ONE OF IDEAL ABSORBING MATERIALS IN ARCHITECTURAL ACOUSTICS: MICRO-PERFORATED PANEL ABSORBERS

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Abstract: Micro-Perforated panel absorbers (MPA) can be used to reduce or better the noise in architecture. This absorber was developed in 1960s, when a robust sound absorber was needed for severe environments, without porous materials. It has a simple structure and the absorption properties can be exactly calculated. The panel can be made of any materials from cardboard, plastic, plywood to sheet metal, for different purpose. The approximate theory of MPA was first given by Prof. MAA Dah-you in 1975, and then the exact theory was also proposed by him in 1997. MPA has been developed rapidly and used in many fields in recent years. Now the theoretical and experimental investigations on the performance of the MPA are still under progress. Theoretical and experimental investigations on MPA are reviewed in this paper. By reviewing recent research work, this paper reveals a relationship between the maximum absorption coefficient and the limit of the absorption frequency bandwidth. It has been demonstrated that the absorption frequency bandwidth can be extended up to 3 or 4 octaves as the diameters of the micro-holes decrease. This has become possible with the development of the technologies for manufacturing MPA, such as laser drilling, powder metallurgy, welded meshing and electro-etching to form micrometer order holes. In this paper, absorption characteristics of such absorbers in random fields are presented and discussed both theoretically and experimentally. This review shows that the MPA has potentials to be one of ideal absorbing materials in architectural acoustics in the 21st century.

1 Introduction

Perforated panels as sound absorbing materials have been in use for many years. However, before the late 1960s their applicability had been limited to be protective covering materials due to the requirement of using them with conventional porous materials. By the early 1970s, this limitation had been overcome with the development of micro-perforated panel absorbers (MPA). At that time robust sound absorbers were needed for severe environment where conventional porous materials could not be applied.

Being widely used in many fields, MPA have been developed rapidly in recent years. As early as 1975 Professor Maa Dah-You presented for the first time an approximate theory of MPA, followed by an exact theory proposed also by him in 1997. The relationship between the maximum absorption coefficient and the limit of the absorption frequency bandwidth has been discussed in the exact theory. Since then the absorption characteristics of such absorbers in random as well as high intensity sound fields have been investigated both theoretically and experimentally. Theoretical and experimental investigations on the performance of MPA are still in progress. Over these years, the design of such absorbers has been further developed, while important applications have been found as well.

It is the purpose of this paper to review advances in MPA in recent years, and to reveal the potentials of MPA for years to come. Some theoretical and experimental results are given and discussed. This review shows that MPA have the potentials to be one of ideal absorbing materials in architectural acoustics in the 21st century.

2 General Theory of microperforated-panel absorbers (MPA)

The microperforated-panel absorber and its equivalent circuit are show in Fig.1.

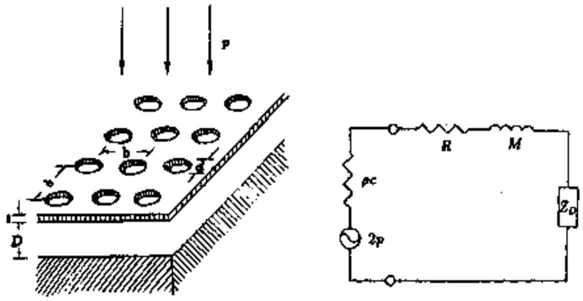


Fig.1: The microperforated-panel absorber and its equivalent circuit

The reference [1][2] shows that for different values of the acoustic resistance r, the frequency interval of absorption depends on the perforate constant k, where

$$k = d\sqrt{\frac{f}{10}} \quad (1)$$

The absorption frequency band is formulized as:

$$\Delta f / f_0 = \left(\frac{4}{\pi}\right) tg^{-1}(1+r) \quad (2)$$

$$f_2 / f_1 = \left(\frac{\pi}{ctg^{-1}(1+r)}\right) - 1 \quad (3)$$

According to the general theory of MPA, when the diameter of micro-holes are reduced to submillimeter size (less than 0.3mm), so as to provide, by themselves, enough acoustic resistance and low acoustic mass reactance necessary for wide-band sound absorber, up to 3 or 4 octaves. However, it doesn’t mean the smaller the diameter of holes are, the wider the absorption frequency is. When the diameters of holes keep on reducing to certain value, the absorption frequency bandwidth would not increase any more, and therefore, comes to utmost frequency bandwidth.

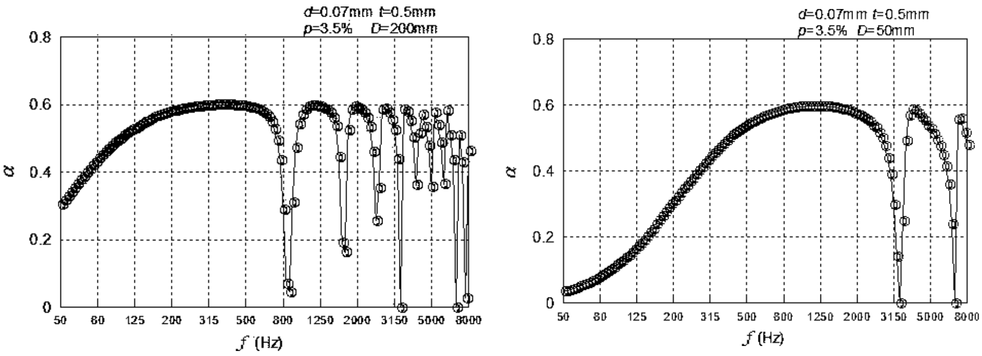
The maximum absorption coefficient and maximum possible absorption bandwidth are decided by the value of r. An extremely wide band with good absorption is found to be possible with the MPA, but its realization is limited by the value of the perforate constant.

Table 1: *Utmost absorption bandwidth possible of MPA.*

α_{max}	1	0.92	0.9	0.87	0.8	0.7	0.6	0.5
r	1	1.79	1.92	2.12	2.6	3.4	4.4	5.8
$\Delta f/f_0$	1.41	1.56	1.581	1.605	1.657	1.717	1.77	1.815
f_2/f_1	5.78	8.12	8.54	9.12	10.65	13.13	16.28	20.6

Based on Eq.(2) and Eq.(3), the maximum absorption coefficient and maximum possible absorption bandwidth are all decided by the value of r. An extremely wide band with good absorption is found to be possible with the MPA, but its realization is limited by the value of the perforate constant. The values are tabulated in Table 1, it is seen that the potentiality is tremendous.

Table 1 shows that if maximum absorption coefficient α_{max} is less than 0.92, the absorption frequency bandwidth will have a chance up to 3 octaves, f_2/f_1=8; if α_{max} is less than 0.6, the absorption frequency bandwidth might come to 4 octaves, f_2/f_1=16.
A program has been made, according to the general theory of MPA, to calculate the absorption frequency bandwidth. The theoretical absorption characteristics of two typical structures are shown in Fig.2.



(a) (b)

Fig.2: The theoretical limit of absorption frequency bandwidth of two structures of MPA

It can be seen that the absorption frequency bandwidth for Fig2.(a) is about 50-800 Hz, and 200-3200 Hz for Fig2.(b). Both are over 4 octaves, $f_2/f_1 > 16$.
As for a wide-band MPA, the minute holes in MPA are difficulty to process.

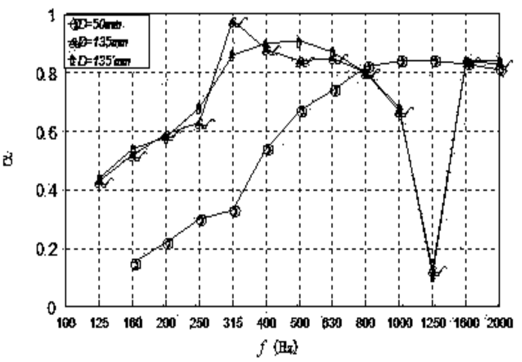


Fig.3: The absorption coefficient of wire mesh sinter MPA sample

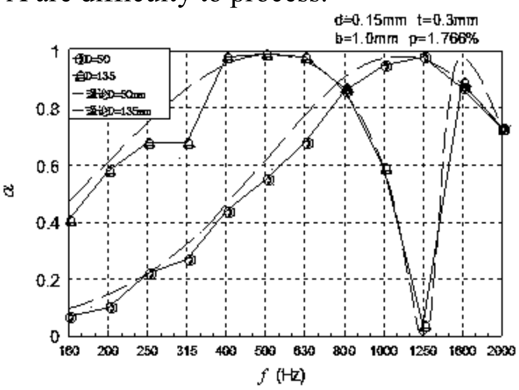


Fig.4: The absorption coefficient of electric etching MPA sample

Recently, some non-mechanical processing technologies for manufacturing MPA have been developed, such as powder metallurgy, welded meshing and electro-etching etc., to form minute holes. Measurements have been made to some test samples, Fig. 3 shows the measurement result of the MPA sample processed by wire mesh sinter, and Fig. 4 is for the sample made by electric etching. It can be seen that the both of samples' absorption frequency bandwidth are over about 4 octaves, only for the first absorption frequency bandwidth. It is said that some non-mechanical processing technologies mentioned above might be available for MPA applications to be used as wide band sound absorption materials.

3 Sound Absorption Characteristics of Micro-perforated Absorbers (MPA) for Random Incidence

It has been shown that the computed statistical absorption coefficients agree well with experiments, thus the behavior of the MPA in diffuse sound field can be calculated. This leads to global survey of the acoustical behavior of the MPA in diffuse sound field. This relation is very important, because the computation of statistical coefficient of MPA is much more involved than the computation for normal incidence, and may be replaced by the latter, when their exact relations exist. For the secondary absorption band, it is found when the value of k is reduced they become more and more significant and pretty soon they start to play an important role in absorption, as the perforate constant is reduced to a low value, and the absorption is extended far into high frequencies. Thus the MPA may be used as a general absorber or absorber for specific purposes.

The absorption coefficient of the MPA when sound is incident on it at an angle θ to its normal is given by

$$\alpha(\theta) = \frac{4r\cos\theta}{(1+r\cos\theta)^2 + (\omega m\cos\theta - ctg(\frac{\omega D\cos\theta}{c})^2)} \tag{4}$$

In a diffuse sound field, the statistical absorption is the average of all angles of incidence and equal to

$$\alpha_{stat} = \int_0^{90} \alpha(\theta)\sin 2\theta d\theta \tag{5}$$

Substituting Eq(13) into Eq(14) and writing x for cosθ and ξ for f/f_0, it gives

$$\alpha_{stat} = \int_0^1 \frac{8rx^2 \cdot dx}{(1+rx)^2 + (\omega mx - ctg(\frac{\omega Dx}{c}))^2} \tag{6}$$

The absorption coefficient of MPA at normal incidence

$$\alpha_n = \frac{4r}{(1+r)^2 + (a\xi - ctg(b\xi))^2} \tag{7}$$

Where the parameters a and b are the function of k and r, so it is also a function of the parameters k and r.

Thus the acoustical behavior of MPA, either for normal incidence or in diffuse sound field depends on the values of perforate constant k and the resistance ratio r. Among the two parameters k is the most important one, because the value of r is rather limited, considering its effect on the magnitude of maximum absorption. An investigation of the acoustical behavior involves only the computation and measurements of MPA over parameter values of k and r.

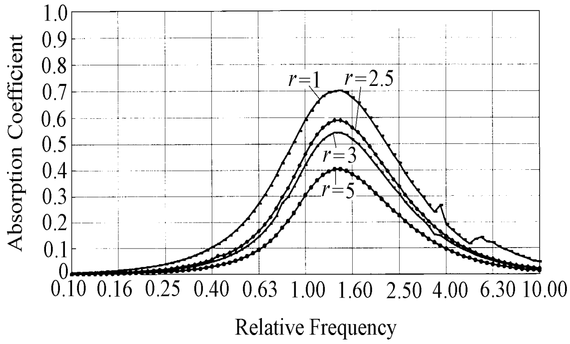


Fig.5: Absorption curve in diffuse field for k=2.5

When k is 2, 2.5, to 3, the absorption curves for different values of r in random field are quite alike. Fig.5 shows the absorption curves for different values of r in random field for k=2.5. The secondary absorption band for k=2.5 become a ripple on the absorption curve and negligible in absorbing sound. The secondary band essentially disappears.

It is evident that better absorption requires smaller values of the perforate constant k. First try the extreme, k=0.5, lower than which the behavior of MPA does not change significantly.

The situation is entirely different from that for large k. Normal incidence absorption curves are shown in Fig. 6 for different values of r. The main absorption bands are exactly what were predicted in a previous work. The band interval increases rapidly with the value of r. The rise of secondary absorption bands is tremendous, having comparable band widths and essentially the same maxima as the main bands.

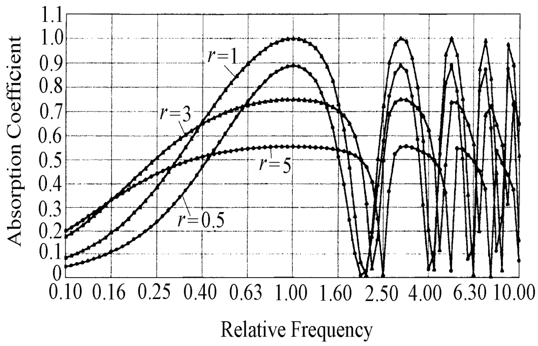


Fig.6: Absorption curves for k=0.5 at normal incidence

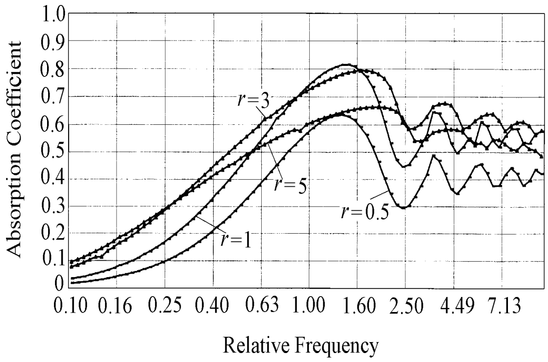


Fig.7: Absorption curves for k=0.5 in diffuse field

All these improvements of the frequency characteristics for normal incidence are reflected to the acoustical behavior of the MPA in diffuse sound field (Fig. 7). The secondary absorption bands have merged with the corresponding main absorption band to make it greatly extended.

The perforate constant k and relative acoustic resistance r have been taken for computation to make a survey of acoustical behavior of MPA for random incidence, and it has been established that under specific conditions of k and r, the absorption of the MPA may be extended to higher frequencies tremendously by emphasizing the contributions of the secondary absorption bands. This makes the MPA entirely different from what one can imagine heretofore. The relation of the behavior of MPA in random field to that at normal incident, as described by maximum absorption α_m and frequency shift ξ_m , as well as the absorption of the secondary absorption bands make it a straight forward process to design the MPA from the desired characteristics. To realize the absorber, its structure constants, say d, f_0, b, t, D are easily determined through the Eqs with known values of k and r. Among these, t and d or f_0 may be arbitrarily chosen to suit the purpose, within some reasonable limits. The board material may also be freely chosen from metal, wood, plastics, paper board or films.

4 Conclusions

This paper has briefly discussed the general theory of micro-perforated-panel absorbers as well as the relationship between the maximum sound absorption coefficient and the absorption frequency bandwidth. The sound absorption characteristics of these absorbers in random acoustic fields have been also discussed. There are potentials in the application of micro-perforated-panel absorbers, so further research is needed to make these absorbers one of ideal absorbing materials in architectural acoustics of this century.

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