UTILIZATION OF SOUND PATH DIFFERENCE TO FURTHER ENHANCE LOW FREQUENCY SOUND ABSORPTION PERFORMANCE OF THE PERFORATED PANEL RESONATOR WITH FLEXIBLE TUBE BUNDLES

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The perforated and micro-perforated panel resonators have been widely used in sound absorption applications, due to their good acoustical performance. Based on them, the perforated panel resonator with flexible tube bundles was presented in 2000 to improve low frequency sound absorption performance of traditional perforated panel resonator. Is it possible to further enhance its low frequency sound absorption performance? The answer is affirmative. In this paper, by incorporating a bypass circuit tube into each flexible main tube and properly designing bypass tube length, by utilizing sound path difference to fulfil low frequency sound destructive interference, a new kind of sound absorption structure, the perforated panel resonator with flexible tube bundles containing bypass circuits, is presented. According to noise reduction principle of the silencer with bypass circuits, while sound path difference reaches odd times of the half wavelength, when sound wave coming from main tube encounters sound wave coming from a bypass tube, their phases are inverse. Therefore, a passive destructive interference phenomenon occurs. The expected low frequency sound in a flexible main tube can be cancelled in a passive antiphase method. The sound absorption results measured in an impedance tube demonstrate that the implant of bypass circuits is useful to some extent to further enhance low frequency sound absorption performance of the perforated panel resonator with flexible tube bundles. We may well design some bypass circuit tubes with different sound path difference to adjust and increase sound absorption peaks, especially in a sensitive resonant low frequency range of interest, so as to conform to the requirements of noise source cancellation to the utmost.

Keywords: sound path difference, low frequency sound absorption, perforated panel resonator with flexible tube bundles, destructive interference

1. Introduction

There are many sound absorbing materials and constructions which are widely used in all sorts of noise reduction engineering. According to their different principles in 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]-[5]. 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' phenomena. In order 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 space limitations, this method is not feasible completely, 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 [6]-[8] and micro-slotted resonator with flexible tube bundles was also presented [9].

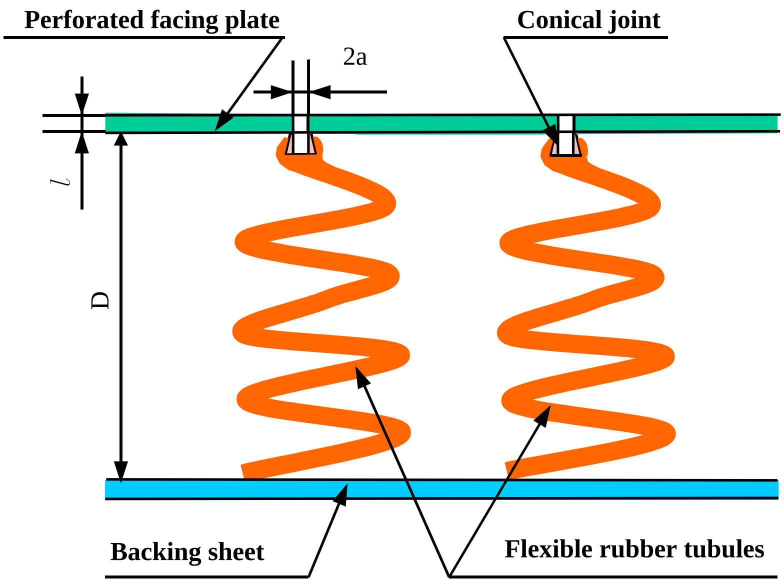

Figure 1: The structure of the perforated panel resonant absorber with flexible tube bundles

The perforated panel resonant absorber with flexible tube bundle consists of the perforated plate and backing sheet and the side plates, which form a resonant enclosure, as well as the flexible long tube bundles, which are a combination of many rubber or polytetrafluoroethylene tubes shown in Figure 1. Each flexible tube connects with the opening hole of the perforated facing sheet through the conical joint fixed together with the facing plate. Without taking account of assembling and manufacturing tolerances, the outer diameter of the cone joint is nearly the same as the diameter of the opening hole in the facing plate. The inner diameter of the flexible tube is almost the same as the inner diameter of the conical joint. The tube length can be much greater than the cavity depth, and can be made different from one another to absorb sound at different frequencies of interest. The incorporation of the flexible tube bundle into the resonant absorber is expected to widen the frequency band of absorption and further enhance low frequency sound absorption.

Is it possible to further enhance its low frequency sound absorption performance? The answer is affirmative. Based upon the perforated panel resonator with flexible tube bundles, by inserting a bypass circuit into each tube with properly designing the bypass tube length, by utilizing sound path difference to produce low frequency sound destructive interference, a new kind of sound absorption structure, the perforated panel resonator with flexible tube bundles having bypass circuits, is presented in this paper. This paper is chiefly dedicated to introduce the perforated panel resonator with flexible tube bundles containing bypass circuits, and its structure, sound absorption mechanism, acoustical properties and measurement results.

2. Structure and sound absorption mechanism

The perforated panel resonator with flexible tube bundles containing bypass circuits is based upon the perforated panel resonator with flexible tube bundles to design its structure of the flexible tube bundles. The structure of the perforated panel resonator with flexible tube bundles having bypass circuits is shown in Figure 2. One end of 'main flexible tube' is connected to the aperture of the facing plate, which opens into an enclosed cavity, the other end of ‘main flexible tube’ is incorporated freely into the enclosed cavity. The in-between ‘main flexible tube’ is connected to some other bypass flexible tubes with different well-designed lengths through T-type joints, which are mounted at liberty in the cavity. Thus, the perforated panel resonator with flexible tube bundles containing the bypass circuits comes into shape.

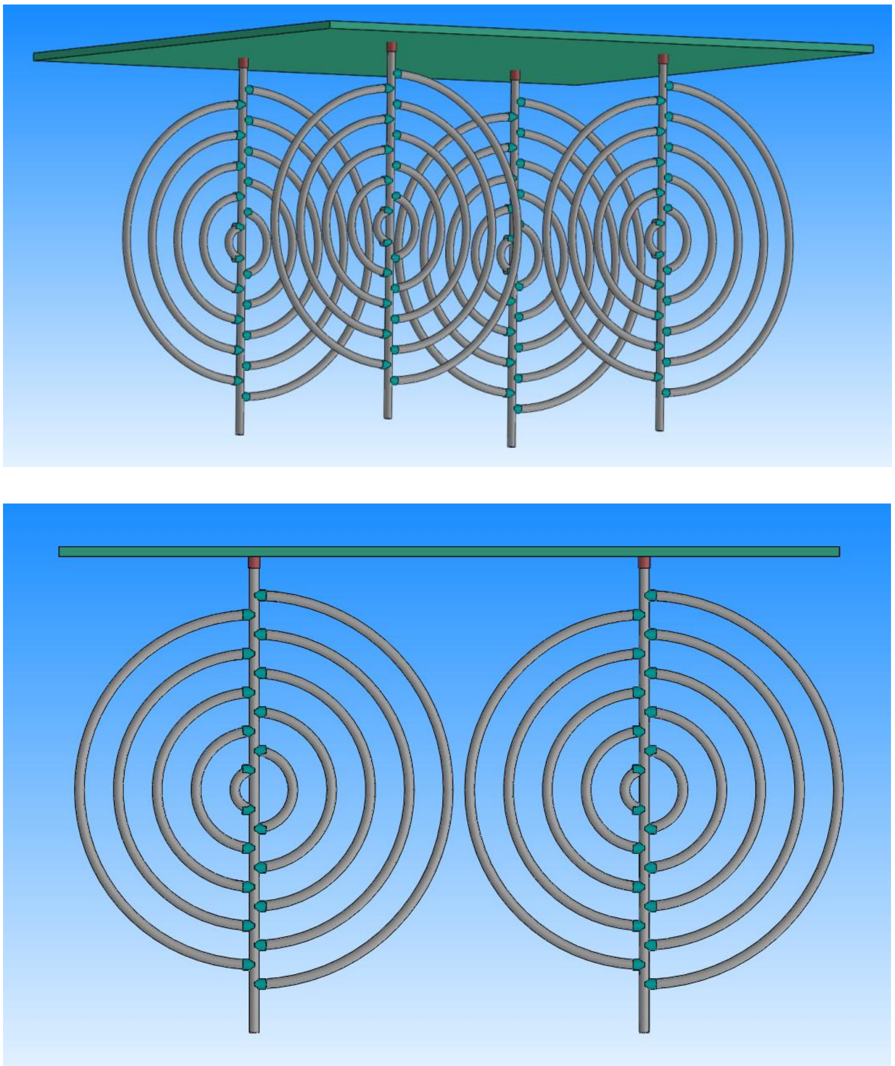

Figure 2: Schematic illustration of the perforated panel resonator with flexible tube bundles containing bypass circuits

According to noise reduction principle of the silencer with bypass circuits, while sound path difference reaches odd times of the half wavelength, when sound wave coming from main tube encounters sound wave coming from bypass tube, their phases are inverse. Their amplitudes almost are the same. Therefore, a destructively passive interference phenomenon occurs. The expected noise of low frequency of interest in a main tube can be cancelled deliberately.

Assuming the length of the bypass circuit tube is s_2, the length of flexible main tube in-between two ends of bypass circuit tubes is s_1, thus sound path difference induced by the bypass circuit tube is $s_2 - s_1$, if sound path difference reaches up to odd times of the half wavelength, i.e.

$$s_2 - s_1 = \frac{\lambda}{2}(2n-1), n = 1, 2, 3... \qquad (1)$$

Then while wavelength $\lambda = \frac{2(s_2 - s_1)}{(2n-1)}$ (i.e. $f_{\mathrm{dc}} = \frac{c(2n-1)}{2(s_2 - s_1)}$, where n=1,2,3…, f_{dc} is called destructively interference frequencies), sound wave coming from main tube encounters sound wave coming from bypass tube, their phases are inverse. Their amplitudes almost are the same. Therefore, a destructively passive interference phenomenon occurs. While $n=1$, destructively passive interference at the lowest frequency can occur. Sound wave at the low-order frequencies of f_{dc} can't effectively radiate into the downstream segment of the flexible main tube. The sound energy is transformed in heat energy through microscopic vortex movements.

3. Measurement results

The sound absorption comparison measurements of the perforated panel resonator with flexible tube bundles containing bypass circuits and original perforated panel resonator with short rigid conical tube bundles, original perforated panel resonator with flexible tube bundles as well as original perforated panel resonator are conducted in an impedance tube. The detail geometric parameters of the specimens are listed as below.

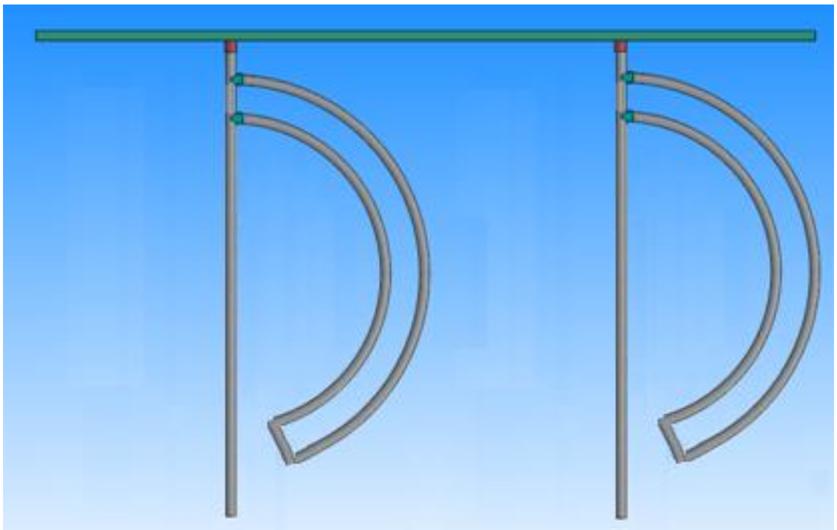

Figure 4: Schematic illustration of the test specimen configurations of the perforated panel resonator with flexible tube bundles containing bypass circuits

1) Original perforated panel resonator: The apertures on the facing plate are arranged in a square, aperture diameter is 2mm, the distance between two adjacent aperture centres is 4mm, facing plate thickness is 0.6 mm, open area ratio is 4.8%.

2) The perforated panel resonator with short rigid conical tube bundles: facing plate thickness is 0.6 mm, the apertures on the facing plate are arranged in a square, the distance between two adjacent aperture centres is 4mm, conical tube length is 10mm.

3) Original perforated panel resonator with flexible tube bundles: facing plate thickness is 0.6 mm, the apertures on the facing plate are arranged in a square, the distance between two adjacent aperture centres is 4mm, conical tube length is 10mm, flexible tube's inner diameter is 2mm.

4) The perforated panel resonator with flexible tube bundles containing bypass circuits: facing plate thickness is 0.6 mm, the apertures on the facing plate are arranged in a square, distance between two adjacent aperture centres is 4mm, length of conical tube is 10mm, length of flexible main tub is 100mm, length of bypass circuit tube is 750mm, flexible main tube and bypass circuit tube's inner diameter is 2mm.

The test specimen configurations of the perforated panel resonator with flexible tube bundles containing bypass circuits are shown in Fig.3. Only a single bypass circuit tube of 750mm length is incorporated into each flexible main tube in an enclosed cavity. The inlet end and outlet end of the bypass circuit tube are aligned closely. So sound path difference is roughly 750mm. The bypass circuit tubes and main tubes thereof are made of flexible rubber material.

The comparison measurement results are shown in Fig. 4.

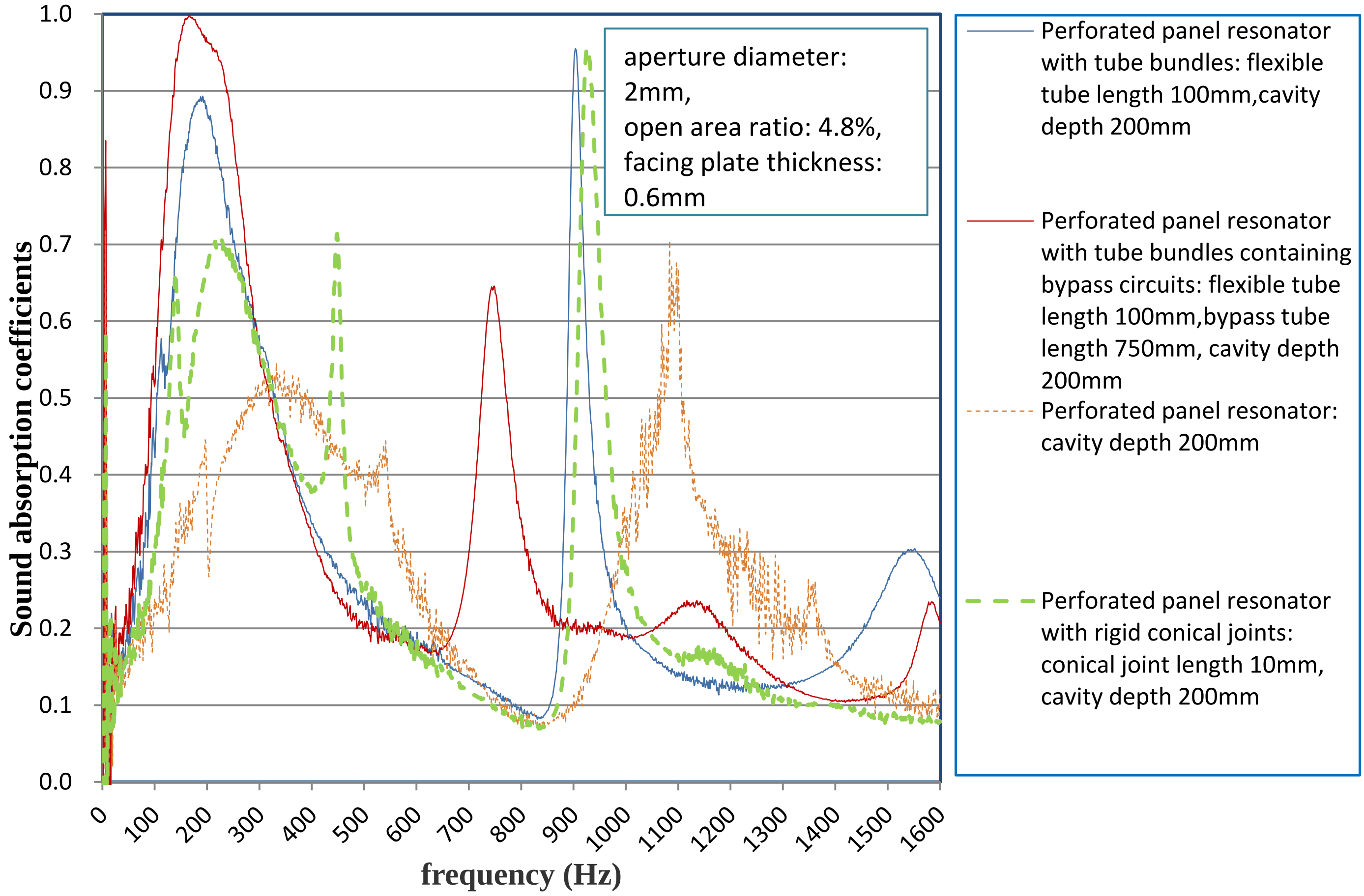

Figure 3：The sound absorption measurement comparisons of the perforated panel resonator with flexible tube bundles containing bypass circuits and original perforated panel resonator with short rigid conical tube bundles, original perforated panel resonator with flexible tube bundles as well as original perforated panel resonator

With reference to the perforated panel resonator with flexible tube bundle containing such a by-pass circuit construction, according to the above-mentioned formula for sound path difference of odd multiple of the half wavelength, the frequency of destructively sound interference caused by the bypass circuit tubes is about 220Hz. It can be shown from Fig. 3 that in the cases of 200mm cavity depth, in the frequency range of 120-300Hz, sound absorption peaks of the perforated panel resonator with flexible tube bundle containing bypass circuits are higher than that of conventional perforated panel resonators with tube bundle not containing bypass circuits obviously. Its secondary sound absorption peak is shifted to a lower frequency. Meanwhile, sound absorption performance of the perforated panel resonators with tube bundles containing or not containing bypass circuit construction is superior to that of conventional perforated panel resonator. The configuration parameters of the bypass circuit tubes, such as their length, number, diameter, can influence the resonant absorption peaks and bandwidth.

4. Conclusions

Based upon a principle of anti-phase passive noise cancellation by utilizing sound path difference up to par of the odd multiples of the half wavelength at the frequency of interest, the perforated panel resonator with flexible tube bundles containing bypass circuits is presented. Its structure characteristics are introduced. Its sound absorption mechanism is analyzed qualitatively. The sound absorption measurement comparison between the perforated panel resonator with flexible tube bundles containing bypass circuits and the perforated panel resonator with short rigid conical tube bundles, the perforated panel resonator with flexible tube bundles as well as original perforated panel resonator are conducted.

It can be made conclusions from measurement comparisons that under the theoretical guidance of sound path difference anti-phase noise cancellation, incorporating the bypass circuit tubes into flexible main tubes is helpful to further enhance low frequency sound absorption performance of the perforated panel resonator with flexible tube bundles. Accordingly, we may well design some bypass circuit tubes with different sound path difference to adjust dominant sound absorption frequency bandwidth and increase sound absorption peaks as much as possible, especially in a sensitive resonant low frequency range of interest, so as to conform to the requirements of noise source cancellation to the utmost.

5. Acknowledgements

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