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<td>Author(s)</td>
<td>Sakagami, Kimihiro / Morimoto, Masayuki</td>
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Sound absorption structures including a microperforated panel, permeable membrane and porous absorbent: An overview

Kimihiro Sakagami 1, and Masayuki Morimoto 1

1Environmental Acoustics Laboratory, Graduate School of Engineering, Kobe University, Kobe, Japan

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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 paper, an overview of the authors’ studies on sound absorbing structures composed of an MPP, permeable membrane and/or porous absorbent is given. Even in the simplest single-leaf MPP absorber, a permeable membrane or porous absorbent in its back-cavity makes it more wideband than a conventional single MPP absorber. In this paper, various more complex sound absorbing system including MPPs, permeable membranes and porous absorbents are introduced and discussed.

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 typical use of an MPP is to place it with a rigid-back wall with an air-cavity in-between. Thus, a perforation and the 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 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 use two MPP leaves to make a double resonator [1-2]. 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 but also an additional absorption due to the acoustic resistance of the leaves at low frequencies offer wider absorption frequency range. 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 [16-17]. The simple method to make a typical single-leaf MPP absorber more wideband is to put a permeable membrane [18] or porous absorbent [19] in the cavity.

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 paper, the main results of the authors’ various project in attempt to obtain wideband and efficient sound absorbers with combination of an MPP and a permeable membrane and porous absorbers are summarised and reviewed as an overview to give the readers the basic idea about these complex MPP sound absorbing structures.

2. A single-leaf MPP absorber backed by a porous absorbent

The simplest 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, new-type porous absorbers which have overcome various shortcomings of a porous absorbent are available, and 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 specific acoustic impedance of the back cavity (filled with the air or a porous absorbent) is given by conventional formula [14-4]. 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].

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, 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 end-correction value [20]. According to the results in Ref [20], the difference caused in absorption coefficient by the difference of end-corrections (one is for the
air (Maa’s formulae) and the other for porous material derived by the traditional theory [21]) 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 are shown.

Figure 2 shows typical results of the absorption characteristics of a single-leaf MPP absorber backed by a porous absorbent, in comparison with that backed by an air-layer. Comparing these results, even though the peak value is slightly decreased, the width of the peak is significantly increased. Thus, it is found that the porous absorbent in the cavity of an MPP sound absorber can make it more wideband.

The effect of the porous material in the cavity can be changed with the parameters of porous absorbent. 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. The effect of the porous absorbent depends on the entire acoustic resistance, thus when the resistance of the MPP itself is already high enough the additional resistance by the porous layer can deteriorate the performance.
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) was first proposed by Maa [1]. This is to produce two Helmholtz resonators and eventually to cause two absorption peaks. Adjusting parameters of the sound absorption system the two peaks can be merged into 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 the two leaves can be substituted by another less expensive - but acoustically efficient - material, it should be more advantageous.

As for a substituting material for the double-leaf system, the authors proposed 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 [22-24]. It is acoustically almost transparent yet absorbs sound energy due to its acoustic flow resistance. Therefore, a similar role as a 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.

Two types 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.

As is observed in the figures, 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. This absorption system was originally inspired by a double-leaf permeable membrane space absorber [25]. 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.
Fig. 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.

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.

Fig. 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 is slightly lower in the combination absorber.

Thus, a permeable membrane can be useful substitution of the MPP in this type multiple-leaf MPP space sound absorbers.

5. Concluding remarks

In this paper, 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, 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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