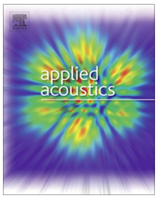
Applied Acoustics 124 (2017) 48–51

Contents lists available at ScienceDirect

Applied Acoustics

journal homepage: www.elsevier.com/locate/apacoust



Pilot study on wideband sound absorber obtained by adopting a serial-parallel coupling manner

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ARTICLE INFO

Article history:
Received 1 March 2017
Received in revised form 17 March 2017
Accepted 22 March 2017

Keywords:
Micro-perforated panel (MPP) absorber
Serial and parallel coupling
Absorption bandwidth

ABSTRACT

Micro-perforated panel (MPP) absorber has been widely used in noise control and is regarded as a promising alternative to the traditional porous materials. However, the absorption bandwidth of single MPP absorbers is always insufficient to compete with the porous materials. In this paper, aiming at obtaining high absorption over broad frequency band, a compound MPP absorber array adopting the series-parallel coupling manner is proposed and investigated. Firstly, a theoretical model for the normal absorption coefficient of the series-parallel coupled MPP absorber is established based on the electrical circuit analysis. And then measurements of the normal incidence absorption coefficients are carried out to verify the theoretical predictions. The experimental data are in agreement with the theoretical calculation and prove that the composite structure has the characteristics of broadening the absorption bandwidth through a combination of serial and parallel coupling, which may provide a new technique to improve the absorption performance of such type of MPP absorbers.

1. Introduction

Micro-perforated panel (MPP) absorber is very promising as a basis for the next generation of sound absorbing constructions [1–4]. MPPs are usually used with an air-back cavity and a rigid back wall, so that Helmholtz-type resonators are formed owing to the perforation of the MPP and the air-back cavity. MPP absorber can keep a good sound absorption without using any porous materials. Due to this, MPP absorber is clean, health friendly and reliable in hostile temperature and pressure environments. And since Maa's pioneering works [1], as an innovative fiber-free solution to noise pollution control, MPP absorber has been used for many different applications [5–8]. However, although MPP absorber offers an outstanding alternative to the traditional porous materials, it has one obvious disadvantage that is it is effective only in a narrow band around its resonance frequency because of its nature as a resonator, which makes its sound absorption capacity usually insufficient for a general purpose absorber, and thus greatly prevents it from wider application. In efforts to widen the absorption frequency range, many research studies have been performed. So far, plenty of research has shown that introducing extra absorption peaks may be the most effective and promising way to broaden the absorption bandwidth of MPP absorber. There are mainly three methods to introduce additional absorption peaks. One is to utilize a series combination of cavities and MPPs, in which case the panels are arranged in tandem and serial coupling mechanism between multi-layer MPPs and cavities can be formed to introduce extra absorption peaks. A two-layer MPP absorbers, for example, was first proposed by Maa [1,3] and several studies have followed [9,10], which is intended to produce a double resonator with two resonance frequencies or more and has been proven successful in improving the absorption property of MPP absorbers. Another one is through a parallel combination of different MPP absorbers, named as a compound absorber array [11–14], in which case, the absorber array consists of two or more parallel-arranged MPP absorbers with different frequency characteristics. In practical application, these absorber arrays are periodically arranged alternately and parallel to each other. And as long as the period is shorter than the wavelength of sound, additional resonance peaks can be introduced because of the parallel coupling formed between different MPP absorbers arranged in parallel. A multi-size MPP absorber [11], a combination of two different micro-perforated panel (MPP) absorbers [12,13] and parallel arrangement of multiple micro-perforated panel absorbers with different cavity depths [14] are all such type of parallel coupled MPP absorbers, which have attracted much attention due to their great potential for achieving a broader absorption frequency range and saving space.

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http://dx.doi.org/10.1016/j.apacoust.2017.03.021
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Aiming at introducing added absorption peaks and then widening the absorption bandwidth, the last one way is by positively utilizing the vibration effect of a flexible MPP itself and some valuable techniques have been provided by Lee et al. [15–17]. They come to the conclusion that the absorption peak due to the panel vibration effect can be used to widen the absorption bandwidth of an MPP absorber by appropriately selecting its parameters. Although the third approach is possible, however, to effectively control and utilize such panel resonance, the parameters not only involve the structural parameters but also the mechanical parameters, which makes it too complicated and difficult to implement in practice when compared with the former two methods.

In fact, nearly all previous theoretical and experimental studies have claimed that whether the MPP absorbers are series coupled or parallel coupled, they both have great potential in broadening the absorption bandwidth. However, most studies have been focused only on their respective role in improving the absorption performance of MPP absorbers, and few efforts have been devoted to obtain broader frequency band through a combination of serial and parallel coupling. To fill this research gap, a compound MPP absorber obtained by adopting a serial-parallel coupling manner is proposed and investigated.

In this paper, it is proposed to make use of both serial and parallel coupling effect to widen the absorption bandwidth of conventional MPP absorbers. Based on this, a series-parallel coupled MPP absorber is studied with theory and experiment to investigate bandwidth increasing effect. Following this introduction, the normal sound absorption coefficient of this composite structure is calculated in Section 2. Experimental verification is showed in Section 3. Finally the conclusion is displayed in Section 4.

2. Absorption coefficient calculation

2.1. Traditional MPP absorber

Before diving into the composite sound-absorbing construction proposed in this study, a brief introduction of a traditional MPP absorber is given. It will help understand a series-parallel coupled MPP absorber better. The basic structure of a traditional MPP absorber consists of a micro-perforated panel, a rigid backing wall and the air cavity between them, as illustrated in Fig. 1a, where d is the perforation diameter, t is the panel thickness, b is the distance between centers of adjacent perforations and D is the depth of the air gap. The basic theory of an MPP absorber was first put forward by Maa [1] which is based on electro-acoustical equivalent circuit under a simplified condition, as modeled in Fig. 1b, where R and M are respectively the specific acoustic resistance and air mass inside the micro pores and Z_D is the specific acoustic impedance of the air cavity. The sound wave impinging on the structure is equivalent to a source of sound pressure 2p as produced on the rigid wall with the time factor $\exp(-j\omega t)$ suppressed throughout (analogous to the open-circuit voltage) and internal resistance ρc as that of air [1], with ρ the air density and c the sound speed. Following Maa's formula [1], the acoustic impedance of MPP is calculated as

$$Z_{MPP} = \rho c(r + j\omega m) \tag{1}$$

with

$$r = \frac{0.147t}{\sigma d^2}k_r, k_r = \sqrt{1+\frac{k^2}{32}} + \frac{\sqrt{2}k}{8}\frac{d}{t} \tag{2}$$

$$m = \frac{0.294\times 10^{-3}t}{\sigma}k_m, k_m = 1 + 1\Bigg/\sqrt{3^2+\frac{k^2}{2}} + 0.85\frac{d}{t} \tag{3}$$

where r and m are respectively the relative (to the characteristic impedance ρc in air) acoustic resistance and air mass of MPP, $\omega = 2\pi f$ is the angular frequency with f the frequency of incident acoustic wave, σ is the perforation ratio of the panel (the ratio of surface area of the perforations to the total surface area of the panel), $\sigma = 0.785(d^2/b^2)$, k is the MPP's constant, $k = d\sqrt{f/10}$. The acoustic impedance of the air cavity behind the MPP with a depth of D is

$$Z_D = -j\rho c\cot(\omega D/c) \tag{4}$$

The overall acoustic impedance of an MPP absorber is given by

$$Z = Z_{MPP} + Z_D \tag{5}$$

The normal sound absorption coefficient is calculated using the following well-known equation

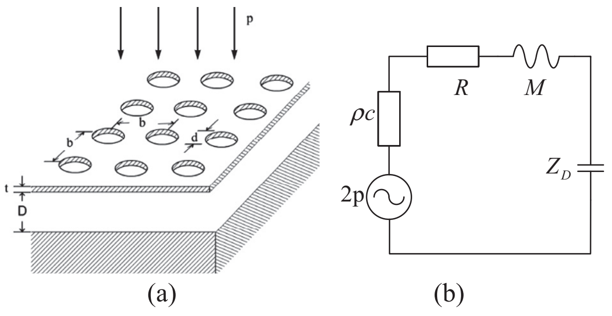
$$\alpha = 1 - \left|\frac{Z-\rho c}{Z+\rho c}\right|^2 \tag{6}$$

2.2. Composite sound-absorbing construction

In this paper, in order to combine the advantages of series coupling and parallel coupling, one basic module of the proposed structure consists of an MPP, a cavity and a parallel arrangement of two MPP absorbers with different cavity depths, as shown in Fig. 2. And in practical use, the whole absorber array is created by arranging the basic series-parallel coupled modules in a periodically repeating pattern. In this study, the panel is assumed to be rigid enough to neglect the panel vibration effect under acoustic loading. Based on the acoustic electric analogy method, the equivalent circuit of the series-parallel coupled MPP absorbers is derived and shown in Fig. 3. As can be seen from Fig. 3 that the part B in Fig. 2. that consists of parallel coupled MPP2 absorbers with different cavity depths is series coupled with MPP1 through the cavity 1. According to this, the total acoustic impedance of the whole structure can be expressed mathematically as

$$Z_{total} = Z_{MPP1} + Z_{D1}//Z_2 \tag{7}$$

where the symbol // represents parallel operation, Z_{MPP1} is the acoustic impedance of MPP1, Z_{D1} is acoustic impedance of the air



(a) (b)

Fig. 1. Schematic diagram of uniform-size MPP absorber and its equivalent circuit.

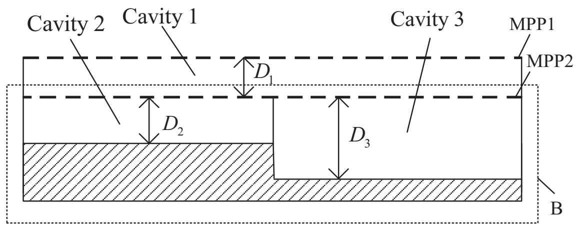


Fig. 2. Schematic diagrams of composite sound absorber structure.