Micro-perforated stretched ceilings and porous materials

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Stretched foils used as ceilings, wall coverings and other set-ups have been applied for more than 30 years. By introducing a nearly invisible micro-perforation into the stretched material the foil becomes highly sound absorptive. The classical set-up of a micro-perforated sound absorber consists of a micro-perforated panel in front of an air cavity. The sound absorption coefficient of these set-ups can easily calculated with a high accuracy according to the well-known approximation of D.-Y. Maa if all defining geometrical parameters (diameter of micro-perforation, distance between orifices, panel thickness and air cavity depth) are known. In this contribution measured sound absorption coefficients of other set-ups with micro-perforated foils as well as combinations with different porous materials will be presented. For these assemblies no closed calculation model exists so far. Finally different applications in various rooms will be presented.

1 Introduction

Stretched ceilings have been used for around thirty years [1]. Within this time this kind of ceiling and wall covering has become a popular product with regard to modern architecture and design. Nearly any shape might be built by this technique. However, only optical and other aspects of the product were generally of interest. After first experiences with a micro-perforated polycarbonate foil [2], micro-perforation of the foil used for the stretched ceiling was seen as an innovative feature. In November 1999, the first micro-perforation of a stretched ceiling has been carried out and successfully been applied in room acoustics [3, 4]. The stretched membrane ceiling consists of a special PVC foil, which is mounted in-situ by clamping it to a frame construction [1]. The foil is heated before mounting, and the membrane acquires its final tension after cooling. The new acoustic property of the stretched ceiling system now opens another wide range of applications for stretched ceilings [3, 4, 5].

2 Theoretical background micro-perforated sound absorbers

The theory of the micro-perforated panel absorber as initially presented in [6] is based on the classical treatment of sound propagation in short tubes. The derivation by Maa [6] first delivers an approximation for the specific acoustic impedance $Z_{MPP}$ 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 [6].

The angle-dependent impedance $Z_{MPP}$ of the micro-perforated sound absorber can easily be calculated by Maa’s approximation [6, 7]. From this impedance, 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 [7, 8, 9]. All formalae used for the calculation have in detail been reported elsewhere, see [7].
3 Results from laboratory

Figure 2 (left) represents a sketch of a classical stretched ceiling set-up for reverberation chamber measurements according to [10, 11]. The foil is stretched on a frame construction 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, so the air volume has no connection to the outside.

By adding a porous material into the air cavity, see Figure 2 right, the acoustic performance of the resonance system made of micro-perforated foil and air cavity can be altered.

For all measurements presented in this paper a constant distance D of 100 mm between micro-perforated stretched foil and acoustically hard surface was used. The thickness of the porous material, here mineral fibre, was 45 mm.

All measurements presented in the following were carried out according to ISO 354 [10], ASTM 423 [11] respectively. Results from reverberation chamber measurements of various assemblies using micro-perforated stretched ceilings are now available for room acoustic planning purposes [1].

The foils have been stretched for the measurements within an aluminium frame that is also used for the installation in rooms. In general, increasing the depth of the air cavity between foil and backing wall shifts the sound absorption maximum towards lower frequencies. To broaden the absorption range of a micro-perforated sound absorbers two or more micro-perforated panels may be combined [2, 6]. In this contribution another approach has been applied to broaden and increase the sound absorption by adding the porous material into the air cavity.

![Figure 2: Sketch of micro-perforated panel absorber (MPA) made of micro-perforated foil with an without porous material (mineral wool) in air cavity.](image1)

![Figure 3: Measured sound absorption coefficient with and without porous material in air cavity, see sketch of set-up in Figure 2.](image2)

In Figure 3 the measured sound absorption coefficient for the two set-ups depicted in Figure 2 are presented. Without the porous material the micro-perforated stretched foils show a typical frequency dependence of a resonant system with a sound absorption maximum at 800 Hz with a value of around 0.7. By adding the porous material into the air cavity the sound absorption maximum is shifted towards lower frequencies and now yields a maximum value of 1.1 at 500 Hz.

![Figure 4: Measured and calculated sound absorption coefficient for a set-up without porous material.](image3)
A comparison of a calculation according to Maa’s [6] theory of the sound absorption coefficient for diffuse incidence and the corresponding measurement of a set-up without any porous material is shown in Figure 4. The agreement between both curves is very high. These results support the findings of other authors: the theory of micro-perforated panel absorbers predicts very precisely the acoustic properties of such materials [2]. Obviously, the theory works well for thin (170 µm) stretched foils with micro-perforation.

The same comparison between a calculation and a measurement of a combination of a micro-perforated stretched ceiling and a porous layer in the air cavity is depicted in Figure 5. The set-up has been interpreted as a layered sound absorber. The formulae given by Mechel [12] for sound propagation in fibrous materials have been applied. Details of the calculation procedure will be reported elsewhere.

4 Application

In this section one example of the application of the micro-perforated stretched ceiling will be discussed. In a traditional restaurant in Cologne (Germany) visitors and staff complained about too much noise, poor speech intelligibility and acoustic discomfort.

The result of an initial measurement of reverberation time revealed a lack of sound absorption especially in mid and high frequency range. In figure 5 the blue dotted lines represent the suggested reverberation time for the size of the room. An acoustical design was worked out using micro-perforated stretched ceilings.

Figure 6: Measured and calculated sound absorption coefficient for set-up with porous material.

Figure 7: View of restaurant before and after reconstruction with stretched acoustic ceiling.
Figure 7 shows the situation in the restaurant before (top) and after (bottom) the reconstruction with micro-perforated ceilings. Altogether 42 m² of micro-perforated stretched ceilings with a distance of 100 mm to the backing original ceiling and 40 mm of porous material in the cavity in conjunction with 32 m² of micro-perforated stretched ceiling with a depths of 30 mm have been applied.

Figure 6 shows the change of reverberation time in comparison with the acoustic design using laboratory values for the sound absorption coefficient. The agreement between prediction and final result is very close. The problems in the room described above have fully been solved.

5 Summary

The classical theory of micro-perforated sound absorbers according to D.-Y. Maa [6] has been applied for the design of micro-perforated sound absorbers made out of stretched foils. The agreement between predictions and simulations for standard set-ups assembled with micro-perforated stretched ceilings can be confirmed. The influence of the stretching process is negligible [4]. Investigations in laboratory on combinations with porous materials also show typical or even better acoustical properties than classical micro-perforated sound absorber set-ups.

Once again the application in

Acknowledgements

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

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