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Sound absorption of microperforated panel mounted with helmholtz resonators

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ABSTRACT

Microperforated panel (MPP) absorbers have been widely used in noise reduction and are regarded as a promising alternative to the traditional porous materials. However, the absorption bandwidth of a single-layer MPP is insufficient to compete with the porous materials. In order to improve the sound absorption ability of the single-layer MPP, MPP mounted with Helmholtz resonators (MPPHR) is introduced. Based on the MPP, Helmholtz resonators theory and electro-acoustical equivalent circuit principle, sound absorption properties of MPPHR are studied. Simulation and experimental results show that MPPHR have two peak frequencies and one anti-resonant frequency. The low-frequency peak is dependent on the Helmholtz resonators, while the high frequency peak is close to the peak of the single-layer MPP. The low-frequency sound absorption peaks move to low frequency with the neck length and the volume of Helmholtz resonators increasing. The high-frequency sound absorption peaks move to high frequency with the volume of Helmholtz resonators cavity increasing. Multiple Helmholtz resonator parallel MPP structure can provide more sound absorption than single MPPHR at low frequency range due to the introduction of more additional sound absorption peaks.

1. Introduction

In recent years, noise control has received much attention for improving living environments. A microperforated panel (MPP) absorber has become widely known as the most attractive alternative for the next generation sound absorbing material [1]. The MPP is first proposed by Maa, who has established its theoretical basis and design principle [2–4]. The MPP absorber is a thin panel or membrane less than 1 mm thick with perforation of less than 1% perforation ratio with air-back cavity and a rigid backing [5]. The fundamental absorbing mechanism of the MPP absorber, which is typically backed by an air cavity and a rigid wall, is Helmholtz-resonance absorption [6]. This type of absorption is mainly due to frictional loss in the air flow of the apertures [6]. With the rapid development of processing technologies and computational methods, micro-perforated panel sound absorption theory has also been further development [7–9]. But usually the single-leaf MPP sound absorbing structure is generally only one resonance absorption peak and the sound absorption bandwidth is usually limited to about two octaves [2–4]. In order to heighten the absorption property of MPP, Maa has proposed a double-leaf MPP backed by a rigid-back wall with an air-cavity [10]. Recently, Asdrubali and Pispola have studied this type of absorber for its application to noise barriers [11]. This absorber is intended to produce two resonators so that a broader absorption frequency range can be obtained. The acoustical properties of a structure composed of two parallel MPP with an air-cavity between them and no rigid backing is studied numerically by Sakagami [12]. Qian et al. have investigated the acoustical properties of MPP with ultra-micro perforations based on MEMS technology [13]. Results show that better absorption capability can be given with MPP by using an ultra-micro perforation [13]. Liu and Herrin have study the sound attenuation performance of MPP with adjoining air cavity [14]. The resulting sound pressure fields indicated that partitioning the adjoining air cavity increase the overall sound attenuation due to the MPP by approximately 4 dB [14]. Wang and Huang have investigated the acoustic properties of parallel arrangement of multiple MPP absorbers with different cavity depths [15].

Compared with single MPP absorber, the absorber array requires lower acoustic resistance for good absorption, and the resonance frequencies shift due to inter-resonator interactions [15]. Tao et al. have studied the sound absorption of a finite micro-perforated panel backed by a shunted loudspeaker [16]. The results show that the composite absorber is more effective than the traditional MPP absorbers especially at the low frequency when there is a length constraint thanks to the resonance absorption provided by the shunted loudspeaker [16]. We have studied the sound

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absorption of a composite MPP sound absorber with membrane cells [17]. Experimental results show that the MPP with membrane cell can provide more absorption than the single-leaf MPP absorber. However, MPPs and their improvements have an inherent disadvantage in suppressing the low frequency noise where the internal acoustic loading of payload fairings is usually very high. The conventional method is to use an array of Helmholtz resonators to reduce this low frequency noise [18–20]. MPP absorbers backed by Helmholtz resonators are introduced to improve sound absorption in the low frequency region by Park [21]. A shallow cavity example demonstrates that the proposed sound absorber can be used to mitigate broad-band interior noise when the application area for the noise control treatment is highly limited [21].

In this paper, we investigate the acoustic properties of the proposed sound absorber, named as MPP mounted with Helmholtz resonators (MPPHR). Structure of this paper will be arranged as follows: In Section 2, electro-acoustical equivalent circuit modal of MPPHR will be introduced. In Section 3, the sound absorption performance of MPPHR will be studied. In Section 4, Multiple Helmholtz resonator parallel MPP structure will be introduced. Finally, the conclusions will be given in Section 5.

2. Theoretical considerations

The acoustic impedance of such a system can be obtained using the impedance type of electro-acoustic analogy. Fig. 1 shows a schematic diagram of one Helmholtz resonators is mounted in a unite area MPP. Fig. 2 shows the equivalent circuit of MPP mounted with Helmholtz resonators mounted at distance D from a rigid wall, where R and M are the specific acoustic resistance and reactance of MPP, Z_D is the normal specific acoustic impedance of the air behind the MPP, Ra, Ma, Ca respectively represent acoustic resistance, mass and compliance of Helmholtz resonators. The sound wave impinging on the structure is equivalent to a source of sound pressure 2p as produced on the rigid wall and internal resistance ρc as that of air.

According to the equivalent circuit, the series impedance of MPPHR is given by

$$Z = \frac{Z_{MMP} Z_{HR}}{Z_{MMP} + Z_{HR}}, \tag{1}$$

$$Z_{MMP} = R + j\omega M - j\cot\left(\frac{\omega D}{c}\right), \tag{2}$$

$$R = \frac{32\eta t}{\sigma \rho c d^2} k_r, \tag{3}$$

$$k_r = \sqrt{1 + \frac{K^2}{32} + \frac{\sqrt{2}K}{8}\frac{d}{t}} \tag{4}$$

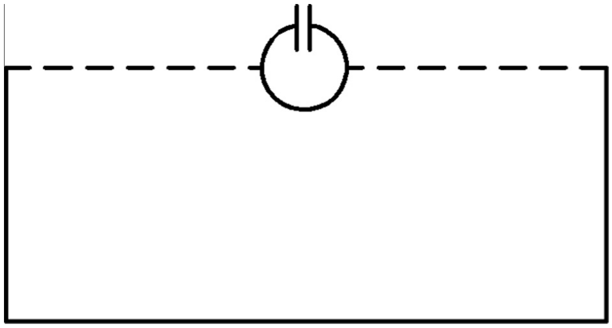

Fig. 1. A schematic diagram of MPP mounted with Helmholtz resonators.

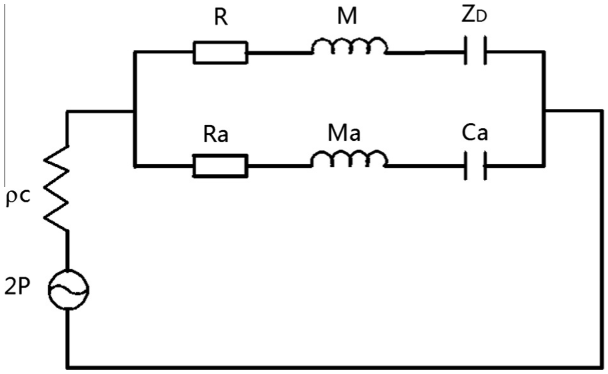

Fig. 2. The equivalent circuit of MPP mounted with Helmholtz resonators.

$$M = \frac{t}{\sigma c} k_m, \tag{5}$$

$$k_m = 1 + \left[9 + \frac{K^2}{2}\right]^{\left(-\frac{1}{2}\right)} + 0.85\,\frac{d}{t} \tag{6}$$

where ρ is air density, c is the sound speed in air, t is the thickness of MPP, ω is angular frequency of the sound, d is the perforation diameter, η is the coefficient of viscosity of the air, σ is the perforation ratio of the MPP, D is the cavity depth and $K = d\sqrt{\frac{f}{10}}$ is the perforate constant, f is frequency.

$$Z_{HR} = R_a + j\omega M_a - \frac{j}{\omega C_a}, \tag{7}$$

$$R_a = \rho c\left\{16kx^2\left[1 + \frac{1}{8x(1+4x^2)}\right]\frac{l}{S} + \frac{k^2}{2\pi}\right\}, \tag{8}$$

$$M_a = \rho\left\{\left[\frac{4}{3} - \frac{10}{3(10+x)}\right]\frac{l}{S}\right\}, \tag{9}$$

$$C_a = \frac{V}{\rho c^2}, \tag{10}$$

$$S = \frac{\pi d_h^2}{4}, \tag{11}$$

$$x = \sqrt{\frac{2\eta}{\rho \omega d_h^2}}, \tag{12}$$

l is the neck length of Helmholtz resonators, d_h is diameter of neck, S is the cross sectional area of neck, V is the volume of Helmholtz resonators cavity, R_a is acoustic resistance of Helmholtz resonators, M_a is acoustical mass of Helmholtz resonators, C_a is acoustic compliance of Helmholtz resonators, $k = \omega/c$ is the wave number [22].

The absorption coefficient can then be calculated by well-known formulary:

$$\alpha = \frac{4R_e(Z)}{[1 + R_e(Z)]^2 + [I_m(Z)]} \tag{13}$$

3. Numerical example and discussion

Fig. 3 shows a typical example of the predicted sound absorptivity of MPPHR. The thickness of the perforated plate $t = 0.5$ mm, perforation diameter $d = 0.3$ mm, perforation rate $p = 1\%$, the cavity depth $D = 60$ mm. The neck length of Helmholtz resonators