



Oblique incidence sound absorption of parallel arrangement of multiple micro-perforated panel absorbers in a periodic pattern



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ARTICLE INFO

Article history:

Received 10 February 2014

Received in revised form

7 August 2014

Accepted 8 August 2014

Handling Editor: R.E. Musafir

ABSTRACT

The sound absorption performance of a micro-perforated panel (MPP) absorber array at oblique incidence and in diffuse field is investigated both numerically and experimentally. The basic module of the MPP absorber array consists of four parallel-arranged MPP absorbers with different cavity depths, and the whole MPP absorber array is created by arranging the basic modules in a periodically repeating pattern. Results show that the influence of incidence angle mainly lies in two aspects. First, the parallel absorption mechanism breaks down at lower frequencies at oblique incidence than at normal incidence due to the non-compactness of the resonating MPP absorber, which becomes non-compact if the time delay of incident wave across it is comparable to or larger than $\pi/2$. Second, the equivalent acoustic impedance of the MPP varies with respect to incidence angle which in turn changes the sound absorption performance of the MPP absorber array. Influence of the azimuthal angle is insignificant. Because of mutual influence among the member MPP absorbers, the normal incidence sound absorption of the MPP absorber array can be noticeably different from that of the basic module tested in impedance tube. The measured sound absorption coefficients of a prototype specimen in reverberation room compare well with the numerical predictions. The extra sound absorption due to diffraction of sound at the free edges of test specimen is the most efficient around 500 Hz.

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1. Introduction

Micro-perforated panels (MPP) have been successfully used in many noise control applications such as noise abatement in buildings [1,2], medical devices [3], launcher fairings [4] and duct mufflers [5,6]. A typical MPP absorber consists of an MPP and a rigid backing cavity. Though the MPP absorber constructed in this way performs much better than other resonant absorbers, its sound absorption capability is usually not quite enough as a general purpose absorber. Both its bandwidth and sound absorption coefficients are insufficient to compete with the fibrous materials. Recently, many efforts have been made to further enhance the sound absorption performance of MPP absorbers. Among them, one practical approach is to add additional MPPs into the backing cavity to form double-layer [7] or multiple-layer MPP absorbers [8,9]. Investigations have

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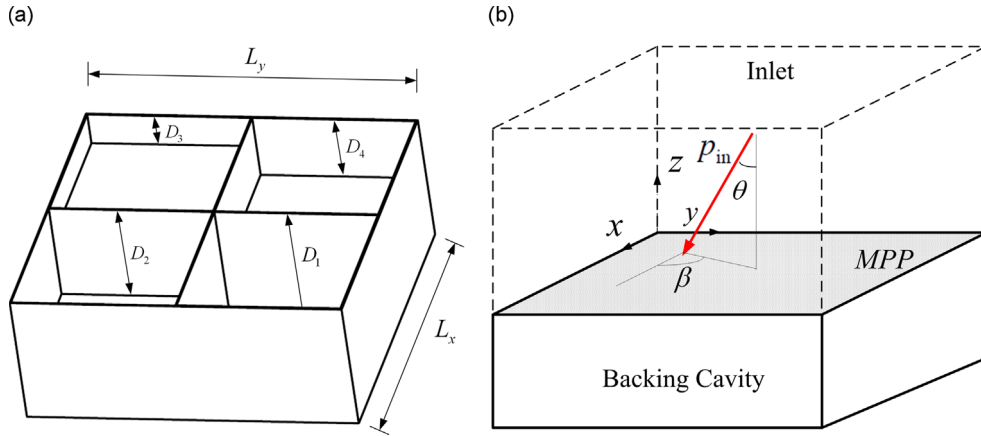


Fig. 1. Configuration of the MPP absorber array. (a) Schematic of the partitioning of the backing cavity in one basic module; (b) Theoretical model of the MPP absorber array. The dashed lines represent the additional virtual duct for modeling the exterior sound field of the MPP absorber array.

also been reported to utilize the structural resonances of the MPP itself to improve its absorption performance of the MPP absorber, especially at low frequencies [10,11].

As far as broadband absorption is concerned, one alternative and possibly more straightforward approach is to arrange multiple MPP absorbers of different frequency characteristics in parallel so as to combine different frequency bands together, hence an MPP absorber array. Previous studies on parallel arrangement of two different MPP absorbers [12–14] have shown great potential of the parallel arrangement to enhance its sound absorption performance. In a recent study by the present authors [15], the parallel absorption mechanism is identified to be contributed by three factors: (i) the strong local resonance absorption, (ii) the supplementary absorption by the non-resonating absorbers and (iii) the change of environmental impedance conditions; and the local resonance absorption mechanism accounts for the increased equivalent acoustic resistance of the MPP in the absorber array. The aforementioned research efforts are focused on the sound absorption of MPP absorber array at normal incidence of plane sound waves. In practical applications, however, the MPP is mainly subject to oblique sound waves, and its acoustic performance at oblique incidence may be quite different from that at normal incidence. The purpose of this work is to study how the parallel-arranged MPP absorber array performs at oblique incidence and in diffuse field.

In this paper, the oblique incidence sound absorption performance of the parallel-arranged MPP absorber array is investigated both numerically and experimentally. One major concern here is how the incidence angle of sound waves affects the parallel absorption mechanism. A finite element model is used to simulate the acoustic performance of an infinitely large MPP absorber array. One basic module of the MPP absorber array consists of a four-cavity configuration as shown in Fig. 1, and the whole MPP absorber array is created by arranging the basic four-cavity modules in a periodically repeating pattern. Results show that its sound absorption coefficients may change noticeably as the incidence angle varies. The diffuse field sound absorption coefficients of a prototype specimen are measured in a reverberation room and compared with the numerical predictions. The extra sound absorption in the experimental study is discussed by considering the diffraction effect due to the finite geometry of the test specimen.

2. Theoretical modeling

A three-dimensional (3D) configuration of the MPP absorber array is considered. Fig. 1(a) shows one basic module of the MPP absorber array. The backing cavity is partitioned into four sub-cavities with different depth D_1 , D_2 , D_3 and D_4 . The cavity walls and partitions are regarded as acoustically rigid. The MPP covering the air cavity can be either rigid or flexible, depending on the material and thickness of the panel. For some light-weight MPP, the effect of structural vibration can be significant at resonance frequencies [10,16], but the effect of panel vibration is excluded in the present study for simplification. Assume that a plane sound wave p_{in} is incident on the MPP with incidence angle θ and the azimuthal angle β . Part of the incident sound energy is reflected or scattered, while the rest is absorbed by the MPP absorber.

A finite element procedure is used to simulate the acoustic performance of the MPP absorber array at oblique incidence in the frequency domain. The computational domain consists of the backing cavity (including the four sub-cavities), the MPP and a virtual duct with finite length as shown in Fig. 1(b). The finite element implementation of the 3D configuration is similar to that of a two-dimensional (2D) configuration described in [15], except that particular measures must be taken to deal with the boundary conditions of the virtual duct so that the scattered field can be simulated correctly. The sound field in the backing cavity and the virtual duct satisfies the Helmholtz equation

$$(\nabla^2 + k_0^2)\phi = 0 \quad (1)$$

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