SOUND ABSORPTION SYSTEMS WITH THE COMBINATION OF A MICROPERFORATED PANEL (MPP), PERMEABLE MEMBRANE AND POROUS MATERIAL: SOME IDEAS TO IMPROVE THE ACOUSTIC PERFORMANCE OF MPP SOUND ABSORBERS

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ABSTRACT

A microperforated panel (MPP) is one of the most promising and attractive alternatives among various type next-generation sound absorbers. However, an MPP absorber has a shortcoming that its absorption frequency range is limited into the resonance frequency range. In order to overcome this problem, various attempts to make it more wideband since it was proposed. The authors also have tried to make it wideband in our previous studies. Among them, a simple alternative is to use MPPs with a permeable membrane and/or porous absorbent. In this article, a review introducing the main results of the studies in the author's group on sound absorbing structures composed of an MPP, permeable membrane and/or porous absorbent, as attempts to improve MPP absorbers, is presented. Even in the case of a simple MPP absorber, a permeable membrane or porous absorbent in its back-cavity are useful to make a more wideband sound absorber. In this review, also some more complex sound absorbing system including MPPs, permeable membranes and porous absorbents are introduced and the basic idea is given.

Keywords: *Sound absorption, Microperforated panel, Permeable membrane, Porous absorbent, Wideband absorber*

1. INTRODUCTION

A microperforated panel (MPP) is recently known to be one of the most promising alternatives of next-generation sound absorbing materials. It was first proposed by Maa [1-4] and intensively studied by many researchers [5-11]. It is a thin panel or film (metal or plastics) with submillimetre perforations in it (typically its hole diameter and thickness are less than 1 mm, perforation ratio is less than 1 %). The main point of the MPP's advantages is that, by making such a small hole in thin panel, the acoustic resistance and reactance optimal for sound absorption are realised. The typical use of an MPP is to place it with a rigid-back wall with an air-back cavity in-between. Thus, a perforation and the air-back cavity form a Helmholtz type resonator, which show a peak sound absorption around the resonance frequency.

The typical MPP absorber can offer a high absorption peak and wider (in comparison with traditional ordinary perforated panel absorbers) absorption frequency range when the parameters, i.e., hole diameter, thickness, and perforation ratio are optimised, however, its sound absorption effect is still limited into resonance frequency range which is usually less than two octaves [4]. In order to make it wider, various attempts have been made so far: The most basic idea to realise it is to use two MPP leaves with rigid-back wall to make a double resonator [1-2], which is the oldest idea that Maa, who invented an MPP, himself proposed. On the other hand, the authors proposed a double-leaf MPP space absorber (DLMPP) which has no backing structure [12-13]. In a DLMPP not only the resonance absorption of Helmholtz type, but also an additional absorption due to the acoustic resistance of the leaves at low frequencies offer wider absorption frequency range. This additional low frequency absorption is typical for any kind of permeable materials, such as permeable membranes, etc. Also variations of DLMPP are proposed [14-15]. As an attached structure which improves MPP absorbers' performance the use of a honeycomb is studied for a single- and double-leaf MPP absorber (with a back wall) and for a DLMPP [15,16]. The simple method to make a typical single-leaf MPP absorber more wideband is to put a permeable membrane [17] or porous absorbent [18] in the cavity.

In so doing, the most difficult problem is to minimise the cost of production: MPPs are still expensive material and using two leaves or more means that the absorber becomes more costly. In order to avoid this problem, the author's group have been studying various way to minimise the cost for improvement, and the basic idea of this is to use a less expensive material and compose a sound absorbing system with an MPP and such a material in combination. Therefore, using a permeable membrane or porous material can be a good idea for this purpose.

As mentioned above, MPPs can be made more wideband and efficient when they are used in combination with a permeable membrane and/or porous absorbent layer. In this review, the main results of the various project by the author's group in attempt to obtain wideband and efficient sound absorbers with combination of an MPP and a permeable membrane and porous absorbers are introduced and summerised to give the readers the basic idea about these complex MPP sound absorbing structures. In the following, the theory is not explained in the text, therefore, the readers are advised to consult the references in which the detailed formalism and theoretical consideration are found.

2. A SINGLE-LEAF MPP ABSORBER BACKED BY A POROUS ABSORBENT

The simplest idea is a combination of an MPP and a porous absorbent is a single-leaf MPP absorber (with a rigid-back wall) with a back cavity filled with a porous absorbent. Originally MPPs were developed as a substitute for porous material. Therefore this combination looks contradictory, however, recently various new-type porous absorbents which have overcome various shortcomings of a porous absorbent are available, e.g., porous aluminium, porous ceramics etc, and it is worth considering.

Figure 1 (left) shows a sketch of a porous-absorbent backed MPP single absorber. Assuming a plane wave of unit pressure amplitude incidence, this absorber can be modelled by the electro-acoustical equivalent circuit in Fig. 1 (right).

The specific acoustic impedance of the MPP is given by Maa's formulae [1-4]. The formulae are based on the theory of air flow in the half-infinite tube with viscous loss, and Maa arranged the results in practical form. The specific acoustic impedance of the back cavity (filled with the air or a porous absorbent) is given by conventional formula [1-4]. The total impedance is given from the circuit model in Fig. 1 (right), which gives the absorption coefficient. In this study for the characteristic acoustic impedance and the propagation constant of the porous absorbent are given by Miki's model [19], which is a modified version of empirical formulae for porous materials proposed by Delany and Bazley[20].

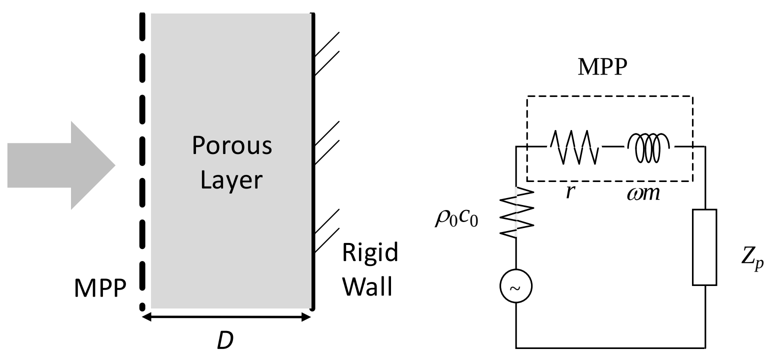

Figure 1. Geometry of a porous layer-backed single MPP absorber (left) and its electro-acoustical equivalent circuit model (right)

Here, one should note that the Maa's formulae for the resistance and reactance of the MPP include the open-end correction which is derived in the case of that the aperture is surrounded by the air. Therefore, when the MPP is backed by a porous layer as in the present case, the end correction should be adjusted accordingly. Regarding this problem, the authors have investigated how much difference can be caused by the difference of the open-end correction value [21]. According to the results in Ref [21], the difference caused in absorption coefficient by the difference of open-end corrections, one is for the air (Maa's formulae) and the other for porous material derived by the traditional theory [22], is in many cases inferred to be negligible. The same study concludes that Maa's formulae can be applied also to the porous-layer backed cases without correction and it gives fairly good results. Therefore, in the followings the results calculated by Maa's formulae (with open-end correction for the air) are shown.

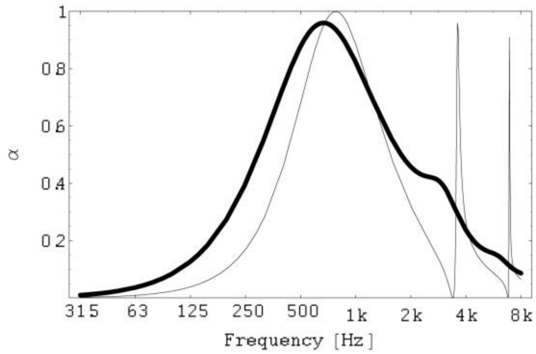

Figure 2. Comparison of the absorption characteristics of an MPP absorber backed by an air cavity (thin line) and that backed by a porous absorbent layer (thick line). The hole diameter d=0.3 mm, thickness t=0.3 mm, perforation ratio p=0.8 %, flow resistance of the absorbent R=10 kPa s m^{-1}, and cavity depth D=50 mm.

Figure 2 show a typical result of the absorption characteristics of a single-leaf MPP absorber backed by a porous absorbing layer, in comparison with that backed by an air-layer. Comparing these results, even though the peak value is slightly decreased, the resonance peak becomes broader, i.e., the width of absorption frequency range is significantly increased. Thus, it is found that the porous absorbent in the cavity of an MPP sound absorber can be useful to make it more wideband.

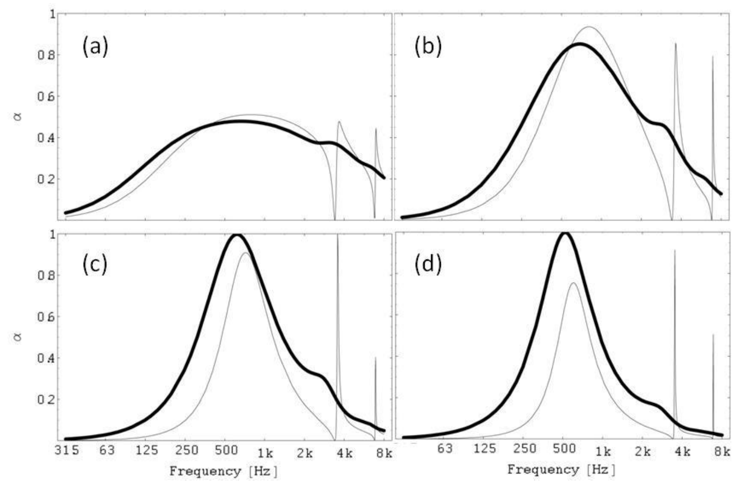

Figure 3. Effect of the hole diameter of a porous layer-backed single MPP absorber. Thick line: porous layer-backed MPP; Thin line: air layer-backed MPP. The hole diameter d=0.1 mm (a), 0.2 mm (b), 0.5 mm (c) and 1.0 mm (d). The thickness t=0.3 mm, perforation ratio p=0.8 %, flow resistance of the absorbent R=10 kPa s m^{-1}, and cavity depth D=50 mm.

The effect of the porous material in the cavity mentioned above can be changed with the parameters of the porous material. Also, it can be changed with the MPP parameters (hole diameter, thickness, and perforation ratio). For an example, the effect of hole diameter on the absorption coefficient of a porous-backed MPP absorber is shown in Fig. 3. As is observed, the effect of the porous absorbent depends on the entire acoustic resistance, thus, when the resistance of the MPP itself is already high enough (i.e., around the optimal value), the additional resistance by the porous layer makes the entire acoustic resistance too high, resulting in deteriorated sound absorption performance.

Just for a reference, a similar effect is observed in the case of a DLMPP [23]. DLMPP is two MPPs placed in parallel with an air-cavity in-between, without any backing structure. In this case, when a porous layer is put in the cavity, the sound absorption performance is greatly improved: the absorption performance is improved in all frequency range. The main theme of this article is substituting an MPP with a less expensive material to improve the performance, therefore, we skip the detail of this results relating to DLMPP, which is costly structure, however it is of some interest that a similar effect is observed even in a space sound absorber without a backing structure.

3. COMBINATION OF A PERMEABLE MEMBRANE AND AN MPP (WITH A RIGID-BACK WALL)

A double-leaf MPP absorber (backed by a rigid-back wall with air-back cavities) was first proposed by Maa [1]. This is to produce two Helmholtz resonators among two MPPs and rigid-back wall, and eventually to cause two absorption peaks. Adjusting parameters of the sound absorption system, the two peaks can be merged into a large and wide peak to cover wider frequency range.

However, using two MPP leaves is, from the viewpoint of the total cost, less advantageous even though sound absorption performance is superior to the conventional single-leaf MPP absorbers, because MPPs are still expensive. Therefore, if one of those two MPP leaves can be substituted by another less expensive - but acoustically efficient - material, it should be more advantageous.

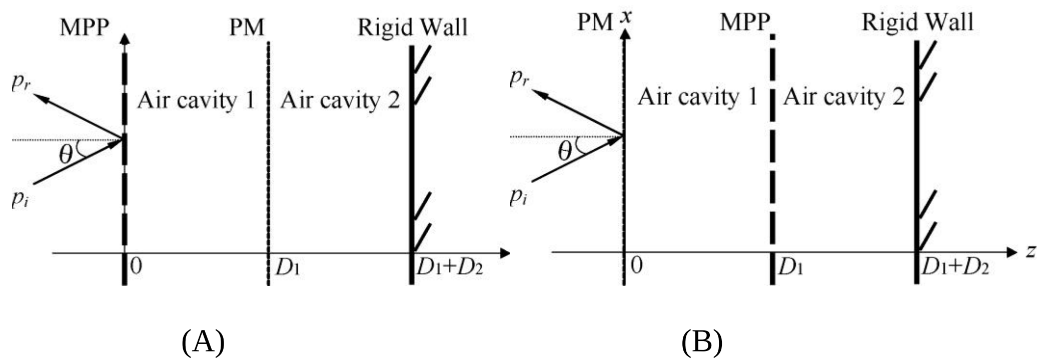

Figure 4. A sketch of wall-backed MPP-membrane combination absorbers: (A) MPP on the illuminated side with permeable membrane (PM) in the cavity (Type A); (B) Permeable membrane on the illuminated side with MPP in the cavity (Type B).

As for the substituting material for the double-leaf system mentioned above, we proposed to use a permeable membrane (PM). A permeable membrane is one of the alternatives in the next-generation non-porous sound absorbing materials, and studied for various applications [24-26]. It is acoustically almost transparent yet absorbs sound energy due to its acoustic flow resistance. Therefore, a similar role as the second MPP leaf in the double-leaf MPP absorbers can be expected.

Figure 4 shows a model of a double-leaf sound absorbing system consisting of an MPP and a permeable membrane, and a rigid-back wall. In this case, two types of arrangement can be considered: Type A is with the MPP on the illuminated side, and Type B is with the permeable membrane on the illuminated side. The results calculated by the wave theory for the sound absorption characteristics of the Types A and B are shown in Fig. 5.

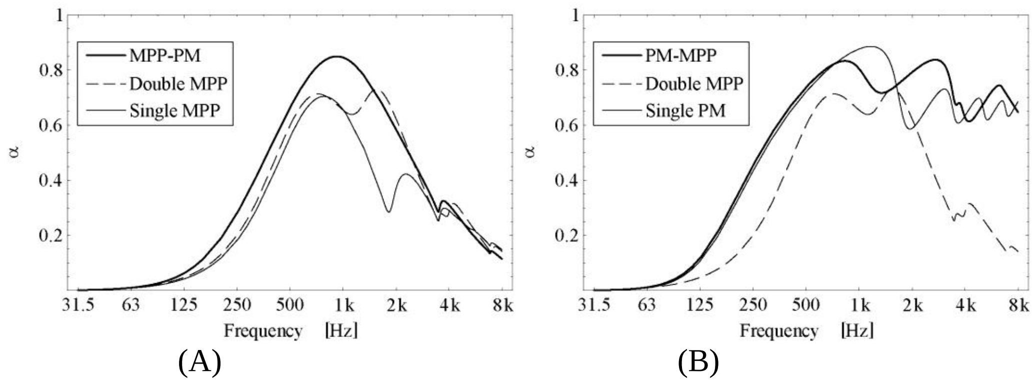

Figure 5. Calculated examples of the field-incidence averaged absorption coefficients of Types A (A) and B (B), both indicated by thick lines, in comparison with the ordinary wall-backed single- MPP (left) and single PM absorber backed by a wall (thin lines) and wall-backed double-leaf MPP absorber (dashed line). MPP: hole diameter: 0.3 mm, thickness: 0.3 mm , perforation ratio: 1.0 % , surface density: 1.0 kg m^{-2}; PM : flow resistance: 816 Pa s m^{-1}; PM: surface density: 1.0 kg m^{-2} , air cavity depths: 50 mm. The tension of the membrane is assumed to be zero.

As is observed in the results, in the Type A the PM enhances the resonance peak absorption and the peak becomes higher and broader. Thus, the PM inside the cavity makes the MPP absorber more wideband and effective. On the contrary, in the Type B, the characteristics are almost the same as those of a single PM with an air-cavity. This means that the MPP in the Type B does not work and has little contribution to the total absorption. From these results, as for the MPP and PM combination absorber, Type A is more useful than Type B.

4. COMBINATION OF A PERMEABLE MEMBRANE AND AN MPP (SPACE ABSORBER)

As mentioned above, the authors proposed a double-leaf MPP space sound absorber, in which two MPP leaves are placed in parallel to each other with an air-cavity in-between [26]. This absorption system was originally inspired by a double-leaf permeable membrane space absorber [27]. This system shows porous-like absorption characteristics at mid-high frequencies, and additional low frequency absorption due to the flow resistance of the leaves, which makes it fairly wideband. As an MPP are also permeable material which has acoustical flow resistance, a similar effect can be expected when MPPs are put into a similar structure.

As expected a DLMPP exhibits low frequency additional absorption which is quite similar to a double-leaf permeable membrane. Considering this fact, it is also expected that one of the MPPs can be substituted by a permeable membrane, i.e., a combination of an MPP and a permeable membrane can also be effective absorber.
Note that, in this case, acoustic properties depends on which side is illuminated: when an MPP is on the illuminated side a resonance properties can appear in the characteristics, on the contrary, a permeable membrane is on the illuminated side there is no resonance behaviour and characteristics can be similar to a porous absorbent.

Figure 6 shows a model of the space sound absorber with an MPP and a permeable membrane of infinite extent with a plane incident wave of unit pressure amplitude. Using a Helmholtz-Kirchhoff integral formulation the absorption coefficient is obtained.

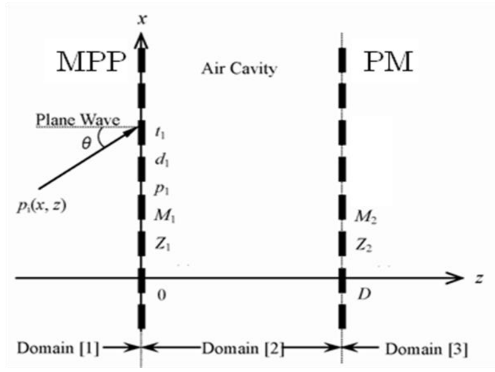

Figure 6. Geometry of a double-leaf structure with an MPP and a PM. t_1, d_1, p_1 are the MPP's thickness, hole diameter, perforation ratio, respectively. M_1 and M_2 are the surface densities of the leaves. D is the cavity depth.

Figure 7 shows a calculated example comparing the sound absorption characteristics of a DLMPP and the MPP-PM combination space sound absorbers. The values are indicated in the difference of the absorption and transmission coefficients ($\alpha-\tau$), as they are space absorbers which cause sound transmission. The difference indicates the portion of the energy dissipated in the system. In both cases the characteristics are the average of those for the sound incidence from both sides. As is seen, the combination absorber shows higher absorptivity at high frequencies. They show almost the same absorptivity at mid and low frequencies. The resonance peak becomes slightly lower in the combination absorber, probably because that the lower sound transmission loss of the PM.

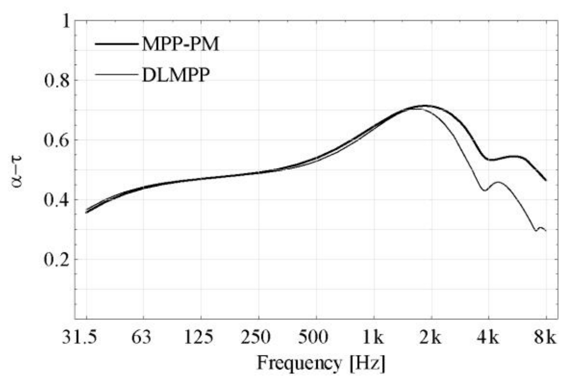

Figure 7. Comparison of $\alpha-\tau$ of a double-leaf structure with a PM and an MPP. (Thick line) and a DLMPP (thin line). The MPP parameters in both DLMPP and MPP-PM structure are: t_1=(t_2=) 0.4 mm, d_1=(d_2=) 0.15 mm, p_1=(p_2=)1.5%, D =50 mm. M_1=M_2 =3.0 kg m^{-2}. The flow resistance of the PM in MPP-PM structure is 816 Pa s m^{-1}.

Another example of the combination of an MPP and a PM can be derived by putting a PM in the cavity of a DLMPP, to increase the acoustic resistance of total system. As mentioned in the previous section, in the case with a rigid-back wall, putting a PM in the air-cavity improves the absorption performance of an MPP sound absorber. This idea can be also applied to a DLMPP: this makes a triple-leaf MPP-PM-MPP combination space sound absorber [28]. A theoretical analysis based on Kirchhoff integral formalism was carried out, and an example of the calculated result is shown in Fig. 8 in comparison with a DLMPP without the PM and TLMPP (triple-leaf MPP space sound absorber [29]). As is seen from the results, by the effect of the PM, the resonance absorption peak becomes more significant and broader by the effect of the resistance of the PM, which offers better sound absorption performance. Slight decrease in sound absorptivity is seen at very low frequencies, which can be attributed to rather exceeding acoustic resistance due to the additional resistance of the PM. However, this is not very important, because the PM on the whole improves the performance. In general, a TLMPP uses three leaves of MPP, which is very costly and disadvantageous, therefore the MPP-PM-MPP absorber can be said to be more efficient considering its performance and the cost. Thus, a permeable membrane can be useful, and less expensive substitution of the MPP in this type multiple-leaf MPP space sound absorbers.

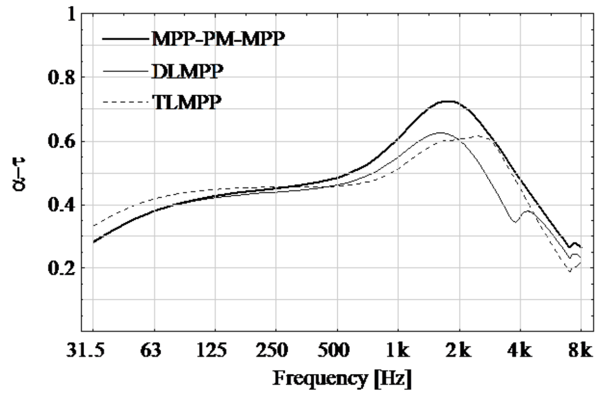

Figure 8. Calculated example of the sound absorptivity (a-t) of a MPP-PM-MPP space absorber in comparison with that of a DLMPP and a TLMPP. Parameters are: MPP : t=0.2mm , d=0.2mm , p=0.8% , ρ=7874 kg/m^3 , E= 205 ×10^9 Pa , η_{MPP}= 0.0001 , ν= 0.3, PM : R=816Pa s/m , M_{PM}=1.0kg/m^2 , D_1=D_2=25mm

5. CONCLUDING REMARKS

In this review, the main results of our studies on the sound absorbing structures including an MPP, a permeable membrane and a porous absorbent are overviewed. An MPP is, as widely known, quite useful and powerful. However, to make it more useful and versatile, it is advantageous to make it wideband and applicable to more various situations. For this purpose, with minimising the cost, it has been shown in this paper that using MPPs with other absorption components such as a permeable membrane or a porous absorbent can be somewhat useful. Thus, the authors believe that a more versatile sound absorption structure can be produced in such methods discussed above.

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