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Effect of a membrane attached to a microperforated panel absorber on its sound absorptivity: Possibility of adjusting the acoustic properties of a microperforated panel by covering materials

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Abstract: In this note, the effect of a permeable or impermeable membrane attached behind an MPP on its absorption characteristics is theoretically analysed. Attached membranes give an additional acoustic reactance, as well as an additional acoustic resistance in the case of a permeable one. The possibility to adjust the absorption characteristics of an MPP absorber by these effects is discussed through numerical examples. The results show that: (1) a permeable membrane of suitable resistance can increase the peak absorption of an MPP absorber. The mass of a permeable membrane has only negligible effect. (2) The additional reactance of an impermeable membrane can be used to shift the absorption peak of an MPP to lower frequencies.

Keywords: Microperforated panel (MPP), membrane, permeability, resistance, reactance

1. Introduction

Microperforated panels (MPPs) are now very popular among the next-generation sound absorption materials. Since Maa's pioneering work [1-3], there have been many studies on their applications [4,5]. MPPs are typically made of a thin metal panel and their manufacturing process requires high technical standard. This often results in the high cost of MPPs. In actual situations in a building, it is necessary to tune sound absorbers to have desirable absorption characteristics for each particular case. However, since MPPs are expensive and it is not easy to adjust their properties, such a customisation cannot be available in reality. It can be useful to extend MPP's applicability and to lower its cost, if the absorption characteristics of an MPP can be adjusted by some simple means. It is well known that the absorptivity of an MPP is fully dependent on the acoustic resistance of its submillimetre perforation. The use of a porous absorbent in a cavity, as practised for conventional perforated panels, can spoil MPP's resonant absorption efficiency. Therefore, an adjustment should be made by adding acoustic resistance or reactance to MPP's perforation.

One possibility of adjusting the acoustic properties of an MPP is by using a covering material, e.g., a thin limp material such as a permeable or impermeable membrane. These covering materials can add acoustic resistance and reactance if they are permeable, or reactance only if they are impermeable, thereby affecting the acoustical properties of MPP sound absorbers. For example, the additional acoustic resistance of a permeable covering material can improve an MPP with insufficient resistance due to inadequately designed perforation. Also, the additional reactance of impermeable covering material can be used to adjust an MPP's resonance frequencies.

Similar studies were conducted to investigate the effect of an attached thin permeable material on the acoustic properties of a conventional perforated panel with much larger perforations [6,7]. In these studies, the acoustical effect of textiles and other thin permeable materials attached behind a conventional perforated panel were experimentally investigated, and it was shown that the use of a permeable material can increase both the absorption coefficient and the relationship between the material's flow resistance and the absorption. Although these results are limited to the cases of conventional perforated panel with perforations much larger than MPPs, they suggest that the additional resistance due to a permeable material can be used to adjust an MPP's acoustic properties. This may be applied even for an MPP made with a larger perforation, e.g. around 1mm, that is less difficult and costly to make, but less effective with lower acoustic resistance.

As for the effect of an impermeable limp material, it is empirically known from published data of a commercial product that a sheet of paper or a film can affect the absorption characteristics of a conventional perforated panel absorber. However, detailed discussion on the mechanisms associated with the use of an impermeable membrane to provide additional reactance (to the authors' knowledge) does not exist. In this note, the effect of permeable and impermeable covering membranes on the acoustical properties of MPPs is theoretically studied. Numerical results demonstrate the possibility to control MPP's acoustical properties by covering materials.

2. Analysis

Figure 1 shows the model for analysis of an MPP with a membrane attached on its exposed surface. There is an air back cavity of depth D [m] between the MPP and a rigid wall. The MPP is characterised by its hole diameter d [m] thickness (throat length) t [m], perforation separation b [m] and perforation ratio p. The membrane is characterised by its surface density m_m [kg/m^2], and when it is permeable, its flow resistance r_m [Pa s/m^2].

The analysis is performed by using the electrical equivalent circuit shown in Fig. 2. In the circuit the impedance of the MPP is represented by:

$$z = r - i\omega m \tag{1}$$

where r is the specific acoustic resistance and ωm is the specific acoustic reactance of the MPP. Note that all impedances are normalised by the air impedance ρc hereafter. Now, r and ωm are given by the following Maa's formulae [3]:

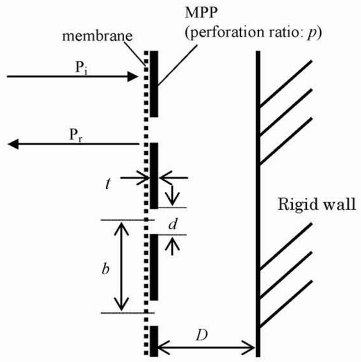

Figure 1. Sketch of the MPP absorber with an attached membrane.

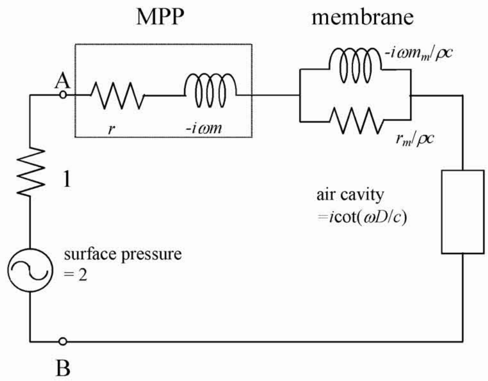

Figure 2. Electrical equivalent circuit of the MPP with a membrane on the surface (Fig. 1).

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

$$\omega m = \frac{\omega t}{pc}\left(1+\frac{1}{\sqrt{9+\dfrac{k^2}{2}}}+0.85\frac{d}{t}\right) \tag{3}$$

where

$$k = d\sqrt{\frac{\omega\rho}{4\eta}}, \tag{4}$$

ω is the radian frequency (ω=2πf) and η the coefficient of viscosity of the air (η=17.9 μPa s).

The impedance of the membrane is given as:

$$z_m = \frac{1}{\rho c}\left(\frac{1}{r_m} + \frac{1}{-i\omega m_m}\right)^{-1} \tag{5}$$

for the permeable case, and

$$z_m = \frac{-i\omega m_m}{\rho c} \tag{6}$$

for the impermeable case. Note that the membrane impedance should be added only to the holes of the MPP. Considering the impedance of a hole of the MPP, zp, and the impedance of the membrane adjacent to the hole $z_m p$, the impedance of the hole becomes $zp + z_m p$. Therefore, the average impedance per unit area of the combined membrane-MPP is given by $z + z_m$.

The acoustic reactance of the air-back cavity is

$$Z(D) = i\cot(\omega D / c) \tag{7}$$

The total impedance of the absorber is now represented by the impedance between A and B in the equivalent electrical circuit (Fig. 2). Defining this as $Z_{total} = r_{total} - ix_{total}$, the absorption coefficient is derived as

$$\alpha = \frac{4r_{total}}{(1 + r_{total})^2 + x_{total}^2} \tag{8}$$

3. Numerical results and discussion

Numerical results are presented to illustrate the sound absorption characteristics of (1) an MPP with a permeable membrane attached to its surface, and (2) an MPP with an impermeable membrane attached to its surface. The geometric parameters of the MPP are given in Table 1 (unless otherwise stated).

Table 1. Geometric parameters of the MPP.

	Reference value
Hole diameter d [mm]	0.4
Hole separation b [mm]	3.5
Thickness of Panel (throat length) t [mm]	0.4
Perforation ratio p [%]	1.0
Depth of air-back cavity D [mm]	50.0

(1) MPP with a permeable membrane attached to its surface

The use of a permeable membrane attached to the surface of an MPP gives additional acoustic resistance to the sound absorbing system, which can result in an increase of the absorption coefficient. Figure 3 presents the absorption characteristics of an MPP with a permeable membrane, compared with the MPP without the membrane. Results show that when a permeable membrane (of flow resistance 204 Pa s/m and surface density 1 kg/m^2) is attached, the absorption coefficient increases at almost all frequencies: the absorption peak becomes broader and the maximum value reaches unity. Another example shown in this figure is an MPP with and without a permeable membrane layer, of the same geometric parameters as before but with a larger hole diameter of 0.8mm. In this case, its absorption coefficient is lower, however it increases up to about 0.8 when the permeable membrane is attached. This proves the possibility to adjust the absorption characteristics of an MPP by attaching a permeable membrane. This can be utilised when an MPP is not manufactured properly, for example, due to poor precision in the perforating process. Making submillimetre perforations in thin metal panels is very costly. A permeable membrane can be used with an MPP with larger perforation, which is easier to make and less costly, to obtain a similar performance. However, one should note that if the MPP is already optimised, the attached membrane can deteriorate the absorption characteristics of the sound absorbing system when the membrane's flow resistance is too high. For example, the acoustic performance of an MPP with the parameters given in Table 1 deteriorates when a permeable membrane of flow resistance higher than 816 Pa s/m is attached. In order to gain more physical insight, the effect of the flow resistance of the membrane is now examined.

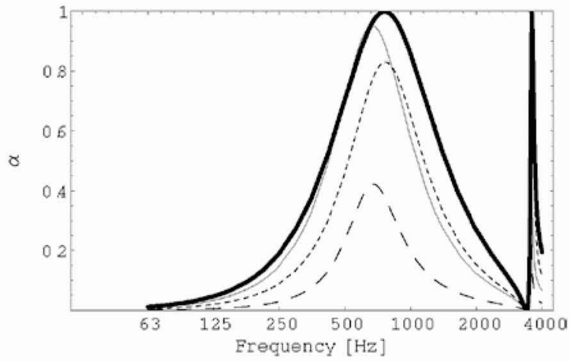

Figure 3. Examples of calculated absorption coefficient of an MPP with a permeable membrane attached on the surface. Thick solid line shows an MPP with the parameters in Table 1 with a permeable membrane (r_m=204 Pa s/m, m_m=1.0 kg/m^2) on the surface, to be compared with the MPP without membrane (dotted line). Thin solid line shows another MPP with the parameters in Table 1, but hole diameter is changed to 0.8 mm, with the same permeable membrane, to be compared with the case without the membrane (dashed line).

Figure 4 shows the effect of the flow resistance of the attached permeable membrane (of surface density 1 kg/m^2). The parameters of the MPP are given in Table 1. As discussed above, the absorption peak becomes almost unity when the flow resistance is 204 Pa s/m, but it decreases when the flow resistance is increased to 816 Pa s/m. However, the peak value is still high around 0.8 and the peak becomes broader. How much effect occurs is dependent on the acoustic resistance of the original MPP: it is dependent on each individual MPP case. In the case of a conventional perforated panel with a much larger perforation, the resistance of the panel is usually quite low and the additional resistance due to the permeable leaf is dominant in many cases [6,7]. This is due to the fact that the leaf can offer the maximum absorption when its flow resistance is around unity (normalised to ρc). However this is not the case for MPP absorbers: the total acoustic resistance can exceed its optimal range due to the additional resistance of the attached leaf if the acoustic resistance of the original MPP is already optimised. Kimura [6,7] pointed out for conventional perforated panels, one should note that the maximum absorption is obtained when the total acoustic resistance of the absorbing system, including the membrane, is close to unity. Maa [1-3] also demonstrated that an MPP absorber becomes most efficient when its acoustic resistance is unity. Therefore, the flow resistance of the membrane should be adjusted to make the total acoustic resistance of the combined membrane-MPP system unity to obtain the best results.

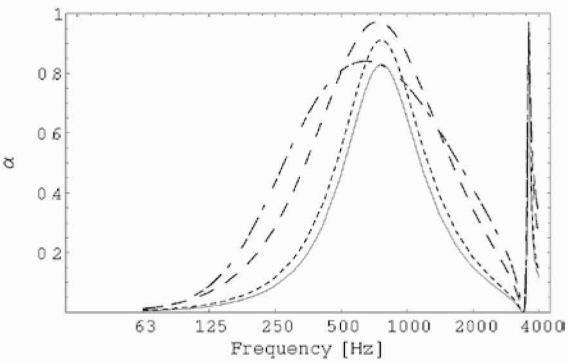

Figure 4. Effect of the flow resistance r_m of the permeable membrane attached on the surface of an MPP. Solid line: no membrane; Dotted line: r_m=51 Pa s/m (=ρc/8); Dashed line: r_m=408 Pa s/m (=ρc); Dotted-dashed line: r_m=816 Pa s/m (=2ρc). Memebrane's surface density m_m is 1 kg/m^2. MPP parameters are as in Table 1.

As for the effect of the surface density of the permeable membrane, it is shown not to affect significantly the absorption coefficient. Figure 5 shows the effect of the membrane's surface density on the absorption characteristics of an MPP with a larger perforation (d=0.8 mm) with a permeable membrane (r_m=204 Pa s/m). When the membrane is 0.5 kg/m2 or heavier, the absorption characteristics do not change at all. However, if the membrane is very lightweight, 0.1 kg/m2 in this example, the absorptivity slightly decreases. This is caused by the effect of the vibration of the membrane, which makes the acoustic resistance of the membrane lower [8]. As this effect is not very significant, it can be stated that the surface density of the permeable membrane attached to the MPP surface does not greatly affect the absorption characteristics. However, if a very lightweight material is used, this effect should be taken into consideration.

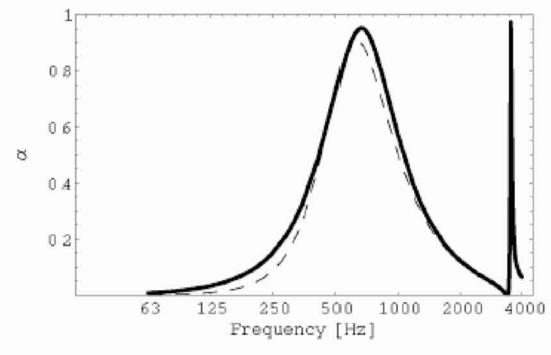

Figure 5. Effect of the surface density m_m of the permeable membrane attached on the surface of an MPP. The MPP with a larger perforation (d=0.8 mm) with a permeable membrane of the flow resistance r_m=204 Pa s/m. Other MPP parameters are as shown in Table 1. Thick solid line: immobile membrane; Thin solid line: m_m=1 kg/m^2; Dotted line: m_m=0.5 kg/m^2; Dashed line: m_m=0.1 kg/m^2. Note that the results for the cases with the surface density over 0.5 kg/m^2 are overlapped.

(2) MPP with an impermeable membrane attached to its surface

Attached impermeable membranes give additional acoustic reactance to the sound absorption system, which can result in a shift of the resonance frequency of the Helmholtz resonator of an MPP. This effect may be used to adjust the absorption characteristics of an MPP sound absorbing system. Figure 6 shows numerical results of the absorption coefficients of an MPP with an impermeable membrane, for different values of the surface density of the layer. Also shown is the absorption coefficient of the MPP in the absence of the attached membrane. The parameters of the MPP used are given in Table 1. The resonance peak shifts to lower frequencies as the surface density of the membrane increases. However, the peak value also decreases and the peak becomes sharper. Therefore, although this effect can be utilised to adjust the peak frequency, one should note that the maximum absorption and absorption width are sacrificed.

As shown in Fig. 6, when the surface density is 0.1 kg/m^2, the effect of the attached membrane is not very significant. The peak value keeps almost the same value as the original MPP without a membrane. The peak frequency shifts to lower frequencies. The peak is sharpened so that its absorption width becomes narrower. Therefore, although the additional reactance by an impermeable membrane can shift the peak frequency and can be used to adjust the absorption characteristics of an MPP, it is difficult to shift the resonance absorption significantly whilst maintaining the original wide-band characteristics.

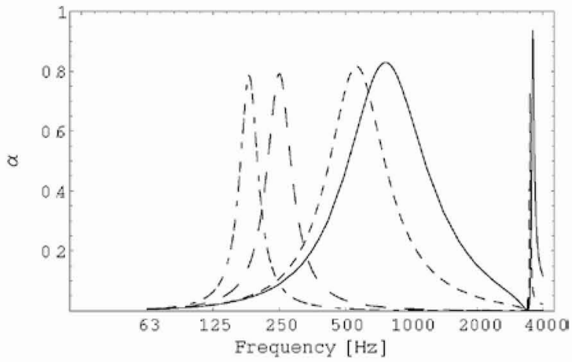

Figure 6. Effect of the surface density mm of the impermeable membrane attached on the surface of an MPP. Solid line: no membrane; Dotted line: m_m=0.1 kg/m^2; Dashed line: m_m =1.0 kg/m^2; Dotted-Dashed line: m_m =2.0 kg/m^2. MPP parameters are as in Table 1.

4. Concluding remarks

In this study, the acoustical effect of permeable and impermeable membranes attached to the surface of an MPP sound absorber is theoretically studied. A permeable membrane gives additional acoustic resistance to the sound absorbing system, thereby making the absorption peak higher and broader. However, if the total acoustic resistance of the system exceeds its optimal range by adding a permeable membrane, the absorption performance deteriorates. The surface density of the membrane does not greatly affect the characteristics when it is permeable.

In the case of an impermeable membrane, it gives additional acoustic reactance which results in a shift of the MPP resonance peak. However, it decreases the maximum absorption as well as the width of the effective absorption. If an impermeable membrane layer is used, it should be as lightweight as possible.

The results above can be applied not only to control the acoustic properties of MPPs, but also to use cover material due to other considerations. For example, covering materials may be required for protection of the surface or design considerations.

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References

1) Maa D-Y. Theory and design of microperforated panel sound-absorbing constructions. Scentia Sinica 1975;1:55-71.
2) Maa D-Y. Microperforated-Panel Wideband Absorbers. Noise Control Eng. Journal 1987;29:77-84.
3) Maa D-Y. Potential of microperforated panel absorber. J Acoust Soc Am 1998;104 (5):2861-2866.
4) Fuchs HV, Zha X, Drotleff HD. Creating low-noise environments in communication rooms. Applied Acoustics 2001;62:1375-1396.
5) Zha X, Fuchs HV, Drotleff HD. Improving the acoustic working conditions for musicians in small spaces. Applied Acoustics 2002;63:203-221.
6) Kimura S. Sound absorbing characteristics of a perforated panel with various porous materials attached to its back surface. Transactions of the Architectural Inst of Jpn 1960;64:12-20 (in Japanese).
7) Kimura S. Sound absorbing characteristics of a perforated panel absorber of various configuratios. Transactions of the Architectural Inst of Jpn 1961;69:25-28 (in Japanese).
8) Sakagami K, Kiyama M, Morimoto M, Takahashi D. Detailed analysis of the acoustic properties of a permeable membrane. Applied Acoustics 1998;54(2):93-111.

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