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PROPERTIES AND APPLICATION OF MICRO-PERFORATED STRETCHED CEILINGS

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1 INTRODUCTION

The first publication[1] by D.-Y. Maa on the theory and design of micro-perforated panel absorbers (MPA) has been published in 1975. Further developments of the theory and applications are presented in various other papers[2-7]. The potential of MPA is shown in a recent publication[8] 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[9,10] in 2000. Other aspects and further investigations on micro-perforated structures are still under development and described for example in[11,12].

Stretched ceilings have been introduced around thirty years ago. The stretched membrane ceiling consists of a special PVC foil, which is mounted in-situ by clamping it to a frame construction. The foil 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 30 years this kind of ceiling and wall covering has become a popular product with regard to modern architecture and design. However, so far only optical and other aspects of the product were generally of interest. After first experiences with a micro-perforated polycarbonate foil[13], micro-perforation of the foil used for the stretched ceiling was seen as an innovative feature. This new acoustic property may open another range of applications for stretched ceilings. In 2001 the first micro-perforation of a stretched ceiling has been introduced and successfully been applied for room acoustic purposes.

With this contribution a brief introduction of the underlying theory of micro-perforated sound absorbers according to D.-Y. Maa will be given. This description refers to other publications[1,9,10] to give a general idea of the theoretical background. The theory presented is used in the following to compare with measured results.

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

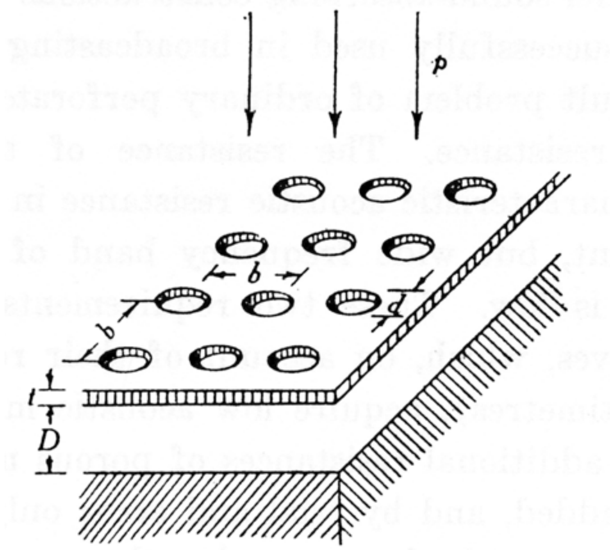
The last part of paper briefly deals with two applications of micro-perforated stretched ceilings. Two examples of room acoustic projects will be described in which the micro-perforated stretched ceiling has been successfully applied to reduce reverberation.

2 THEORETICAL BACKGROUND

A micro-perforated panel consists of small orifices spaces regularly in a surrounding material, see Fig. 1 for round orifices on a square grid. The geometry of micro-perforated panel absorber with round wholes on a square grid is fully defined by the four geometrical parameters:

- d – diameter of the wholes,
- b – distance between the wholes,
- t – thickness of the panel and
- D – air cavity depth

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



The theory of the micro-perforated panel absorbers as presented in [1] is based on the classical treatment of sound propagation in short tubes. The derivation by Maa first delivers an approximation for the specific acoustic impedance Z_{MPP} for a micro-perforated panel of thickness t as

$$Z_{MPP} = r + j\,\omega\, m$$

The formulae for *r* and *m* are given in several publications, see for example [1,9]. 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 $Z_{AIR}(\theta)$ of the air cavity of depth *D* at an angle θ to the normal of the surface given by

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

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

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

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

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

This equation for $\alpha(\theta)$ 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

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

This formula for α_{stat} represents the limiting case for equally distributed angels of incidence and can also be obtained from an exact analysis of normal modes in a room[9].

3 SOUND ABSORPTION COEFFICIENTS OF MICRO-PERFORATED STRECTCHED CEILINGS

So far, room acoustical design projects using micro-perforated stretched ceilings had to rely on the theory of micro-perforated sound absorbers. On the one hand, this was a chance, because this made possible a purely theoretical planning of the objects. From other publications such as [9,10,13] it is known that the theoretical predictions agree well with corresponding measurements. On the other hand, proofing measurements in laboratory and in the field for this new product had been urgently required for planning purposes and material suppliers.

In the following section the results of reverberation chamber measurements of various assemblies using micro-perforated stretched ceilings are presented. All measurements have been carried out according to the procedure described in DIN EN 20354 (ISO 354)[14]. The theoretical results are calculated in accordance with the approximate theory using the following geometrical features of the micro-perforated stretched ceiling:

diameter of the wholes d = 0.2 mm,
distance between wholes b = 2.0 mm,
thickness of panel (stretched foil) t = 0.17 mm to 0.20 mm
air cavity depth D varied between 30 mm and 200 mm

The foils have been stretched within an aluminium frame of 3 m x 4 m in size. The same frame construction is used for the installation in rooms[15].

Figure 2 shows sketches of the mounting of the micro-perforated and the non-perforated stretched ceiling in the reverberation chamber. The backing wall is formed by the floor of the reverberation chamber. The side walls between frame and floor were closed. Figure 3 gives an impression of the set-up in the reverberation chamber.

Figure 2 : Sketch of set-up of the non-perforated and the micro-perforated stretched ceiling, both with 100 mm distance to the backward ground.

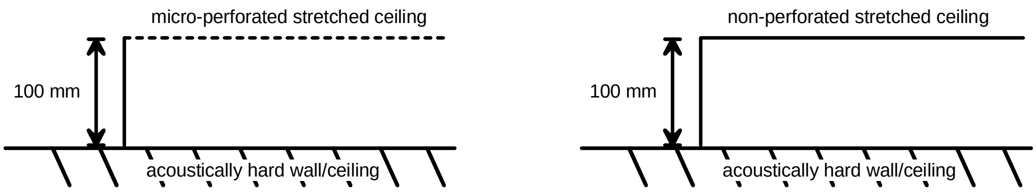


Figure 3 : Micro-perforated stretched ceiling with 100 mm distance to the floor set up in the reverberation chamber.

In Figure 4 the frequency-dependent sound absorption coefficient according to ISO 354 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[16] 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 4 : Sound absorption coefficient of the non-perforated and the micro-perforated stretched ceiling, both with 100 mm distance to the backward ground.

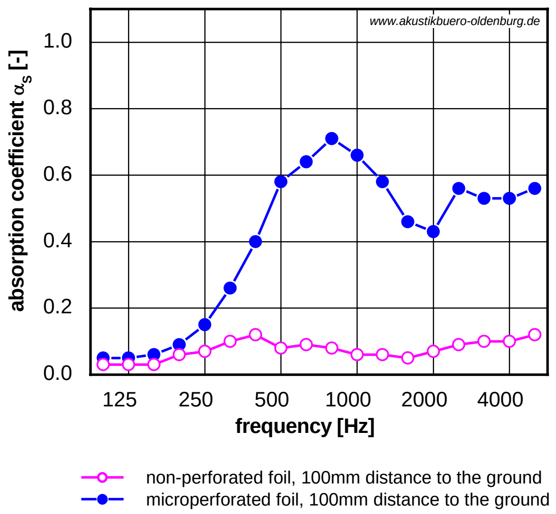


Figure 5 : Absorption coefficient of the micro-perforated foil with 100 mm distance to the ground in comparison with the calculated values.

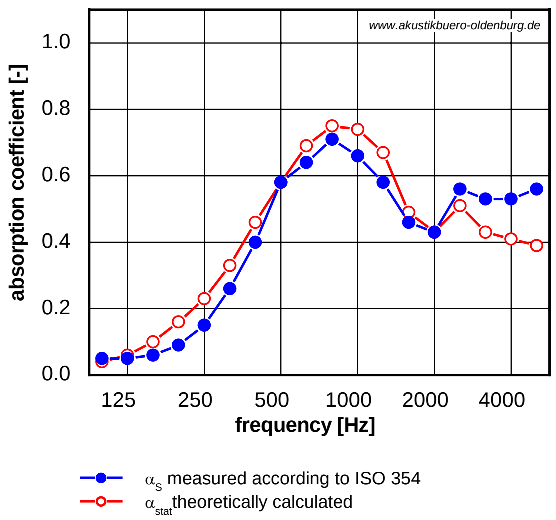
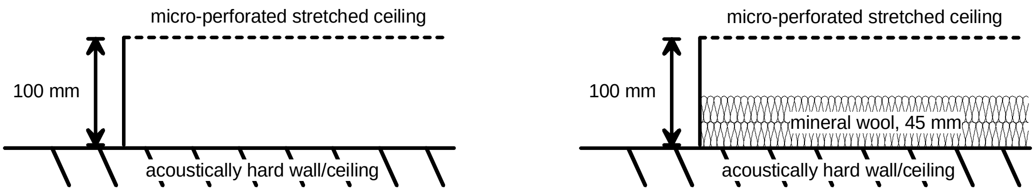


Figure 5 shows the comparison of the frequency-dependent sound absorption coefficient for the micro-perforated stretched foil measured according to ISO 354 and calculated according to D.-Y. Maa's theory[1-11]. The two curves agree quite well. Only for frequencies higher than 3150 Hz the deviations become larger than 0.10. The theoretical calculations have been carried out using statistical sound absorption coefficient.

Increasing the depth of the air cavity between foil and backing wall shifts the sound absorption maximum towards lower frequencies. Vice versa, smaller distances between the foil and the backing wall let the sound absorption maximum move towars higher frequencies. To broaden the absorption range of a micro-perforated sound absorber two or more micro-perforated panels may combined[1,7,9,13].

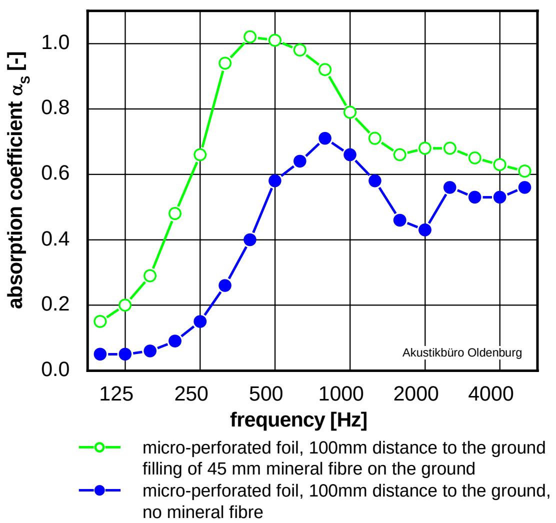
Another possibility to broaden the sound absorption curve is to add porous material into the air cavity between the stretched foil and the backing wall. Figure 6 shows the set-up for a micro-perforated stretched ceiling with and without a porous material in the air cavity between the foil and the backing wall. Several positions of the material in the cavity have been investigated such as directly on the floor/ceiling, directly behind the foil and somewhere between both surfaces. In the following, only results for the situations depicted in Figure 6 are presented.

Figure 6 : Sketch of set-up of the micro-perforated stretched ceiling (100 mm distance to the backward ground) with and without porous material (45 mm mineral fibre) in the air cavity.



The results for the situation with and without mineral wool behind the stretched foil is shown in Figure 7. The porous material results in an increase of the sound absorption coefficient for all frequencies. 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 7 : Sound absorption coefficient of the micro-perforated foil with 100 mm distance to the wall with and without partly filling of 45mm mineral fibre, placed directly on the ground of the reverberation chamber behind the foil.



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.

4 APPLICATIONS OF MICRO-PERFORATED STRETCHED CEILINGS

In this section two projects are presented where micro-perforated stretched foils have been used to decrease and smooth the reverberation time in a room. The first project was carried out on a purely theoretical basis as only calculated values of the micro-perforated stretched foil had been available. The second example shows the application in a large sports hall.

4.1 Meeting room in a church

The users of a historical meeting room complained about too much reverberation during presentations, discussions and chamber music concerts. The main usage of the room are meetings with several people. The floor is made of wood, the walls are covered by wooden panels up to a height of 2.2 m. Above this height the walls are made of plaster. Large side windows are on two sides in the upper part of the walls. The acoustical treatment required to be nearly “invisible”, furthermore it should allow some air flow behind due to humidity concerns. These requirements let the responsible architect decide for micro-perforated stretched foils.

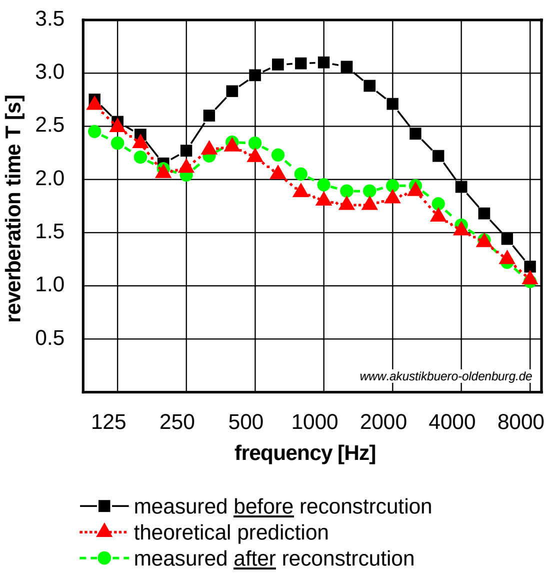
In Figure 8 one of the three arches is shown after the treatment with micro-perforated wall covering as well as a detail of the wall covering. The closer view shows the 0.2 mm wholes of the foil.

Figure 8 : Picture of micro-perforated stretched wall covering in historical church room.

Close view of micro-perforated stretched foil

Due to the previous complaints described above an initial measurement of the reverberation time of the room had been carried out. The result of this measurement (carried out according to ISO 3382)

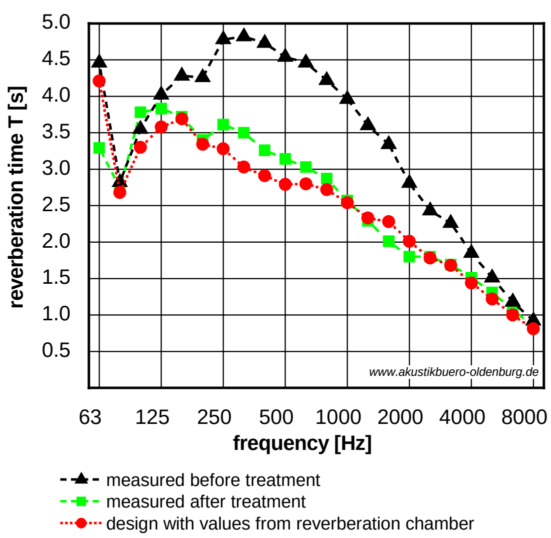
Figure 9 : Measured reverberation time before and after treatment with micro-perforated stretched wall covering in comparison with the theoretical estimate.



is depicted in Figure 9 in comparison with the theoretical estimate and the measurement after the treatment.
Initially, the reverberation time showed maximum values of approx. 3 s between 500 Hz and 1250 Hz with a large decrease down to 1.2 s at 8000 Hz. Below 500 Hz the reverberation time showed a minimum of 2.1 s at 200 Hz. Overall, the reverberation curve had much too high values as well as a very uneven course. Accordingly, the aim of the theoretical prediction was to lower the values between 250 Hz and 2000 Hz as well as to smooth the reverberation curve over frequency. These aims have been achieved by the micro-perforated stretched foil. Over all 35 m^2 of micro-perforated stretched foil with a distance of 70 mm to the backing plaster wall have been applied. 70 mm for the air cavity depth were chosen to obtain highest absorption at 800 Hz. The theoretical prediction and the proving measurement after the reconstruction agree very well as shown in Fig. 9

4.2 Multi-purpose hall

Figure 10 : Measured reverberation time before and after treatment with micro-perforated stretched ceiling in comparison with the theoretical estimate.



A newly built multi-purpose hall with approximately 11.000 cbm volume had the reverberation time shown in Figure 10. The maximum value of 4.8 s was reached at 315 Hz. Speech intelligibility was poor. The hall is used as a sports hall for schools, for performances of music and theatre as well as for meetings, fairs and other local activities.
The floor is made of rubber finishing, the walls are covered with 2 mm thick felt.
The measured reverberation curve before the treatment clearly shows the influence of the felt at the walls with a large decrease from 315 Hz to 8000 Hz. At frequencies below 315 Hz the reverberation time also decrease, most probably due to the influence of the layered metal-mineral wool-metal structure of the ceiling. Due to static reasons the architect had to use a light weight material. So, the decision was made to use the micro-perforated stretched ceiling with a weight of 200 g/m^2.
Figure 11 shows some parts of the ceiling. Altogether, around 2/3 of the 1000 m^2

ceiling surface have been covered with micro-perforated stretched ceiling. The distance between the foil and the metal ceiling varies between 150 mm and 240 mm. The initial design had been carried out with 200 mm but had to be altered during installation due to other obstacles. The alteration may explain the small deviations between the measurement afterwards and the room acoustical design shown in Figure 10.

Figure 11 : Picture of micro-perforated stretched ceiling in the multi-purpose hall.

5 ACKNOWLEDGEMENT

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6 REFERENCES

1. Dah-You Maa. Theory and design of microperforated panel sound-absorbing constructions. Scientia Sinica, 18(1):55-71 (1975).
2. Dah-You Maa. Direct and accurate impedances measurement of micro-perforated panel. In Proc. of Internoise 83, pages 363-366 (1983).
3. Dah-You Maa. Wide-band sound absorber based on microperforated panels. In Proc. of Internoise 84, pages 415-420 (1984).
4. Dah-You Maa. Wide-band sound absorber based on microperforated panels. Chinese Journal of Acoustics, 4(3):197-208 (1985).
5. Dah-You Maa. Microperforated-panel wideband absorbers. Noise Contr. Eng. Journ., 29(3):77-84 (1987).
6. Dah-You Maa. Design of microperforated panel constructions. Acta acustica (in Chinese), 13(3):174-180 (1988).
7. Dah-You Maa. General theory and design of microperforated-panel absorbers. Chinese Journal of Acoustics, 16(3):193-202, (1997).
8. Dah-You Maa. Potential of microperforated panel absorber. J. Acoust. Soc. Am., 104(5):2861-2866 (1998).
9. Christian Nocke, Ke Liu, and Dah-You Maa. Statistical absorption coefficient of microperforated absorbers. Chinese Journal of Acoustics, 19(2):97-104 (2000).
10. Ke Liu, Christian Nocke, Dah-You Maa. Experimental investigation on sound absorption characteristics of micropperforated panel in diffuse fields, Acta acustica (in Chinese), 25(3): 211-218 (2000)
11. Dah-You Maa and Ke Liu. Sound absorption characteristics of microperforated absorbers for random incidence. Chinese Journal of Acoustics, 19(4):289-298 (2000).
12. Dah-You Maa, Theory of microslit absorber, 20(1):1-10 (2001).
13. X. Zha, C. Nocke, C. Häusler et al.: Lösung raumakustischer Probleme mit mirkoperforierten transparenten Bauteilen, Bauphysik 20(6) 198-208 (1998)
14. DIN EN 20354 (ISO 354), Acoustics, Measurement of sound absorption in a reverberation chamber, 1985
15. Documentation technique, BARRISOL® Normalu, F-68680 Kembs, www.barrisol.com
16. ASTM C 423, Standard Test Method for Sound Absorption and Sound Absorption Coefficients by the Reverberation Room Method, 2001.