MULTIPLE-LEAF SOUND ABSORBERS WITH MICROPERFORATED PANELS: AN OVERVIEW

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Since the pioneering work by Maa, multiple-leaf microperforated panel (MPP) sound absorbers of various configurations with different materials have been studied. Multiple-leaf structures are primarily employed to obtain wideband sound absorption. The authors have proposed double-leaf microperforated panel space absorbers (DLMPP), which consist of two MPPs and an air-cavity in-between, without a back wall. A DLMPP is a wideband sound absorber, which is also effective at low frequencies. However, an MPP is still expensive. If one of the MPPs in such a structure can be substituted with another material, such as a permeable membrane, it can be effective and also economical. The authors, therefore, have been exploring various multiple-leaf structures including both MPPs and permeable membranes. This paper gives an overview of our studies on such multiple-leaf sound absorbing structures with MPPs, including a DLMPP, a triple-leaf MPP space absorber, a space sound absorber consisting of an MPP and a permeable membrane. Also it includes a multiple-leaf structure with MPPs and membranes backed by a rigid wall.

INTRODUCTION

Microperforated panels (MPP) are one of the most promising alternatives among various next-generation sound absorbing materials. MPPs were first intensively studied by Maa [1-4] and intensively studied for room acoustical applications by Fuchs [5-7]. Recent studies also include the applications for low-frequency sound absorbers, duct muffling devices, acoustic window systems, highway noise barriers, etc [8-11].

Attempts in development of new-type MPP absorbers for wider absorption frequency range have been made by using multiple-leaf absorbers [2, 12-15], two MPP absorbers arranged in parallel [16], etc. In Maa's early work, he proposed a double-leaf MPP with a rigid-back wall, which offers wider absorption frequency range due to two resonances [1,2]. The authors proposed a double-leaf MPP space absorber (DLMPP) which consists of two MPPs and an air-cavity in-between without a rigid backing [12,13]. This shows a single peak resonance absorption at mid-high frequencies and moderate non-resonance absorption at low to mid frequencies caused by acoustic flow resistance of the leaves. Thus, DLMPPs can offer much wider sound absorption frequency range. This additional low-frequency absorption due to the leaves' acoustic flow resistances is similar to that of single/multiple-leaf permeable membrane space absorbers [17]. This fact suggests that the low frequency absorption can still be caused even if one of the MPPs in a DLMPP is replaced by a permeable membrane, as an MPP can also be regarded as an acoustical permeable material. Therefore, the authors also proposed a double-leaf space absorber composed of an MPP and a permeable membrane [18]. This structure shows characteristics similar to those of a DLMPP when the sound is incident upon the MPP side, and shows those similar to porous-type absorbers when the sound is incident upon the membrane side – thus, it shows moderately high flat absorption characteristics when placed in a diffuse sound field in which the sound is incident from the both sides [18]. Such variations of a DLMPP, including triple-leaf MPP space absorbers (TLMPP) [15] and space absorbers with a combination of an MPP and a permeable membrane, can be used for various purposes as an effective alternative to classical sound absorbers. Also a combination of an MPP with a permeable membrane backed by a rigid wall has been studied by the authors [19].

In order to enhance the resonance absorption, the authors have proposed the use of a honeycomb in the air-cavity in the MPP sound absorbing structures [20,21]. The authors also examined its effects on the sound absorption performance of the multiple-leaf MPP sound absorbers and confirmed that the honeycomb can effectively improve the multiple-leaf MPP absorbers' sound absorption performance [14].

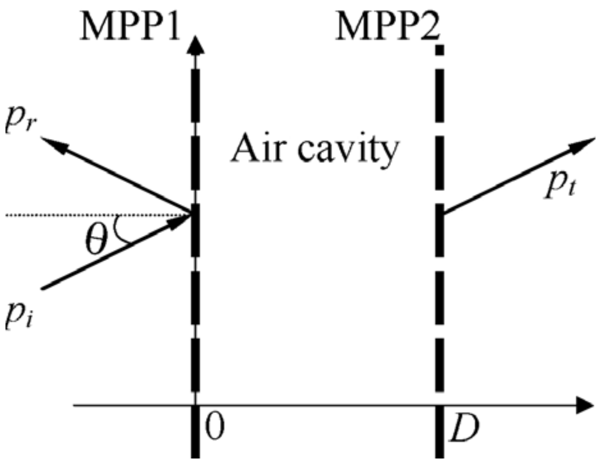
In this paper, the authors' studies on the multiple-leaf MPP sound absorbing structures mentioned above are reviewed. First, the studies on a DLMPP and its variations are reviewed. Secondly, the sound absorbing structures with a combination of an MPP and a permeable membrane, with and without a rigid-back wall, are introduced. Furthermore the studies on the effect of a honeycomb on these absorbers are reviewed.

MULTIPLE-LEAF SPACE SOUND ABSORBERS WITH MPPS

The most basic form of multiple-leaf MPP absorbers is the double-leaf MPP absorber with a rigid-back wall proposed by Maa [1,2]. By using two leaves, two resonance peaks occur which are merged into a broader peak, and it can offer wider absorption frequency range than a single absorber. However, as long as the sound absorption is solely caused by Helmholtz-type resonance, the absorption frequency range is limited in its resonance frequency range. On the other hand, permeable membranes can offer a flat frequency response at low frequencies with moderate absorption coefficients [17]. Considering the fact that MPPs are also permeable materials with acoustic flow resistance, which should behave similarly to permeable membranes, multiple-leaf MPPs without a rigid backing are expected to show a similar behaviour to a double-leaf permeable membrane. Hence, the studies on multiple-leaf MPPs without rigid-backing were triggered.

Double-leaf MPP space absorbers (DLMPP)

Figure 1 shows a sketch and the photograph of an experimental specimen of a DLMPP. Two MPPs are placed in parallel with an air-cavity in-between. Theoretical analyses were performed by using a Helmholtz integral formulation considering the sound-induced vibration of the leaves [13]. A typical result of the sound absorption characteristics of a DLMPP (a theoretical result in comparison with an experimental one) is shown in Fig. 2. In Fig. 2 the theoretical results of the absorption characteristics are shown in the difference between the absorption and transmission coefficients ($\alpha-\tau$), which indicates the ratio of the energy dissipated in the sound absorbing system. This is proven to correspond to the diffuse sound field absorption coefficient measured in a reverberation chamber [22].



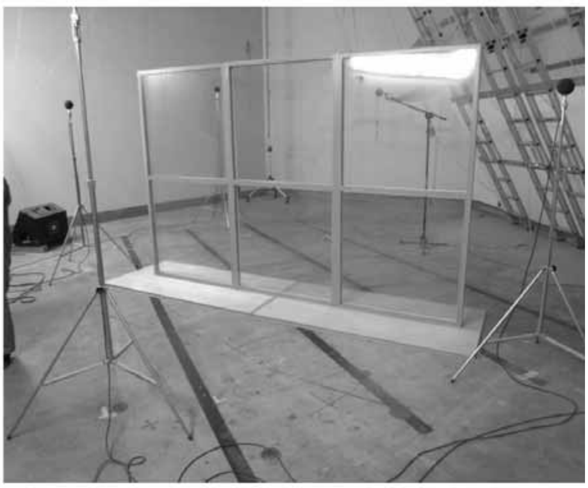


Figure 1: A sketch of a DLMPP (top) and a photograph of its experimental specimen of DLMPP (bottom).

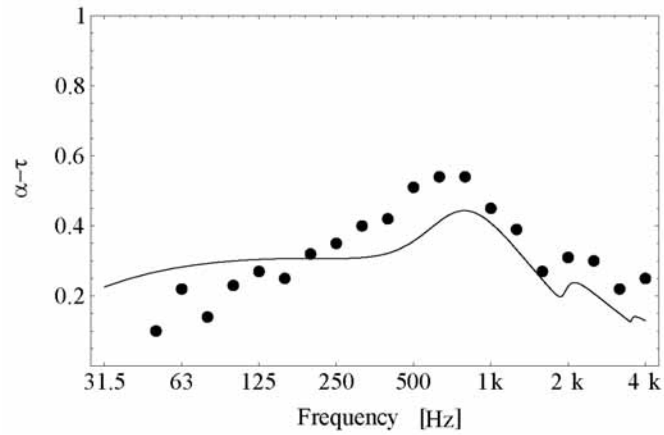


Figure 2: An example of a calculated result of the sound absorption characteristics ($\alpha-\tau$: solid line) of a DLMPP in comparison with experimental results measured in a reverberation chamber (dots). The two leaves have the same parameters: hole diameters 0.5 mm, thicknesses 1.0 mm, perforation ratios 1.23 %, surface densities 1.2 kg m^{-2}, and air cavity depth 100 mm.

As shown in the figure, a peak caused by the resonance, similar to a single MPP absorber, is shown at mid and high frequencies. This infers that a single resonator is produced by the MPP on the illuminated side with the MPP on the back side which plays the role of the back wall. An additional sound absorption at low frequencies is observed, which is not seen in other typical wall-backed MPP absorbers. Thus, a DLMPP can be shown to be an effective wide-band absorber.

Triple-leaf MPP space absorbers (TLMPP)

As Maa proposed [1,2], a wall-backed double-leaf MPP absorber using two MPP leaves makes two resonators, which produces two resonance peaks. When its air-cavity depths are adjusted so that the two peaks occur close enough to be merged into one broader peak, it offers wider sound absorbing frequency range [1,2]. Applying this idea to an MPP space absorber, replacing the rigid-back wall of a Maa's wall-backed double-leaf absorber with the third MPP makes a triple-leaf MPP space absorber (TLMPP), which is expected to produce a broader peak due to two resonances with an additional non-resonance low-frequency absorption from the leaves' acoustic flow resistances.

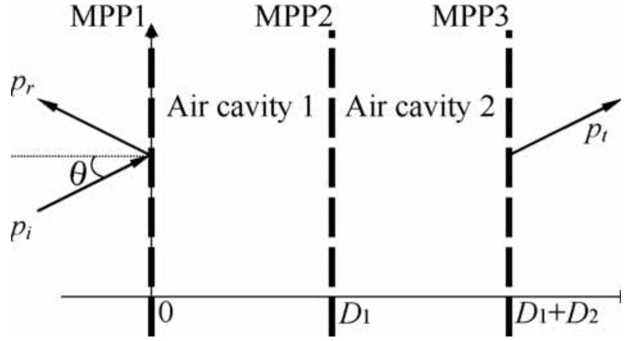


Figure 3: A sketch of a triple-leaf MPP space absorber (TLMPP).

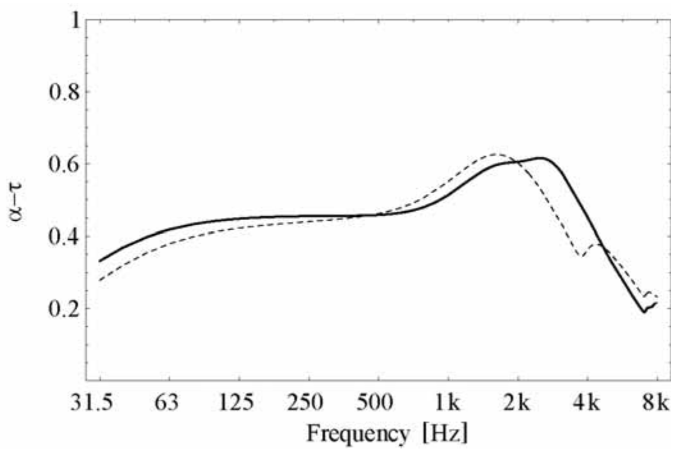


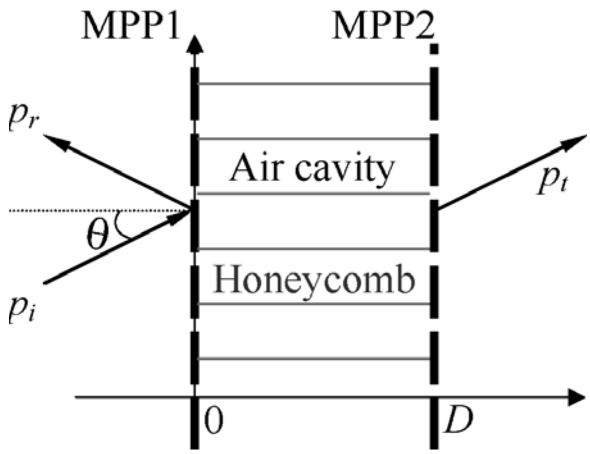
Figure 4: A comparison of the calculated field-incidence averaged sound absorptivity (α−τ) of a TLMPP (solid line), with a DLMPP (dashed). Hole diameters: 0.2 mm; thicknesses: 0.2 mm; perforation ratios: 0.8 %; depths of each cavity of the TLMPP: 25 mm; cavity depth of the DLMPP: 50 mm; surface densities: 1.8 kgm^{-2}.

Figure 3 shows a sketch of a TLMPP. Theoretical analyses have been made using a Helmholtz integral formulation, which is similar to that of DLMPPs, and a closed form solution for the difference of the absorption and transmission coefficients, α−τ is obtained. An example of the theoretical result is shown in Fig. 4. As is seen at mid-high frequencies there is a broader peak in which the two resonance peaks are merged. Therefore, the resonance absorption becomes somewhat broader than a DLMPP. Also in this case, the additional non-resonance sound absorption due to acoustic flow resistances of the MPPs appears as similar to a DLMPP at low frequencies. Thus, a TLMPP can also be effective as a wide-band space sound absorber.

Effect of honeycomb in the air-space

Use of a honeycomb is known to enhance the sound absorption of a porous material [23]. This is known as a "locally reacting absorber". A similar effect is also observed in a single MPP absorber (with a rigid-back wall) [20,21]. A sound wave obliquely incident upon the MPP is forced to travel normally to the incidence surface, which makes the absorption system to show characteristics similar to those in the normal incidence case. This results in a higher and broader resonance peak that is shifted to lower frequencies. Thus, a honeycomb can improve the sound absorption performance of an MPP sound absorber.

The honeycomb is also applied to multiple-leaf MPP space sound absorbers: Figure 5 shows a sketch and a photograph of an experimental specimen of a DLMPP with a honeycomb in the air-cavity. In Fig. 6 an example of the calculated and experimental absorption characteristics of the DLMPP with a honeycomb in the air-cavity, as well as those for the same DLMPP without the honeycomb are shown for comparison. Comparing these two results it is observed that the resonance peak is enhanced and shifted to lower frequencies, although no change is observed in the additional low frequency absorption. As mentioned above the low-frequency non-resonance absorption is caused by the acoustic flow resistance of the leaves, and does not depend on the cavity condition, whereas the resonance peak is largely affected by the honeycomb: a honeycomb makes the sound incident from the back side from the cavity normal to the leaf, and the sound incidence condition becomes close to that in the case of normal incidence (in which the peak is in general larger and appears at lower frequencies). A detailed study reveals that the optimal range of the MPP parameters becomes wider due to the honeycomb. This implies that the optimisation of the MPP parameters is less critical in the honeycomb attached case.



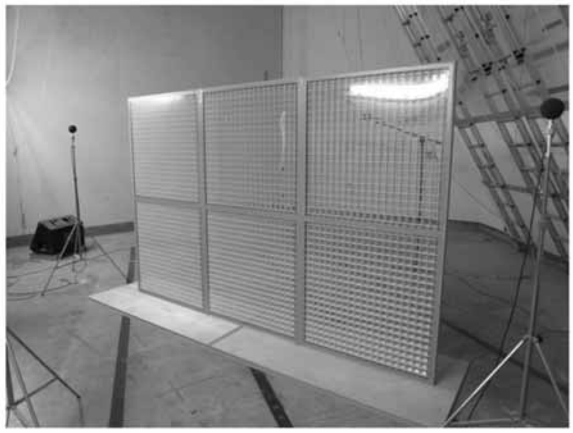


Figure 5: A sketch of a DLMPP with a honeycomb (top) and a photograph of its experimental specimen (bottom).

MULTIPLE-LEAF SOUND ABSORBERS WITH COMBINATION OF MPPS AND PERMEABLE MEMBRANES

One of the demerits of multiple-leaf MPP absorbers is that it uses more MPPs than a single absorber, which costs more than simple absorbers. In order to avoid this problem it can be useful if one of the MPPs in a multiple-leaf structure can be replaced by other less expensive materials. A possible alternative is permeable membranes. As an MPP and a permeable membrane are both acoustically permeable materials with a certain acoustic flow resistance, at least permeable membranes can act as a resistive element to give the additional low-frequency absorption in space absorbers. Also in wall-backed absorbers it can be effective to replace one MPP with a permeable membrane. Here, the possibility of the replacement of an MPP with a permeable membrane is discussed.

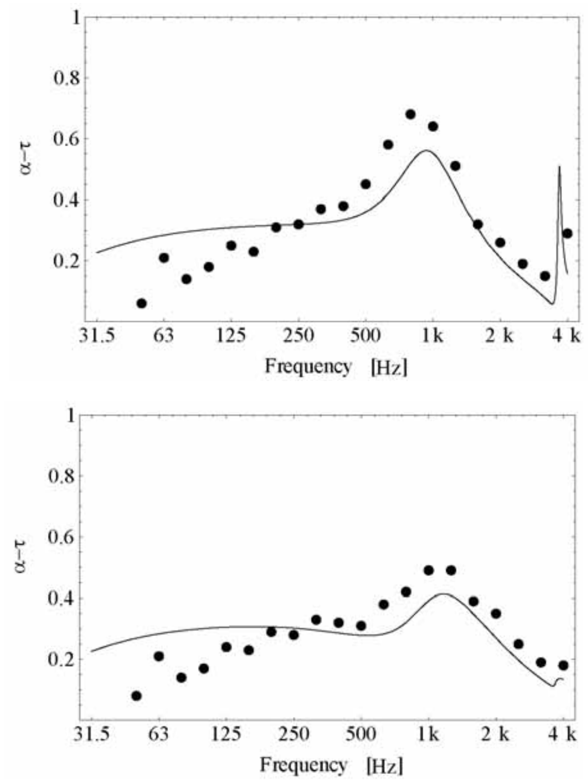


Figure 6: A comparison of the calculated (field-incidence averaged: solid line) and experimental (measured in a reverberation chamber: dots) results for a DLMPP with honeycomb (top) and without honeycomb (bottom). The two leaves have the same parameters: hole diameters 0.5 mm, thicknesses 1.0 mm, perforation ratios 1.23%, surface densities 1.2 kg m^{-2} and air-cavity depths 50 mm.

Sound absorbers with a rigid-back wall

The original form of a double-leaf MPP absorber proposed by Maa [2] consists of two MPPs with air-layer in-between with an air-back cavity with a rigid-back wall. This type uses two MPPs, which costs more than a simple MPP absorber. Hence, we consider the possibility of substituting one of those MPPs with a permeable membrane.

In this case, two alternative structures can be considered (Fig. 7). In Case A the second MPP (inside the air-cavity) is replaced with a permeable membrane, and in Case B the illuminated side MPP is replaced with a permeable membrane. The calculated examples of their sound absorption coefficients are shown in Fig. 8. In these figures the characteristics of the ordinary double-leaf MPP with a back wall are also shown for comparison. In Case A the absorption peak becomes broader and higher which offers more effective absorption in wider frequency range than the ordinary wall-backed double-leaf MPP. In Case B the characteristics are more similar to those of a porous blanket which shows higher absorption at high frequencies. Also it is noted that the contribution of the MPP is not significant because the resonance does not appear clearly. Hence, replacing the second MPP in the cavity with a permeable membrane can be a good alternative which can offer better absorption performance than the ordinary wall-backed double-leaf MPP absorbers.

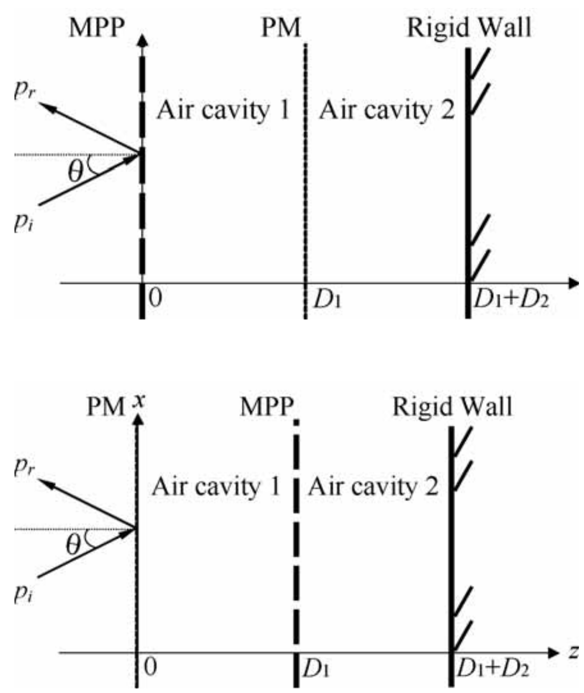


Figure 7: A sketch of wall-backed MPP-membrane combination absorbers: (Case A) MPP on the illuminated side with permeable membrane (PM) in the cavity (top); (Case B) Permeable membrane on the illuminated side with MPP in the cavity (bottom).

Space sound absorbers

The same idea as above can be also applied to multiple-leaf MPP space absorbers such as a DLMPP. Here, the absorption performance of space absorbers with a combination of an MPP and a permeable membrane is examined. One of the MPPs in a DLMPP (Fig. 1) is now replaced with a permeable membrane.

Figure 9 shows a calculated example of the absorption characteristics (α−τ) of multiple-leaf space absorber with a combination of MPP and permeable membrane (PM). Figure 9 compares the characteristics for a sound incidence on the MPP side, those for a sound incidence on the PM side, and the average of (a) and (b) which corresponds to the diffuse sound incidence to the both side (i.e., reverberation absorption coefficient [22]).

Figure 9 shows a typical resonance peak quite similar to a DLMPP in the case of MPP side incidence, whereas a high absorptivity plateau at high frequencies similar to porous materials appear in the case of PM side incidence. Actual absorbing characteristics are considered as are the averaged values, which show moderately high resonance absorption with a low-frequency absorption typical for DLMPP. Thus, this type space absorber can be a good substitution for a DLMPP and can be produced at lower cost.

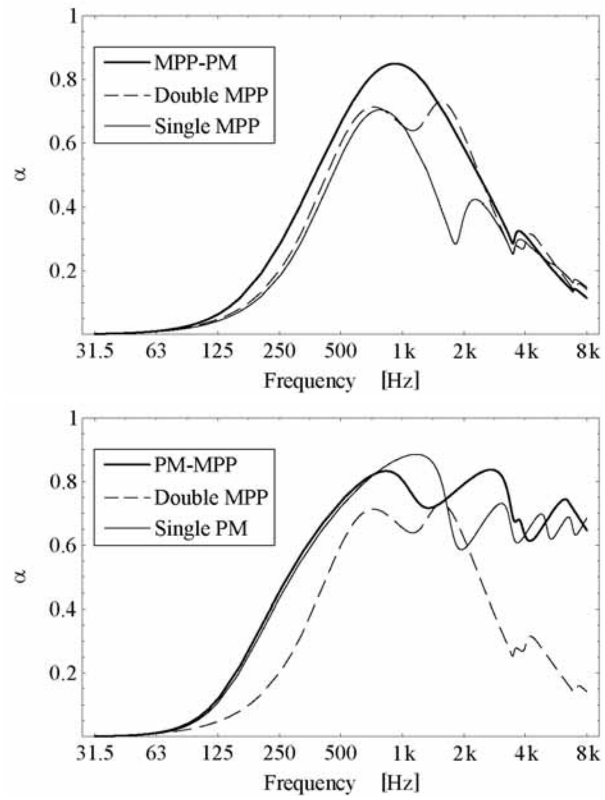


Figure 8: Calculated examples of the field-incidence averaged absorption coefficients of Cases A (top) and B (bottom), both indicated by thick lines, in comparison with the ordinary wall-backed single- MPP (left) and single PM absorber backed by a wall (thin lines) and wall-backed double-leaf MPP absorber (dashed line). MPP: hole diameter: 0.3 mm, thickness: 0.3 mm perforation ratio: 1.0 % surface density: 1.0 kgm^{-2}; PM : flow resistance: 816 Pa sm^{-1}; PM: surface density: 1.0 kgm^{-2} air cavity depths: 50 mm. The tension of the membrane is assumed to be zero.

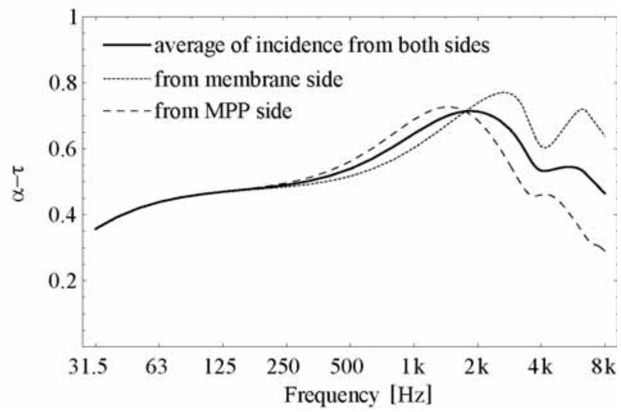


Figure 9: A calculated example of the field-incidence averaged absorption characteristics (α−τ) of a multiple-leaf space absorber with a combination of MPP and permeable membrane (PM). Dashed line: MPP on the illuminated side; Dotted line: PM on the illuminated side; Solid line: Sound incidence from both sides (averaged) which corresponds to reverberation absorption coefficient. MPP: hole diameter: 0.15 mm, thickness: 0.4 mm, perforation ratio: 1.5 %. PM : flow resistance: 816 Pa sm^{-1}; surface density: 3.0 kgm^{-2} air cavity depth: 50 mm. The tension of the membrane is assumed to be zero.

CONCLUDING REMARKS

In this paper, a series of our studies on multiple-leaf sound absorbers using an MPP is reviewed. A multiple-leaf MPP, particularly space absorber type, can be one of the effective alternatives for wideband sound absorbers. Also, a combination of an MPP and a permeable membrane can be a good alternative for multiple-leaf MPP structures: it can be of lower manufacturing cost and still offers reasonably high sound absorption performance.

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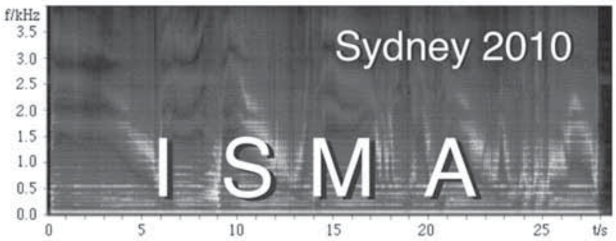

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