fields, Acta acustica (in Chinese), 25(3): pp 211-218.

Nocke, C., Liu, K., and Maa, D.-Y. 2000, Statistical absorption coefficient of microperforated absorbers. Chinese Journal of Acoustics, 19(2): pp 97-104.

Maa, D.-Y. 1975, Theory and design of microperforated panel sound-absorbing constructions. Scientia Sinica, 18(1): pp 55-71.
Maa, D.-Y. 1983, Direct and accurate impedances measurement of micro-perforated panel. In Proc. of Internoise 83, pp 363-366.
Maa, D.-Y. 1984, Wide-band sound absorber based on microperforated panels. In Proc. of Internoise 84, pp 415-420.
Maa, D.-Y. 1985, Wide-band sound absorber based on microperforated panels. Chinese Journal of Acoustics, 4(3): pp 197-208.
Maa, D.-Y. 1987, Microperforated-panel wideband absorbers. Noise Contr. Eng. Journ., 29(3): pp 77-84.
Maa, D.-Y. 1980, Design of microperforated panel constructions. Acta acustica (in Chinese), 13(3): pp 174-180.
Maa, D.-Y. 1997, General theory and design of microperforated-panel absorbers. Chinese Journal of Acoustics, 16(3): pp 193-202.
Maa, D.-Y. 1998 , Potential of microperforated panel absorber. J. Acoust. Soc. Am., 104(5): pp 2861-2866.
Maa, D.-Y., Liu, K. 2000, Sound absorption characteristics of microperforated absorbers for random incidence. Chinese Journal of Acoustics, 19(4): pp 289-298.
Maa, D.-Y. 2011, Theory of microslit absorber, 20(1): pp 1-10.
Zha, X., Nocke. C., Häusler, C. et al. 1998, Lösung raumakustischer Probleme mit mirkoperforierten transparenten Bauteilen, Bauphysik 20(6) pp 198-208