THE MICRO-SLOTTED RESONATOR WITH FLEXIBLE TUBE BUNDLES

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ABSTRACT
A new type resonant absorber, i.e. a micro-slotted resonator with flexible tube bundles, is presented in this paper. The sound absorbing structure consists of a micro-slotted facing plate and a back sheet as well as the flexible rubber tube bundles. Each flexible rubber tube connects to a hole of the facing sheet via a small connecting tube. The flexible tube length may be much greater than the cavity depth, and can be deliberately made different from one another to absorb sound at different frequencies of interest. Due to the incorporation of the tube bundles into the micro-slotted resonant absorber, not only the absorption coefficients can be increased considerably, but also the frequency bandwidth of absorption can be broadened accordingly. In addition, because of the tube-cavity coupling resonances, through properly design, two or more obviously resonant absorption peaks may occur in the frequency spectrum of sound absorption. The sound absorption properties of the resonant absorber with tube bundle are measured in an impedance tube. The effects of the structural parameters of the micro-slotted resonator with flexible tube bundles on sound absorption are measured and analyzed. Furthermore, the sound absorption principles of the absorber are also introduced in this paper.

INTRODUCTION
There are many sound absorbing materials and constructions which are used in all kinds of noise reduction engineering. According to their different principles of sound absorption, they can be roughly classified as the following categories, 1) porous sound-absorbing materials, 2) resonant absorbers including the perforated and micro-perforated panel absorbers, microslotted absorbers, as well as 3) plate and elastic foil absorbers\(^{[1],[3]}\). Although the perforated or micro-perforated panel resonant absorbers have displayed much more advantages in acoustical, aerodynamic and other features over the porous acoustic materials, but they still can’t meet the requirements of noise reduction.

For the common resonant sound absorber, there is an obviously technical ‘bottle neck’ phenomenon. If we want to strengthen its sound absorption performance at a lower frequency, we have to increase its structural cavity depth or sound absorbing material’s thickness. Unfortunately, for many practical applications with strict limitations for space, this method is completely not feasible, because there is no enough space to install such thick structures or materials. Therefore, many acousticians all over the world have been searching for some new type broadband sound absorbers, in particular, which are suitable for suppressing the low-frequency noise. In order to overcome such an acoustical obstacle in designing sound absorbing structure or material, a new type resonant sound absorber, i.e. a perforated panel resonator with flexible tube bundles was presented in reference \([4]\). Based upon this resonator, by replacing the circular perforated facing panel with a micro-slotted panel, this paper is chiefly dedicated to introduce the micro-slotted resonator with flexible tube bundles, and its structure, sound absorption mechanism, properties and measurement results.

STRUCTURE AND MECHANISM OF SOUND ABSORPTION
Based upon conventional micro-slotted absorber\(^{[2]}\) and perforated panel resonator with flexible tube bundles\(^{[4]}\), some flexible tube bundles are incorporated into the cavity of a micro-slotted
perforated panel resonator through firmly connecting one end of each flexible tube to each opening hole of the micro-slotted facing plate, the other end of each flexible tube is freely placed in the cavity of the resonator, there is no need to fix it, so that a micro-slotted resonator with flexible tube bundles is made. The structure of the perforated panel resonator with flexible tube bundles is shown in Figure 1.

![Figure 1.- Schematic illustration and photograph of the micro-slotted resonator with flexible tube bundles](image)

Actually, the resonant sound absorber is a parallel combination of many Helmholtz resonators consisting of the mass of an air volume in openings in a facing plate and the compliance of the air volume in a cavity between the facing plate and the back sheet. The specific acoustical impedance of resonator is the sum of the impedance of the enclosed air volume and that of the air volume oscillating in and around the mouth of resonator[1]. The resonance frequency of a Helmholtz resonator is inversely proportional to the square root of the effective neck length, usually which equals the facing plate thickness plus the internal and external end corrections. If the neck length is artificially prolonged greatly through connecting each flexible tube to each hole of the perforated facing plate, so that acoustic mass of air column oscillating in tube bundles is increased much greatly, correspondingly its resonance frequency is shifted to a lower frequency. Meanwhile, the incorporation of some flexible tube bundles will also result in a considerable increase of acoustic resistance of the resonant absorber. The tube length may be much greater than the cavity depth of the resonator, and can be made different from one another to tune resonance frequency and design sound absorption spectrum of interest to some extent. In addition, because of the tube-cavity coupling resonances, through properly designing tube structure and length, two or more obviously resonant absorption peaks may occur in the frequency spectrum of sound absorption.

**MEASUREMENTS OF SOUND ABSORPTION**

Sound absorption measurements of the micro-slotted resonators with flexible tube bundles are made in an impedance tube.

The structural parameters of the micro-slotted resonator with/without flexible tube bundles are listed as follows. Flexible tube inner diameter is 1.6mm and circular hole is also 1.6mm, micro-slotted facing plate thickness is 1mm, open area ratio is 5%, micro-slot's length is 1.8mm, micro-slot's width is 0.05mm, spacing between two adjacent micro-slots in the same column is 5mm, spacing between two adjacent micro-slots in the same row is 2mm. The comparisons of sound absorption properties for micro-slotted resonators with flexible tube bundles in two different depth's cavities (cavity depth is 100mm, 200mm respectively) are shown in Figure 2 and Figure 3. In Figure 2, resonator's cavity depth is 100mm. In Figure 3, resonator's cavity depth is 200mm.

From Figure 2, by comparing with sound absorption of the micro-slotted resonator without flexible tube bundles, it can be shown that the incorporation of the flexible tube bundles with different lengths into the micro-slotted resonant absorber has not a considerable effect on the overall sound absorption performance. Meanwhile, the effect of resonant frequency shifting to a lower frequency due to the incorporation of the flexible tube bundles into the micro-slotted resonator is not obvious. But in Figure 2, the incorporation of rigid connecting tubes of 10mm length can increase micro-slotted resonator's sound absorption in the frequency range of...
315Hz-800Hz. And due to the incorporation of the flexible tube bundles, the resonant frequency of micro-slotted resonator is shifted from 630Hz to 400Hz.

In two cases of flexible tube bundles with different numbers of open ends and closed ends, the sound absorption property comparisons of the micro-slotted resonators with flexible tube bundles are also shown in Figure 2. The flexible tube bundles with different numbers of open ends and closed ends have a greater influence on sound absorption in middle frequency range of 315-800Hz and above 1250Hz.

Figure 2.- Sound absorption property comparisons of the micro-slotted resonators with flexible tube bundles and the micro-slotted resonator without tube bundle (resonator cavity depth is 100mm)

Figure 3.- Sound absorption property comparisons of the micro-slotted resonators with flexible tube bundles and the micro-slotted resonator without tube bundle (resonator cavity depth is 200mm)
Figure 4.- Sound absorption property comparisons of the micro-slotted resonators with flexible tube bundles in different depth’s cavities (resonator cavity depth is 100mm, 200mm respectively)

From Figure 3, by comparing with sound absorption of the micro-slotted resonator without flexible tube bundles, it can be shown that the incorporation of the flexible tube bundles with different lengths into the micro-slotted resonant absorber has a considerable effect on the overall sound absorption performance. In the case of 920mm tube length, all sound absorption coefficients in the frequency range of 160-2000Hz are greater than 0.52, and sound absorption valley which occurs in micro-slotted resonator at 800Hz is avoided. Meanwhile, the effect of resonant frequency shifting to a lower frequency due to the incorporation of the flexible tube bundles into the micro-slotted resonator is obvious. In the frequency range of below 250 Hz, the sound absorption performance of micro-slotted resonator with flexible tube bundles is superior to that of the micro-slotted resonator without flexible tube bundles. While flexible tube length is greater than 450mm, such as the cases of 650mm, 850mm, 920mm tube length, sound absorption spectrum is changed greatly. Due to the incorporation of the tube bundles into the micro-slotted resonant absorber, not only the absorption coefficients can be increased considerably, but also the frequency bandwidth of absorption are broadened accordingly. In addition, because of the tube-cavity coupling resonances, through properly designing the flexible tube length, two or three obviously resonant absorption peaks occur in the frequency spectrum of sound absorption, for instance the cases of 650mm, 850mm, 920mm tube length.

Figure 4 shows sound absorption property comparisons of the micro-slotted resonators with flexible tube bundles contained in different depth’s cavities, e.g. cavities of 100mm depth and 200mm depth. From Figure 3 and Figure 4, it can be made a conclusion that for specific frequency range noise reduction, it is not necessary to increase flexible tube length to its maximum which cavity volume may contain. There is an optimal problem for tube length. Furthermore, for micro-slotted resonator, cavity depth still plays a greater role in enhancing low frequency sound absorption.

In two cases of flexible tube bundles with open and closed ends, the sound absorption property comparisons of the micro-slotted resonators with flexible tube bundles are also shown in Figure 5. The flexible tube bundles with open ends and closed ends have a greater influence on sound absorption in middle frequency range of 315-1000Hz and above 1250Hz.
CONCLUSIONS
The micro-slotted resonator with flexible tube bundles and its acoustical properties are introduced in this paper. By properly changing the lengths or structures of flexible tubes of the perforated panel resonant absorber with the flexible tube bundle, the resonance frequency of resonant absorber can be tuned to a lower frequency of interest to some extent.

The incorporation of the flexible tube bundles into the micro-slotted resonant absorber has three predominant features. 1) The resonance frequency may be shifted to a lower frequency of interest. 2) Acoustical resistance is further increased. Sound absorption performance may be improved accordingly. 3) The possibilities of designing sound absorption frequency bands and enhancing sound absorption through changing tube length, tube size, tube structure and tube materials are provided. The flexible tube length may be much greater than the cavity depth, and can be deliberately made different from one another to absorb sound at different frequencies of interest. 4) The combination of the perforated panel resonator with flexible tube bundles and conventional sound absorbing materials and resonant absorbers including micro-perforated panel and micro-slotted absorbers is helpful to further broaden sound absorption frequency bands in addition to enhance low frequency absorption properties. In addition, because of the tube-cavity coupling resonances, through properly designing the flexible tube structure and length, two or more obviously resonant absorption peaks may occur in the frequency spectrum of sound absorption.

These dominant features have laid a foundation for its potential engineering applications in the cases with stringent requirements to control low-frequency noise. For example, the micro-slotted resonator with flexible tube bundles may be used in the structural designs of highly sound absorptive wall panels and highly efficient duct silencers as well as compressor and centrifugal fan’s casing treatments and etc.

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References: