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(54) **COMPOUND SOUND ABSORPTION DEVICE WITH BUILT-IN RESONANT CAVITY**

(57) The composite sound-absorbing device of the present invention includes a perforated board having a number of first pores thereon, a back board and side boards, the perforated board, back board and side boards forming a closed cavity, wherein: at least one or more of the resonant cavities being located within the closed cavity; at least one or more of second pores being

located on the resonant cavities; at least one of the second pores being connected with the closed cavity; the resonant cavity having a volume of $V=10\text{mm}^3-1\times 10^{10}\text{mm}^3$, having a thickness of 0.05mm-10mm, the second pores having an aperture of $d'=0.05-100\text{mm}$, with a perforation rate $\sigma'=0.01\%-30\%$. The present invention is beneficial to improve the effect of sound-absorbing and expand the frequency band of sound-absorbing.

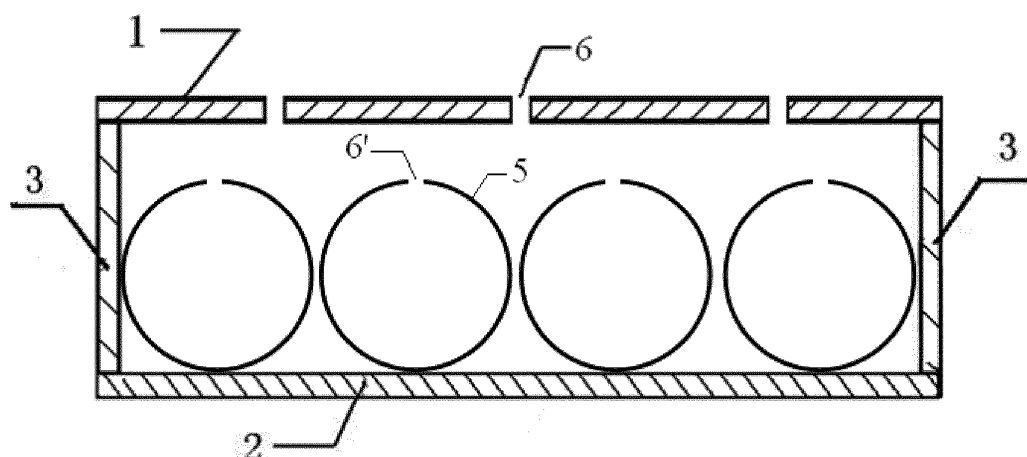


Fig.1

Description

Field of the invention

[0001] The present invention relates to a composite sound-absorbing device and more particularly relates to a composite sound-absorbing device with built-in resonant cavity.

Background of the invention

[0002] In noise control engineering, many types of sound-absorbing material and structures are used, which can be roughly divided into porous sound-absorbing materials and resonant sound-absorbing materials according to their acoustical principles. For example, fiber materials and plaster materials, among others, fall into the category of porous sound-absorbing materials, while resonant sound-absorbing structure of thin board, resonant sound-absorbing structure of membrane and resonant sound-absorbing structure of perforated board fall into the category of resonant sound-absorbing materials. In 1975, Dah-You Maa published an article titled "Theory and Design of Microperforated board Sound-absorbing Structure" published in Science in China and in 2000 "Theory of Micro slit Absorbers" in Chinese Journal of Acoustics, wherein Maa expanded the application range of resonant sound-absorbing structure.

[0003] Although resonant sound-absorbing structure of perforated board, resonant sound-absorbing structure of microperforated board and double layer microperforated sound-absorbing structure are superior to porous sound-absorbing material in terms of sound absorption characteristics, flow resistance, anti-moisture, anti-corrosion and hygiene, they still cannot meet some practical needs of noise control engineering, especially when dealing with low frequency noise within strictly limited space for sound absorption. For as to common resonant sound-absorbing structure, the depth of cavity has to be increased greatly to absorb more low frequency sound, which is almost impossible to realize in practice. Applicant has searched G10K with a special emphasis on G10k 11/172 and found out "The Bundle Type Perforated board Resonant Sound-absorbing Device" with patent number of CN ZL00100641.X and "Muffler with Multi Insert Pipe Parallel Connected Structure" with patent number of CN ZL00264613.7.

[0004] The bundle type perforated board resonant sound-absorbing device features a bundle type perforated board resonant sound-absorbing structure, which is consisted of a perforated board, a bottom board and side board (forming a closed cavity) and a bundle of tubes. The diameter of the tubes is equal to that of the pores on the perforated board and the length of these tubes is not restrained by the cavity depth of the perforated board resonant sound-absorbing device. The tubes can either be longer or shorter than the cavity depth so as to tune resonance frequency and alter sound absorption coefficient.

This sound-absorbing structure is designed on the basis of the sound-absorbing principle of coupling resonance to increase its sound absorption coefficient, acoustic impedance and to enhance the sound-absorbing effect of low frequency sound. However this structure absorbs only sound within low and medium frequency band, which band is not wide enough. The length of those flexible tubes is critical in that if the tubes are not long enough, the sound-absorbing performance would be greatly affected, i.e., greatly degrading sound-absorbing effect. Therefore longer tubes have to be used to ensure good sound-absorbing performance. Accordingly cavity has to be deeper correspondingly. However longer tubes and deeper cavities are not beneficial to expand the application range of this structure. It is further compounded by the fact that the tubes being wire like, this structure cannot give full play the coupling resonance effect of tube cavity. Moreover, the length of the tubes contributes less to the consumption of acoustic energy.

[0005] The muffler with multi insert pipe parallel connected structure described in ZL00264613.7 is designed for the intake system for internal combustion engine of automobiles and that it includes an intake pipe and two or four resonant cavities arranged in parallel. The resonant cavities are arranged in a casing. Each of the resonant cavities is connected to a radial-direction pore axially arranged on the intake pipe, through conduct pipes. The size of the radial-direction pore and the conduct pipes is designed to match with the intake noise spectrum of the internal combustion engine. This muffler is not only able to greatly reduce the intake noise but also increase the power of the internal combustion engine. Moreover, it is compact in size.

[0006] Therefore, it has been a long-time effort internationally in the field of acoustics and noise control engineering to invent a device, which can effectively absorb low frequency sound and has a wide sound-absorbing frequency band to replace or improve conventional sound-absorbing structure which is deficient in absorbing low frequency sound. To this end, this invention proposes a composite sound-absorbing device with built-in resonant cavity. This device is realized based on several principles, namely by combining acoustic scattering inside the resonant cavity, sound elimination of small pores and the coupling resonance of multiple resonant cavities, to increase sound absorption coefficient and expand sound frequency band.

Summary of the Invention

[0007] The purpose of the present invention is to overcome the defect of the above sound-absorbing structure used in current noise control engineering that it cannot absorb enough sound with low and medium frequency by providing a composite sound-absorbing structure with built-in resonant cavity.

[0008] According to the present invention, a composite sound-absorbing device with a built-in resonant cavity,

includes: a perforated board having a number of first pores thereon, a back board and side boards, the perforated board, back board and side boards forming a closed cavity, wherein: at least one or more of the resonant cavities being located within the closed cavity; at least one or more of second pores being located on the resonant cavities; and at least one of the second pores being connected with the closed cavity; the resonant cavity having a volume of $V=10\text{mm}^3\text{---}1\times 10^{10}\text{mm}^3$, the thickness of the wall thereof being 0.05mm-10mm, the second pores having an aperture of $d'=0.05\text{--}100\text{mm}$, with a perforation rate $\sigma'=0.01\%\text{--}30\%$.

[0009] In the composite sound-absorbing device of the present invention, the resonant cavity is in a shape of sphere, ellipsoid or polyhedron. Furthermore, in the composite sound-absorbing device of the present invention, the second pores are connected to the closed cavity directly, or are connected to the closed cavity via tubes. Moreover, in the composite sound-absorbing device of the present invention, when the number of the resonant cavities is more than one, they are located within the closed cavity directly or fixed separately within the closed cavity partitioned by a number of partition boards.

[0010] Preferably, in the composite sound-absorbing device of the present invention, the first or second pores are connected to one end of the tubes and the tubes are located within the closed cavity for increasing acoustical impedance. Preferably, in the composite sound-absorbing device of the invention, the other end of the tubes on the second pores are connected to the closed cavity, the second pores on another resonant cavity or the first pores on the perforated board.

[0011] Preferably, in the composite sound-absorbing device of the present invention, the tubes are made of metal, glass, plastic or rubber; when the tubes are made of rubber, they are connected to the first pores or second pores via binding, or they are connected to the first pores via a first transition joint at the ends of the tubes, or they are connected to the second pores via a second transition joint at the ends of the tubes; when the tubes are made of metal, glass or plastic, they are connected to the first pores or second pores via binding, welding, thread connection or injection, or they are connected to the first pores via a first transition joint at the ends of the tubes, or they are connected to the second pores via a second transition joint at the ends of the tubes.

[0012] Preferably, in the composite sound absorptive device of the present invention, the perforated board has a thickness of 0.5-10mm, the diameter of the first pores on the perforated board d is 0.1-5mm, with a perforation rate of 0.1%-30%. Furthermore, the first pores on the perforated board are arranged regularly in a shape of triangle or square or irregularly. Moreover; the closed cavity has a depth D of 10-2000mm, and is in a shape of cylinder composed by one side board or a polyhedron composed by a plurality of side boards.

[0013] Preferably, in the composite sound-absorbing device of the present invention, the back side of said

perforated board is coated with a layer of porous sound-absorbing material, the layer of porous sound-absorbing material being located within the closed cavity, with a thickness of 0.1 mm-200mm.

[0014] In the above technical solutions, the perforated board can be iron board, steel board, copper board, corrosion resistant board, aluminum board, plastic board, glass board, PVC board, PE board or wood board.

[0015] In the above technical solutions, the resonant cavity can be made of metal, glass, ceramics, rubber, plastic or fiber. The length L of the tubes is 1-5000mm. The diameter of the tubes is 0.1-100mm.

[0016] The present composite sound-absorbing device with built-in resonant cavity comprises a perforated board with a plurality of pores, a back board, side board (s) and multiple resonant cavities. The resonant cavities are small cavities placed in a closed cavity. The resonant cavities are used to scatter sound, connect with the closed cavity and increase acoustic impedance. When a sound wave reaches the resonant cavities, the air inside the cavity vibrates back and forth. Due to viscous damping, part of the acoustic energy is converted into heat energy and is lost. By using the principle of Helmholtz resonator, the pores on the wall of the resonant cavities increase acoustic impedance of the perforated board, sufficiently consume the acoustic energy and so enhance sound absorption. The fact that the resonant cavity being hollow increases acoustic resistance of the present sound-absorbing device. At the same time, the resonant cavities are connected with the closed cavity serially so as to realize multiple cavities' coupled resonance, thereby expanding the frequency band of sound absorption consequently. Furthermore, the size of each of the resonant cavities can be different from each other and the size of each of the second pores can be different from each other in order to tune the resonant frequency and alter sound absorption coefficient under different frequencies. The present invention utilizes the resonant cavity to scatter sound in the closed cavity and utilizes the second pores to increase acoustic impedance and consume acoustic energy. In addition, the present invention modulates formant and sound-absorbing frequency band based on the principle of multiple-cavity coupled resonance. Therefore, the present invention increases acoustic impedance, improves sound quality and the effect of sound absorption and expands sound-absorbing frequency band.

[0017] Major technical features of the present invention include: the resonant cavity is connected with the closed cavity via second pores to realize coupling resonance among cavities and so expand sound-absorbing frequency band. In addition, there is no limitation imposed on the number of the pores on the resonant cavity, thus increasing acoustic impedance of the sound-absorbing device. The number of the pores and the diameter of the pores can be adjusted as required to increase or reduce the acoustic impedance and thus to increase sound absorption coefficient. The tubes connecting to

the resonant cavities increase the thickness of the pores on the resonant cavities, which is not only to the benefit of increasing acoustic impedance but also realizes coupling resonance by connecting the tubes with resonant cavities. Moreover, the present invention advantageously can increase sound absorption coefficient, expand sound-absorbing frequency band and cause the sound absorption frequency band to shift towards low frequency band, so it is beneficial to absorb sound with low frequency. With the coupled resonance of the resonant cavities and the closed cavity, it can be regarded that sound absorption is carried out in a double-deck structure within the same and one cavity. In the meantime, the capacity of the rear cavity is reduced. Therefore, the present invention is suitable to the situations where space for sound absorption is strictly limited. Moreover, in order to expand the frequency range of noise elimination of the present composite sound-absorbing device, each of the resonant cavities can be different from each other in size and shape, and each of the second pores can be different from each other in size and shape, which is beneficial for the present invention to be used in different sound elimination situations. The acoustic scattering on the surfaces of the resonant cavities allows the sound wave to reach to every resonant cavity in the rear cavity and pushes the air in the second pores to vibrate back and forth, thereby consuming acoustic energy sufficiently and being beneficial to absorb sound by using the space of the rear cavity.

[0018] The advantages of the invention lie in that, by arranging a plurality of resonant cavities in the limited space of the rear cavity, the present invention makes full use of the principles of acoustic scattering, pores' acoustic impedance consuming acoustic energy and sound absorption by multi-cavity coupled resonance, as well as the modulation features of the size of the cavities and the pores to formant and sound-absorbing frequency band, thus increasing sound absorption coefficient, enhancing the absorption of low and medium frequency noise and expanding sound-absorbing frequency band.

Description of the drawings

[0019]

Fig.1 schematically shows a composite sound-absorbing device with built-in resonant cavities of the present invention, wherein each of the resonant cavities has a second pore connecting directly with a closed cavity;

Fig. 2 schematically shows another embodiment of the composite sound-absorbing device of the present invention, wherein each resonant cavity has 26 second pores connecting with a closed cavity;

Fig. 3 schematically shows another embodiment of the composite sound-absorbing device of the present invention, wherein each resonant cavity has four second pores, and one of the second pores con-

nects with one first pore on a perforated board via a tube, while the other second pores connect with a closed cavity directly;

Fig. 4 is still another embodiment of the composite sound-absorbing device according to the present invention, wherein each resonant cavity has three second pores, one of which connects with a closed cavity via tubes;

Fig. 5 is still another embodiment of the composite sound-absorbing device according to the present invention, wherein each resonant cavity has two second pores, and for every two resonant cavities there are connected tubes therebetween, the other second pores directly connects with a closed cavity;

Fig. 6 schematically shows an embodiment of the composite sound-absorbing device according to the present invention, wherein a first transit joint and a second transit joint are installed;

Fig. 7 is another embodiment of the composite sound-absorbing device according to the present invention, wherein each of the resonant cavities has two second pores with different diameters;

Fig. 8 is another embodiment of the composite sound-absorbing device according to the present invention, wherein two resonant cavities with different volumes are arranged in a closed cavity;

Fig. 9 is another embodiment of the composite sound-absorbing device according to the present invention, wherein ellipsoid resonant cavities and cubic resonant cavities are arranged in a closed cavity; Fig. 10 schematically shows an embodiment of the composite sound-absorbing device according to the present invention, wherein partition boards are installed;

Fig. 11 is still another embodiment of the composite sound-absorbing device of the present invention, wherein first pores on a perforated board connect with tubes;

Fig. 12 is another embodiment of the composite sound-absorbing device of the present invention, wherein the back side of the perforated board is covered with a layer of porous sound-absorbing material;

Fig. 13 is a comparison chart showing the sound-absorbing performance of resonant sound-absorbing device of the present invention and a perforated board (Cavity depth is 50mm), by using a standing wave meter;

Fig. 14 is a comparison chart showing the sound-absorbing performance of different composite sound-absorbing devices with different number of resonant cavities(cavity depth is 100mm) according to the present invention, by using a standing wave meter; and

Fig. 15 is a comparison chart showing low and medium frequency sound performance of a composite sound-absorbing device with built-in resonant cavity, a perforated board with tubes and a perforated board

(cavity depth is 50mm), by using a standing wave meter.

Detailed description of the embodiments

[0020] In the following, the present invention will be described in details with reference to the accompanying drawings and embodiments.

Embodiment One

[0021] Referring to Fig. 1, the embodiment provides a composite sound-absorbing device with built-in resonant cavity. The device comprises a closed cavity formed by a perforated board 1, a back board 2 and side boards 3 all made up of stainless steel, wherein the depth D of the closed cavity is 40mm. The perforated board 1 is a square board with the length of the side being 80mm and the thickness being 5mm. On the perforated board 1, first pores 6, with a diameter of 3mm, are formed. The perforation rate σ of the first pores 6 is 28%. The first pores 6 are regularly arranged in the pattern of a square on the perforated board 1. In the closed cavity, four resonant cavities 5 are formed, with each resonant cavity 5 being made of aluminum and having a shape of sphere. The volume of the resonant cavity 5 is $1.4 \times 10^4 \text{mm}^3$ and the thickness of the wall of the resonant cavity 5 is 5mm. Moreover, on the wall of the resonant cavity 5, a second pore 6', with a diameter of 2mm, is formed. The perforation rate σ' of the second pore 6' is 0.06%. The resonant cavity 5 is arranged in the closed cavity freely.

Embodiment Two

[0022] Referring to Fig.2, the present embodiment provides a composite sound-absorbing device with built-in resonant cavity according to the present invention. The device comprises a closed cavity formed by a perforated board 1, a back board 2 and side boards 3 all made of stainless steel, wherein the depth D of the closed cavity is 50mm. The perforated board 1 is a round board, with a diameter of 100mm and a thickness of 0.7mm. On the perforated board 1, first pores 6, with a diameter of 1.7mm, are formed. The perforation rate σ of the first pores 6 is 4.6%. The first pores 6 are arranged regularly in the pattern of a square on the perforated board 1. In the closed cavity, four resonant cavities are formed, with each resonant cavity being made of plastic. The volume of the resonant cavity 5 is $3.35 \times 10^4 \text{mm}^3$ and the thickness of the wall of the resonant cavity 5 is 0.4mm. Furthermore, there are 26 second pores 6' on the wall of the resonant cavity 5, evenly distributed on the circumferences of three mutually perpendicular hemispheres. (There are 16 second pores 6' on each hemispherical circumference, with 4 second pores 6' overlapping on every two hemispherical circumferences), the diameter d' of the second pores 6' being 0.5mm and the perforation rate σ' being 0.1 %. The resonant cavities 5 are arranged

in the closed cavity freely.

[0023] An experiment was conducted to test low and medium frequency sound muffling mechanism of the composite sound-absorbing device with built-in resonant cavity by using a standing wave meter. In the experiment, the low and medium frequency sound absorption coefficient of a perforated board, a perforated board whose cavity is provided with sphere without pores and a composite sound-absorbing device with built-in resonant cavity are measured to verify that multiple cavities coupling is beneficial to increase sound absorption coefficient. Other parameters of resonant sound-absorbing structures employed in the experiment are listed as follows:

Parameters of the perforated board: the pores are arranged in the pattern of a square, with the diameter of the pores being 1.7mm, the center to center spacing of the pores being 7mm, the thickness of the perforated board being 0.7mm and the depth of the closed cavity being 50mm.

Parameters of the perforated board whose cavity is provided with sphere without pores: the pores are arranged in the pattern of a square, with the diameter of the pores being 1.7mm, the center to center spacing of the pores being 7mm, the thickness of the perforated board being 0.7mm. Four plastic hollow spheres without pores are placed in the closed cavity, with the thickness of the wall of the sphere being 0.4mm and the volume V of the sphere being $3.35 \times 10^4 \text{mm}^3$. The spheres are arranged in the closed cavity freely, with the depth of the closed cavity being 50mm.

[0024] Fig. 13 shows that the sound absorption coefficient of the perforated board and the perforated board with built-in spheres without pores is similar to each other, with the highest sound absorption coefficient being no greater than 0.35 at the frequency band of 1000Hz and 1250Hz, i.e., the sound-absorbing effect of these two devices is not desirable. As to the composite sound-absorbing device with built-in resonant cavity, its formant reaches 0.928 at the frequency of 630Hz and reaches above 0.5 at the frequency band of 500Hz and 1250Hz (i.e., the band width is 750Hz). From the above, it is apparent that the sound-absorbing effect of the composite sound-absorbing device with built-in resonant cavity is superior to the other two.

Embodiment Three

[0025] Referring to Fig. 2, the embodiment provides a composite sound-absorbing device with built-in resonant cavity. The device comprises a closed cavity formed by a perforated board 1, a back board 2 and side boards 3 all made up of stainless steel, with the depth D of the closed cavity being 100mm. The perforated board 1 is a round board, with a diameter of 100mm and thickness of 0.7mm. On the perforated board 1, first pores 6, with a

diameter of 1.7mm are formed. The perforation rate of the first pores 6 is 4.6%. The first pores 6 are arranged regularly in a pattern of square on the perforated board 1. Separately, nine, seven, four and one resonant cavity 5, made of plastic and having a shape of sphere and a volume V of $3.35 \times 10^4 \text{mm}^3$ and the thickness of the wall of the resonant cavity 5 being 0.4mm, is arranged in the closed cavity. Furthermore, there are 26 second pores 6' on the wall of the resonant cavity 5, evenly distributed on the circumferences of three mutually perpendicular hemispheres (There are 16 second pores 6' on each hemispherical circumference, with 4 second pores 6' overlapping for every two hemispherical circumferences). The second pores 6' have a diameter d' of 0.5mm and the perforation rate σ' of the second pores 6' is 0.1%. The resonant cavities 5 are arranged in the closed cavity freely.

[0026] In the experiment, four composite sound-absorbing devices with built-in resonant cavity according to the present invention are separately provided with nine, seven, four and one resonant cavity inside the closed cavity. The experiment tests the low and medium frequency sound muffling mechanism by using a standing wave meter to verify the impact of the number of resonant cavities on sound absorption coefficient and the frequency band of sound absorption. The other parameters of the resonant sound-absorbing structures employed in the experiment are listed as follows:

Parameters of the perforated board: the pores, with a diameter of 1.7mm, are arranged in a pattern of square, with the center to center spacing of the pores being 7mm, the thickness of the board being 0.7mm and the depth of the closed cavity being 100mm.

[0027] From Fig. 14, it is known that, the sound absorption coefficient of the resonant sound-absorbing device with one resonant cavity is no greater than 0.4 at the formant of 630Hz, and reaches about 0.6 at the frequency of 2000Hz; the sound absorption coefficient of the resonant sound-absorbing device with four resonant cavities is above 0.8 at the formant of 630Hz, and is greater than 0.5 at the frequency band of 500Hz and 800Hz, and is 0.8 at the frequency of 2000Hz; the sound absorption coefficient of the resonant sound-absorbing device with seven resonant cavities is above 0.95 at the formant of 800Hz, and is greater than 0.5 at the frequency band of 400Hz and 800Hz, and is about 0.85 at the frequency of 2000Hz; the sound absorption coefficient of the resonant sound-absorbing device with nine resonant cavities is above 0.9 at the formants of 500Hz and 800Hz respectively, and is greater than 0.5 at the frequency band of 400Hz and 1000Hz, and is about 0.8 at the frequency of 2000Hz. As can be seen, as the number of the resonant cavity provided in the closed cavity increases, the frequency band is expanded and the formant of the major sound-absorbing frequency band becomes bigger gradually and the number thereof increases from one to two,

whose features are similar to the sound-absorbing structure of double-layer microperforated board; in addition, the sound absorption coefficient at the frequency of 2000Hz increases as the number of resonant cavities grows.

Embodiment Four

[0028] Referring to Fig. 3, the embodiment provides a composite sound-absorbing device with built-in resonant cavity. The device comprises a closed cavity formed by a perforated board 1, a back board 2 and side boards 3 all made up of stainless steel, with the depth D of the closed cavity being 200mm, 500mm, 1000mm or 2000mm. The perforated board 1 is a square board, with the length of the side being 1000mm and the thickness thereof being 2mm. On the perforated board 1, first pores 6, with a diameter of 2mm, are formed. The perforation rate of the first pores 6 is 0.031%. The first pores 6 are arranged regularly in a pattern of square on the perforated board 1. In the closed cavity, 100 resonant cavities 5, made of glass and in a shape of sphere and having a volume of $2.7 \times 10^5 \text{mm}^3$ and having a wall thickness of 10mm, are arranged. Four second pores 6', with a diameter d' of 2mm, are provided on the wall of the resonant cavity 5, evenly distributed on the circumference of a hemisphere. The perforation rate σ' of the second pores 6' is 0.06%. Three of the four second pores 6' on each of the resonant cavities 5 are connected with the closed cavity. The other second pore 6' is connected with a tube 4, whose other end is connected with a first pore 6 on the perforated board 1. The tube 4 may be made of metal, rubber or glass, with a length l of 10mm, 50mm or 100mm and a diameter of 2mm. The tubes 4 may be connected to the perforated board 1 by splicing, threaded connection or injection mold.

Embodiment Five

[0029] Referring to Fig. 4, a composite sound-absorbing device with a built-in resonant cavity is provided. The device comprises a closed cavity formed by a perforated board 1, a back board 2 and side board 3. The perforated board 1 may be made of glass, PVC, PE or wood. The back board 2 and the side boards 3 are made of glass, with the depth D of the closed cavity being 100mm. The perforated board 1 is a square board with a side length of 200mm and a thickness of 3mm. On the perforated board 1, first pores 6, with a diameter of 1mm, are provided. The perforation rate of the first pores 6 is 0.6% and the first pores 6 are arranged in a pattern of hexagon on the perforated board 1. In the closed cavity, 16 resonant cavities 5, which are rubber sphere-shaped cavity, are arranged, with the volume of the resonant cavities 5 being $3.35 \times 10^4 \text{mm}^3$ and the thickness of the wall of the resonant cavities 5 being 0.8mm. On the wall of the resonant cavities 5, three second pores 6' are provided, evenly distributed on the circumference of a hemisphere.

The diameter d' of the second pores 6' is 1 mm and the perforation rate σ' of the second pores 6' is 0.047%. Furthermore, the second pores 6' of each resonant cavity 5 are connected with tubes 4 whose other ends are connected with the closed cavity. The tubes 4 are made of rubber and have a length l of 60mm and a diameter of 1 mm. The resonant cavities 5 are connected with the tubes 4 by splicing or injection molding. The resonant cavities 5 are arranged in the closed cavity freely.

Embodiment Six

[0030] Referring to Fig. 5, a composite sound-absorbing device with built-in resonant cavity is provided. The device comprises a closed cavity formed by a perforated board 1 made of copper, a back board 2 made of stainless steel and side boards 3 made of stainless steel, with the depth D of the closed cavity being 40mm. The perforated board 1 is a square board with a side length of 80mm and a thickness of 1mm. On the perforated board 1, first pores 6, with a diameter of 3mm, are provided. The perforation rate σ of the first pores 6 is 28%. The first pores 6 are arranged regularly in a pattern of square on the perforated board 1. In the closed cavity, four resonant cavities 5 made of copper and having a shape of sphere are provided, whose volume is $1.4 \times 10^4 \text{ mm}^3$ and whose wall has a thickness of 5mm. On the wall of the resonant cavities 5, two second pores 6', with a diameter d' of 5mm, are provided. The second pores 6' are evenly distributed on the circumference of a hemisphere. The perforation rate of the second pores 6' σ' is 1.4%. Every two resonant cavities 5 form a group and are connected with two second pores 6' on two resonant cavities through tubes 4 and the other second pores 6' are connected with the closed cavity, as shown in Fig. 5. The tubes 4 are made of steel and have a length of 5mm and a diameter of 5mm. The tubes 4 and the perforated board 1 are connected by splicing, threaded connection or injection molding and the resonant cavities are connected with the tube 4 by welding or threaded connection. The resonant cavities 5 are arranged in the closed cavity freely.

Embodiment Seven

[0031] Referring to Fig. 3 and Fig. 6, a composite sound-absorbing device with built-in resonant cavity is provided. The device comprises a closed cavity formed by a perforated board 1 made of plastic, a back board 2 made of stainless steel and side boards 3 made of stainless steel, with a depth D of 200mm. The perforated board 1 is a square board with a side length of 1000mm and has a thickness of 2mm. On the perforated board 1, first pores 6, with a diameter of 2mm, are provided. The perforation rate of the first pores is 0.031 %. The first pores 6 are arranged regularly in a pattern of square on the perforated board 1. In the closed cavity, one hundred resonant cavities 5, which is in a shape of sphere and made of plastic and having a volume V of $2.7 \times 10^5 \text{ mm}^3$,

are arranged. The thickness of the wall of the resonant cavities 5 is 10mm. On the wall of each of the resonant cavities 5, two second pores 6', with a diameter d' of 2mm, are provided. The second pores 6' are evenly distributed on the circumference of a hemisphere. The perforation rate σ' of the second pores 6' is 0.03%. One second pore 6' of each resonant cavity 5 is connected with the closed cavity and the other second pore 6' is connected with a tube 4 whose other end is connected with a first pore 6 on the perforated board 1. The tubes 4 are made of rubber and have a length of 100mm and a diameter of 2mm. The perforated board 1 is connected with the tubes 4 by using a first transit joint 7 and the resonant cavities 5 are connected with the tubes by using a second transit joint 7'.

Embodiment Eight

[0032] Referring to Fig.7, a composite sound-absorbing device with built-in resonant cavity is provided. The device comprises a closed cavity formed by a perforated board 1 made of plastic, a back board 2 made of stainless steel and side boards 3 made of stainless steel, with a depth D of 200mm. The perforated board 1 is a square board with a side length of 1000mm and a thickness of 2mm. On the perforated board 1, first pores 6, with a diameter of 2mm, are provided. The perforation rate of the first pores 6 is 0.031%. The first pores 6 are arranged regularly in a pattern of square on the perforated board 1. In the closed cavity, one hundred resonant cavities 5, which are in a shape of sphere and made of plastic and have a volume V of $2.7 \times 10^5 \text{ mm}^3$, are arranged. The thickness of the wall of the resonant cavities 5 is 2mm. On the wall of each of the resonant cavities 5, two second pores 6', one of which has a diameter d' of 3mm and the other has a diameter d' of 1 mm, are not evenly distributed on the circumference of a hemisphere. The perforation rate σ' of the second pores 6' is 0.039%. The resonant cavities 5 are arranged in the closed cavity freely.

Embodiment Nine

[0033] Referring to Fig. 8, a composite sound-absorbing device with built-in resonant cavity is provided. The device comprises a closed cavity formed by a perforated board 1 made of copper, a back board 2 made of stainless steel and side boards 3 made of stainless steel, with the depth D of the closed cavity being 40mm. The perforated board 1 is a square board with a side length of 80mm and a thickness of 1mm. On the perforated board 1, first pores 6, with a diameter of 3mm, are provided. The perforation rate of the first pores 6 is 28%. The first pores 6 are arranged regularly in a pattern of square on the perforated board 1. In the closed cavity, four resonant cavities 5, which are in a shape of sphere and made of plastic, are arranged. On the wall of each of the resonant cavities 5, three second pores 6' are provided, which are evenly distributed on the circumference of a hemisphere. The

thickness of the wall of the resonant cavities 5 is 1 mm. Two resonant cavities 5 have a volume of $3.3 \times 10^4 \text{ mm}^3$ and the diameter of the second pores 6' thereon is 2mm and the perforation rate of the second pores 6' thereon is 0.19%, and the other two resonant cavities 5 have a volume of $8.3 \times 10^3 \text{ mm}^3$ and the diameter of the second pores 6' thereon is 1 mm and the perforation rate of the second pores 6' thereon is 0.12%. The resonant cavities 5 are arranged in the closed cavity freely.

Embodiment Ten

[0034] Referring to Fig. 8, a composite sound-absorbing device with built-in resonant cavity is provided. The device comprises a closed cavity, formed by a perforated board 1 made of copper, a back board 2 made of stainless steel and side boards 3 made of stainless steel, with the depth D of the closed cavity being 40mm. The perforated board 1 is a square board with a side length of 80mm and a thickness of 1mm. On the perforated board 1, first pores 6, with a diameter of 3mm, are provided. The perforation rate of the first pores 6 is 28%. The first pores 6 are arranged regularly in a pattern of square on the perforated board 1. In the closed cavity, four resonant cavities 5 made of plastic are arranged, wherein the thickness of the wall thereof is 0.5mm. On the wall of each of the resonant cavities 5, one second pore 6' is provided. Among the four resonant cavities 5, two are ellipsoid having a volume of $3.3 \times 10^4 \text{ mm}^3$ and the diameter of the second pores 6' on them is 2mm and the perforation rate of the second pores 6' is 0.063%, the other two are cubic having a volume of $6.4 \times 10^4 \text{ mm}^3$ and the diameter of the second pores 6' on them is 2mm and the perforation rate of the second pores 6' is 0.03%. The resonant cavities 5 are arranged in the closed cavity freely.

Embodiment Eleven

[0035] Referring to Fig. 10, a composite sound-absorbing device with built-in resonant cavity is provided. The device comprises a closed cavity formed by a perforated board 1, a back board 2 and side boards 3 all made up of stainless steel, with the depth D of the closed cavity being 40mm. The perforated board 1 is a square board with a side length of 80mm and a thickness of 5mm. On the perforated board 1, first pores 6, with a diameter of 3mm, are provided. The perforation rate of the first pores 6 is 28%. The first pores 6 are arranged regularly in a pattern of square on the perforated board 1. In the closed cavity, four resonant cavities 5 made of plastic are provided, wherein the resonant cavities 5 are in shape of a sphere with a volume of 942 mm^3 and the thickness of the wall of the resonant cavities 5 is 1 mm. On the wall of each of the resonant cavities 5, one second pore 6', with a diameter of 2mm, is provided. The perforation rate σ' of the second pores 6' is 0.7%. Furthermore, partition boards are installed inside the closed cavity, thereby separately fixing the four resonant cavities 5.

Embodiment Twelve

[0036] Referring to Fig. 11, a composite sound-absorbing device with built-in resonant cavity is provided. The device comprises a closed cavity formed by a perforated board 1, a back board 2 and side boards 3 all made up of stainless steel, with the depth D of the closed cavity being 50mm. The perforated board 1 is a round board with a diameter of 100mm and a thickness of 0.7mm. On the perforated board 1, first pores 6, with a diameter of 1.1mm, are provided. The perforation rate of the first pores 6 is 1.9%. The first pores 6 are arranged regularly in a pattern of square on the perforated board 1. In the closed cavity, four resonant cavities 5 made of plastic are provided, wherein the resonant cavities 5 are in shape of a sphere having a volume of $3.35 \times 10^4 \text{ mm}^3$ and the thickness of the wall thereof is 0.4mm. Moreover, there are twenty-six second pores 6', with a diameter of 0.5mm, on the wall of the resonant cavities 5, evenly distributed on the circumferences of three mutually perpendicular hemispheres (There are 16 second pores on each hemispherical circumference, with 4 second pores overlapping for every two circumferences). The perforation rate σ' of the second pores 6' is 0.1 %. The resonant cavities 5 are arranged freely in the closed cavity. Each of the first pores 6 on the perforated board 1 is connected with a stainless steel tube 4, which is 8.5mm long and has a diameter of 1.1 mm. The tubes 4 are welded on the first pores 6 of the perforated board 1.

[0037] A comparison experiment is conducted to verify the sound muffling mechanism of low and medium frequency sound of the composite sound-absorbing device according to the present invention and the perforated board with tubes by using a standing wave meter. In the experiment, the low and medium sound absorption coefficient of the perforated board, the perforated board with tubes and the composite sound-absorbing device with built-in cavities are measured respectively to determine the effect of resonant cavities provided in the perforated board sound-absorbing structure. The other parameters of the resonant sound-absorbing structure are listed as follows:

Parameters of the perforated board: the pores are arranged in a pattern of square, with the diameter of the pores being 1.7mm, the center to center spacing of the pores being 7mm, the thickness of the wall of the perforated board being 0.7mm and the depth of the cavity being 50mm.

Parameters of the perforated board with tubes: the pores are arranged in a pattern of square, with the diameter of the pores being 1.1mm, the center to center spacing of the pores being 7mm, the thickness of the wall of the perforated board being 0.7mm, the length of the tubes being 8.5mm and the diameter of the tubes being 1.1 mm. The tubes are welded on the pores on the perforated board. The depth of the cavity is 50mm.

[0038] As shown in Fig. 15, in comparison with the perforated board, the main resonance frequency band of the perforated board sound-absorbing structure with tubes and the composite sound-absorbing device according to the present invention tend to move towards low frequency and their average sound absorption coefficient is greater. In comparison with the perforated board sound-absorbing structure with tubes, the sound-absorbing formant of the composite sound-absorbing device according to the present invention is much higher and its frequency band is wider.

Embodiment Thirteen

[0039] Referring to Fig. 12, a composite sound-absorbing device with built-in resonant cavity is provided. The device comprises a closed cavity formed by a perforated board 1, a back board 2 and side boards 3 all made up of stainless steel, with the depth D of the closed cavity being 300mm. The perforated board 1 is a round stainless steel board and the diameter of the board is 100mm, with a thickness of 0.8mm. On the perforated board 1, first pores 6, with a diameter of 1.1mm, are provided. The perforation rate of the first pores 6 is 1.9%. The first pores 6 are arranged regularly in a pattern of square on the perforated board 1. In the closed cavity, four resonant cavities 5, made of plastic and being in a shape of sphere and having a volume of $3.35 \times 10^4 \text{ mm}^3$, are arranged. The thickness of the wall of the resonant cavities 5 is 0.4mm. Six second pores 6' are arranged on the wall of the resonant cavities 5, evenly distributed on the circumferences of three mutually perpendicular hemispheres. The diameter of the second pores 6' is 0.5mm and the perforation rate σ' of the second pores 6' is 0.023%. The resonant cavities 5 are arranged in the closed cavity freely. Furthermore, the back side of the perforated board 1 is covered with a layer of porous sound-absorbing material, the thickness of the layer being 0.5mm, 5mm, 30mm, 100mm or 200mm and the porous sound-absorbing material being glass wool, foamed aluminum, foamed plastic, slag wool or cotton fiber.

[0040] To conclude, the composite sound-absorbing device with built-in resonant cavity according to the present invention makes full use of the acoustic scattering on the surface of the resonant cavity, acoustic impedance of the second pores on the resonant cavity and the modulation to the sound-absorbing formant and sound-absorbing frequency band by resonant cavities' coupling and etc., to absorb sound, wherein its sound-absorbing frequency band is wider, sound absorption coefficient is bigger and so the absorption effect of low and medium frequency noise is improved, when compared with conventional perforated board resonant sound-absorbing structure. Moreover, the present device is compact, economical and practical. It is clear from the above comparison experiments that the sound-absorbing effect of the present device is obviously superior to the perforated board resonant sound-absorbing device and as the

number of the resonant cavities increases, the sound frequency band becomes wider and the formant of major sound-absorbing frequency becomes higher and gradually evolves into two formants, which is similar to the double layer microperforated board sound-absorbing structure. The number of resonant cavities and the pores on the resonant cavities is crucial to the present device, and if the number of the resonant cavities is not enough, the sound-absorbing effect would be greatly reduced.

[0041] It should be noted that the present invention is not necessarily limited to the foregoing embodiments, which can be further modified in various ways within the scope of the invention as defined in the appended claim.

Claims

1. A composite sound-absorbing device with built-in resonant cavity, including:

a perforated board having a number of first pores thereon, a back board and side boards, said perforated board, back board and side boards forming a closed cavity, wherein: at least one or more of said resonant cavities being located within said closed cavity; at least one or more of second pores being located on said resonant cavities; and at least one of said second pores being connected with said closed cavity; said resonant cavity having a volume of $V=10 \text{ mm}^3 \text{—} 1 \times 10^{10} \text{ mm}^3$, the thickness of the wall thereof being 0.05mm-10mm; said second pores having an aperture of $d'=0.05\text{-}100 \text{ mm}$, with a perforation rate $\sigma'=0.01 \text{ \%}-30 \text{ \%}$.

2. The composite sound-absorbing device of claim 1, wherein the number of said resonant cavities is more than one, which are arranged within said closed cavity directly or fixed separately within said closed cavity partitioned by a number of partition boards.
3. The composite sound-absorbing device of claim 1, wherein said resonant cavity is in shape of sphere, ellipsoid or polyhedron.
4. The composite sound-absorbing device of claim 1, wherein said second pores are connected to said closed cavity directly.
5. The composite sound-absorbing device of claim 1, wherein said second pores are connected to said closed cavity via tubes.
6. The composite sound-absorbing device of claim 1, wherein said first or second pores are connected to one end of said tubes and said tubes are located within said closed cavity for increasing acoustical impedance.

7. The composite sound-absorbing device of claim 6, wherein the other ends of said tubes on said second pores are connected to said closed cavity, said second pores on another resonant cavity or said first pores on said perforated board. 5
8. The composite sound-absorbing device of claim 6, wherein said tubes are made of metal, glass, plastic or rubber, with a length of 1-5000mm and diameter of 0.1-100mm; 10
when said tubes are made of rubber, they are connected to said first pores or second pores via binding, or they are connected to said first pores via a first transition joint at the ends of said tubes, or they are connected to said second pores via a second transition joint at the ends of said tubes; 15
when said tubes are made of metal, glass or plastic, they are connected to said first pores or second pores via binding, welding, thread connection or injection, or they are connected to said first pores via a first transition joint at the ends of said tubes, or they are connected to said second pores via a second transition joint at the ends of said tubes. 20
9. The composite sound absorptive device of claim 1, 25
wherein said perforated board has a thickness of 0.5-10mm, the diameter of said first pores on said perforated board d being 0.1-5mm, with a perforation rate σ of 0.1%-30%; said closed cavity having a depth of $D=10-2000\text{mm}$, and said closed cavity having a shape of cylinder composed by one side board or polyhedron composed by a plurality of side boards; 30
said first pores on said perforated board are arranged in a shape of regular triangle or square or are arranged irregularly. 35
10. The composite sound-absorbing device of claim 1, wherein the back side of said perforated board is coated with a layer of porous sound-absorbing material, said layer of porous sound-absorbing material being located within said closed cavity, with a thickness of 0.1mm-200mm. 40

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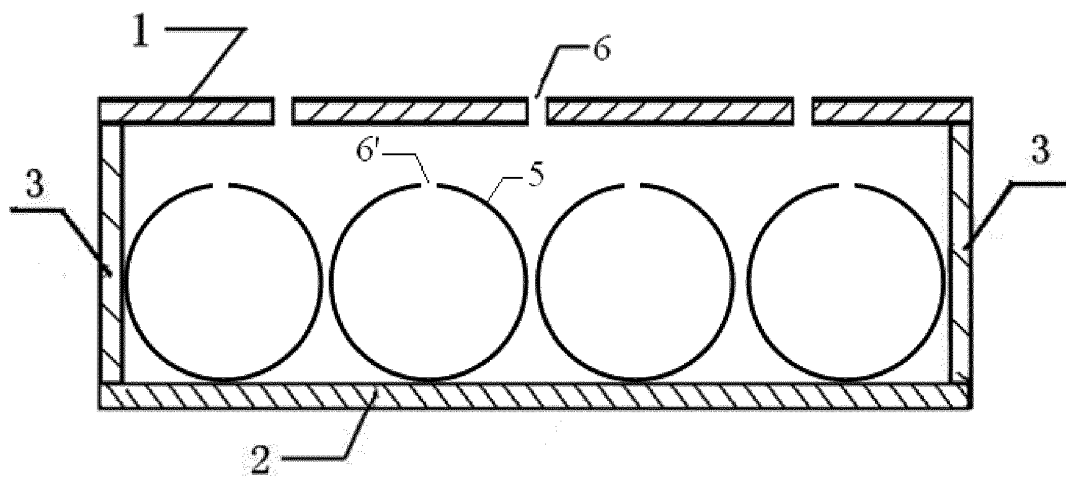


Fig.1

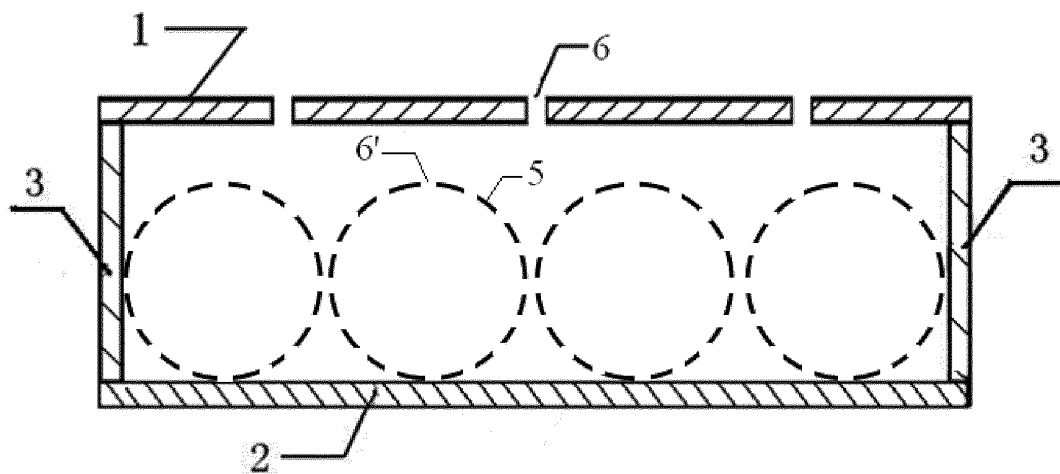


Fig.2

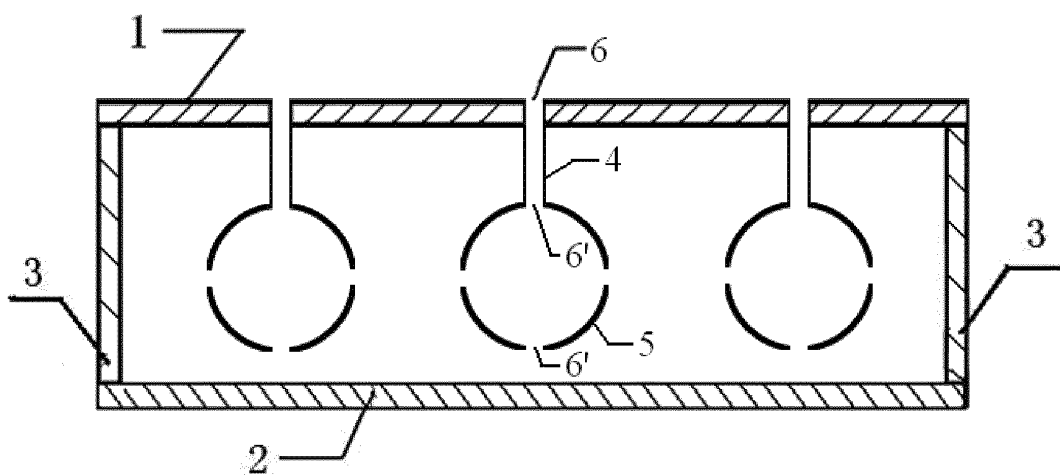


Fig.3

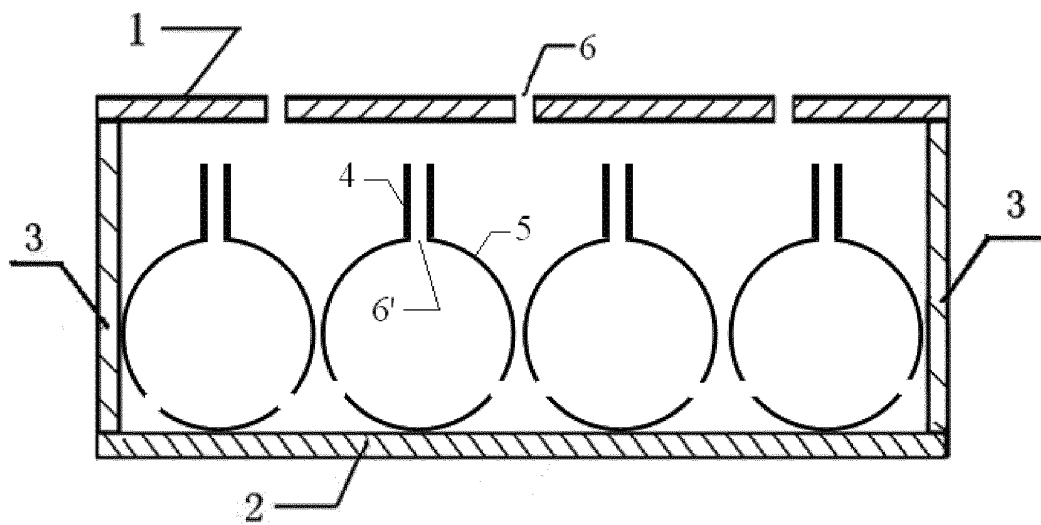


Fig. 4

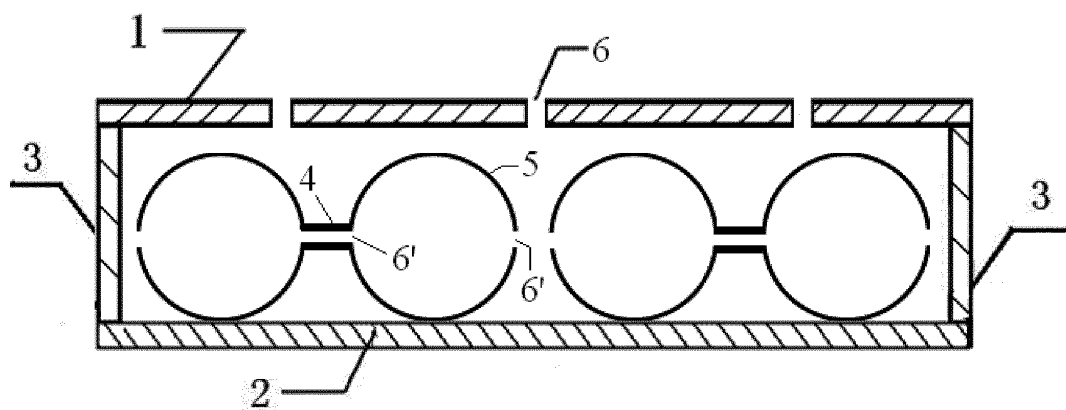


Fig. 5

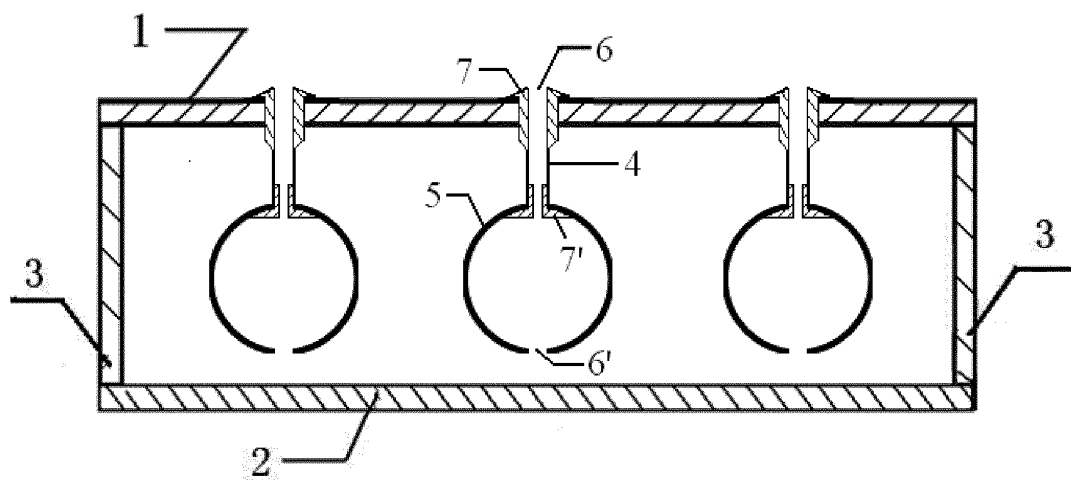


Fig. 6

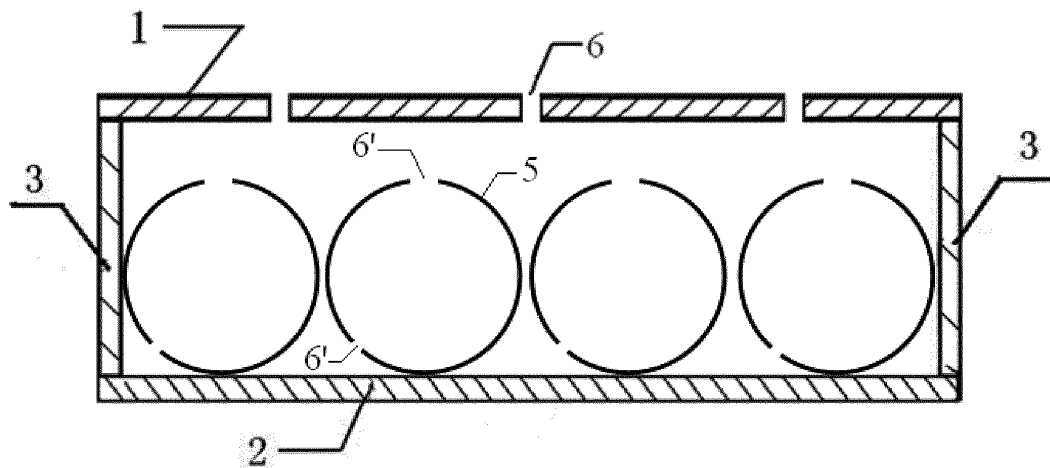


Fig.7

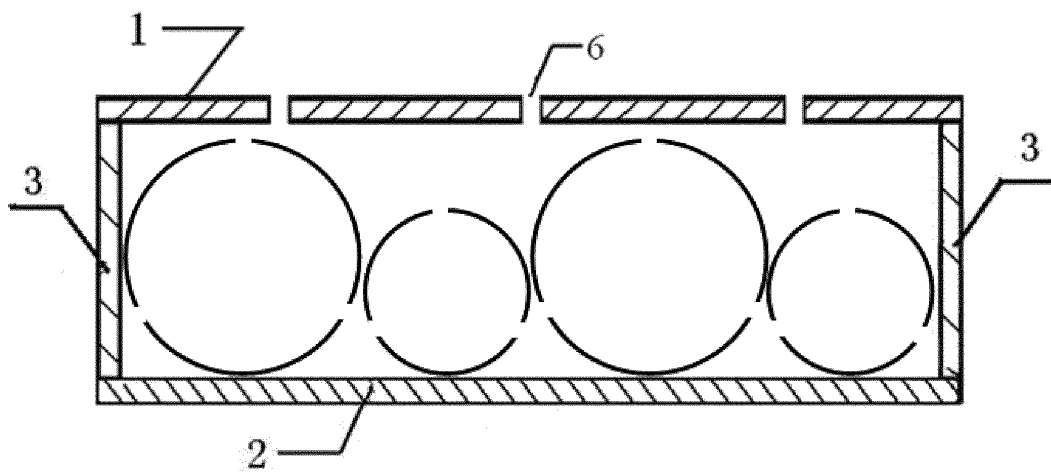


Fig.8

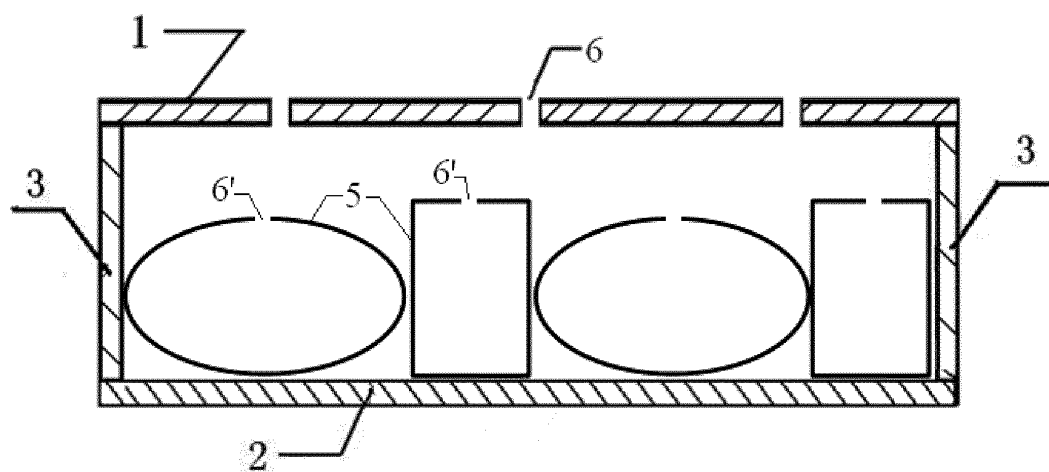


Fig.9

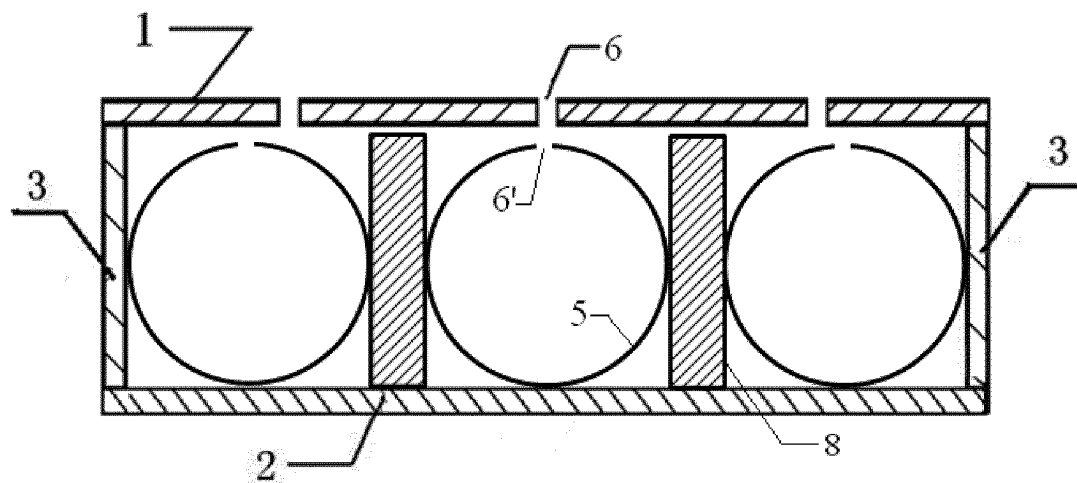


Fig. 10

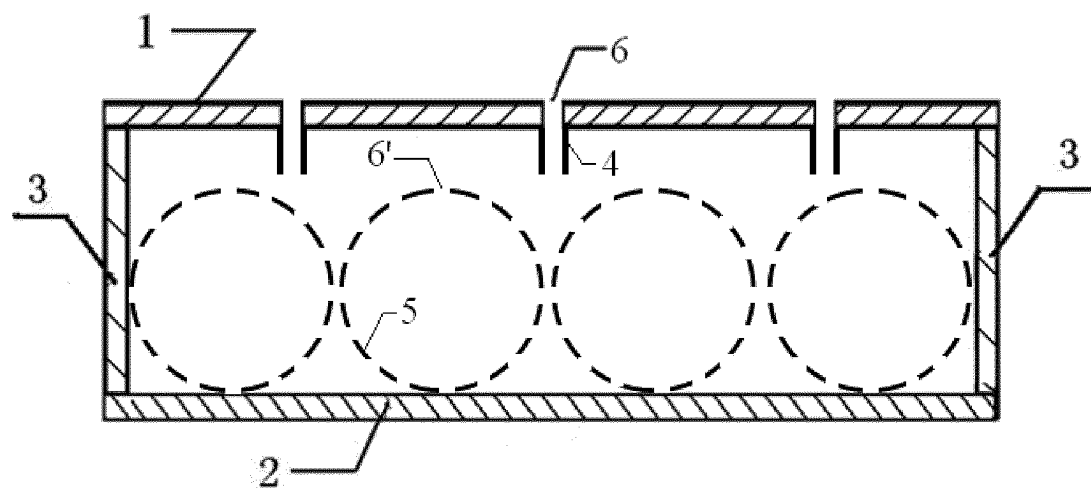


Fig. 11

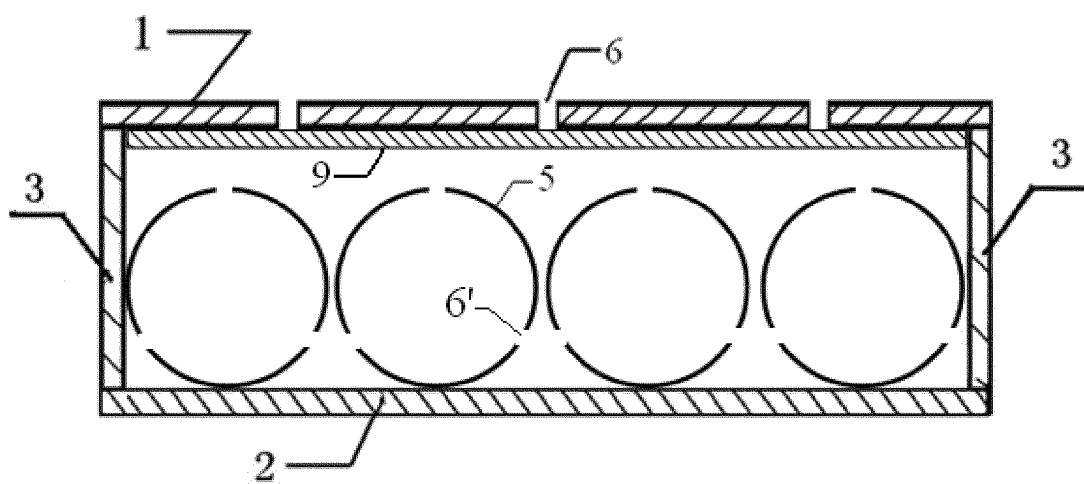


Fig. 12

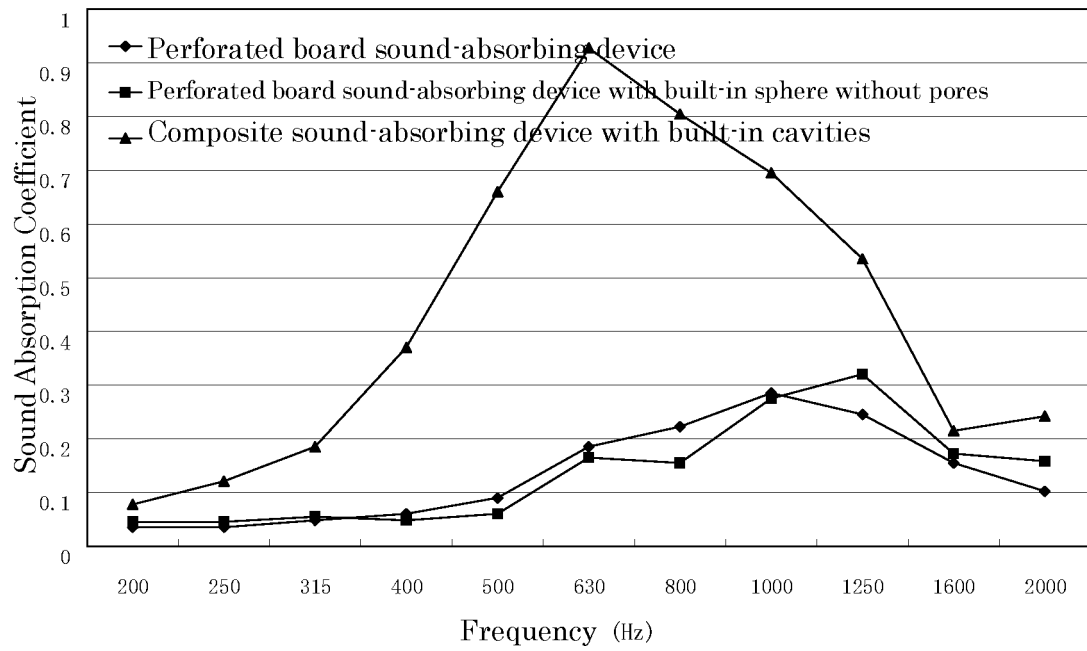


Fig. 13

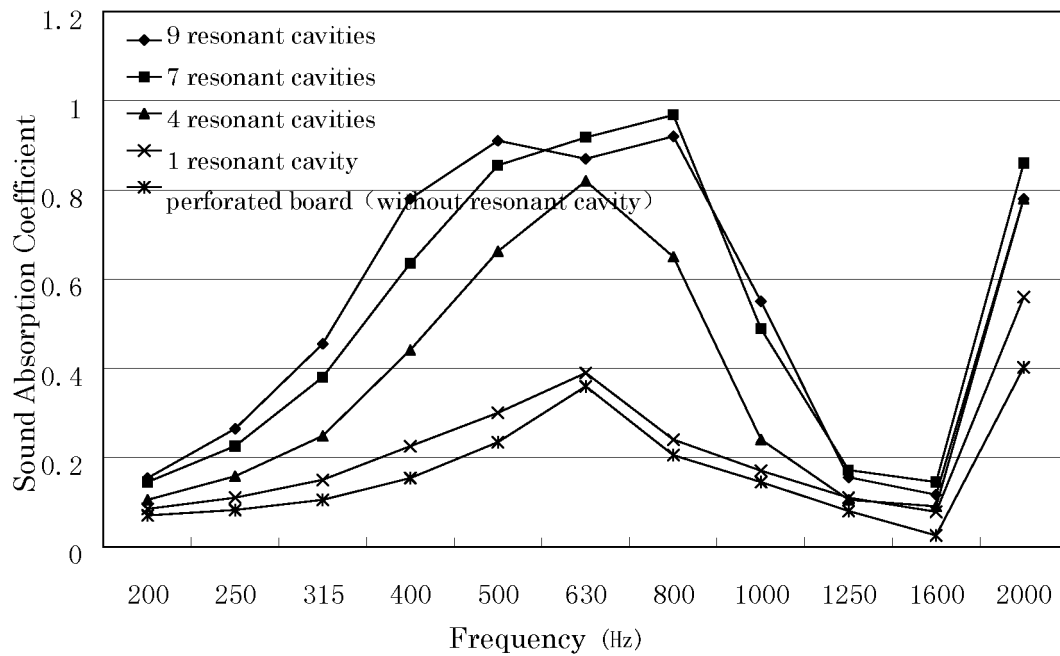


Fig. 14

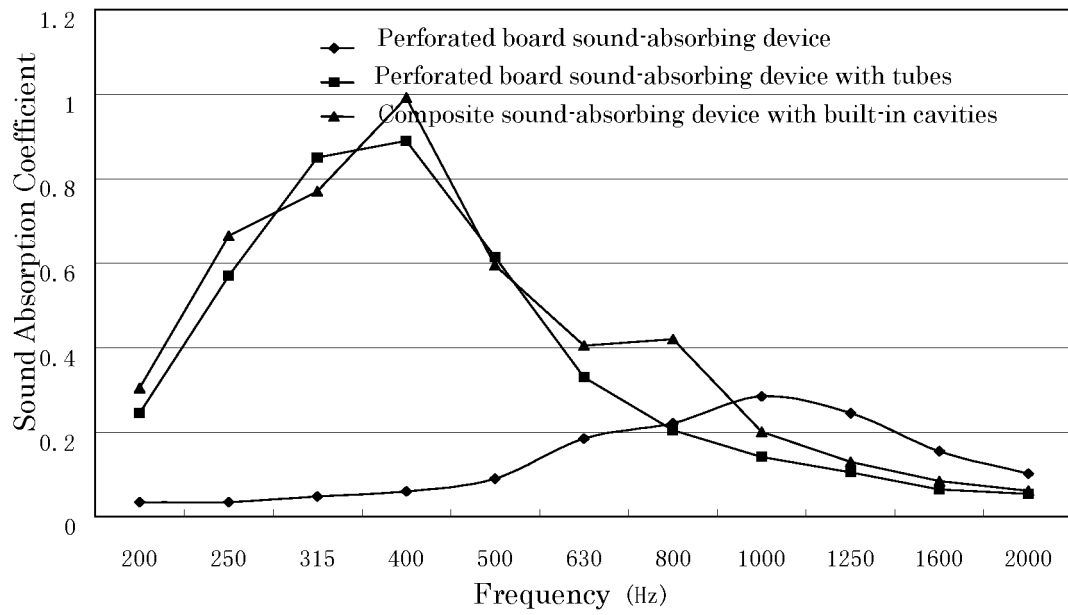


Fig. 15

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2010/001613

A. CLASSIFICATION OF SUBJECT MATTER

See extra sheet

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: G10K 11; E04B 1; E01B 19; F01N 1

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

CPRS, CNKI, EPODOC, WPI: resona+, synton+, hole?, howe?, aperture?, bore?, porous+, plate?, board?, panel?

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
PX	CN 101727894 A (INSTITUTE OF ACOUSTICS, CHINESE ACADEMY OF SCIENCES) 09 Jun.2010 (09.06.2010), see claims 1-10	1-10
X	US 3819007 A (LOCKHEED AIRCRAFT CORP.) 25 Jun.1974 (25.06.1974), see column 2 lines 4-50, column 6 lines 55-58 of the description, figs.1-3	1-4, 6, 8-10
X	JP 2008-9014 A (KOBE STEEL LTD.) 17 Jan.2008 (17.01.2008), see paragraphs [0036]-[0063], figs.1-8	1-4, 6, 8-10
X	CN 101139851 A (ZHANG, Rongchu) 12 Mar.2008(12.03.2008), see page 3 paragraphs 1-5, figs.1-2	1-4, 6, 8-10
X	US 3734234 A (LOCKHEED AIRCRAFT CORP.) 22 May 1973 (22.05.1973), see column 5 line 5 to column 9 line 44 of the description, figs.1-21	1-4, 6, 8-10

☒ Further documents are listed in the continuation of Box C.☒ See patent family annex.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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"E" earlier application or patent but published on or after the international filing date	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L" document which may throw doubts on priority claim (S) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&" document member of the same patent family
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search 20 Dec.2010 (20.12.2010)	Date of mailing of the international search report 20 Jan. 2011 (20.01.2011)
Name and mailing address of the ISA/CN The State Intellectual Property Office, the P.R.China 6 Xitucheng Rd., Jimen Bridge, Haidian District, Beijing, China 100088 Facsimile No. 86-10-62019451	Authorized officer YANG, Shilin Telephone No. (86-10)62085717

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2010/001613

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB 1470036 A (LOCKHEED AIRCRAFT CORP.) 14 Apr.1977 (14.04.1977), see page 4 left column line 2 to page 5 right column line 93 of the description, figs.1-6	1-4, 6, 8-10
A	CN 101003989 A (CHEN, Jixuan) 25 Jul.2007 (25.07.2007), see the whole document	1-10
A	CN 201199437 Y (BEIJING GREENTEC ENGINEERING H) 25 Feb.2009 (25.02.2009), see the whole document	1-10

Form PCT/ISA /210 (continuation of second sheet) (July 2009)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2010/001613

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CN 101003989 A	25.07.2007	None	
CN 201199437 Y	25.02.2009	None	

Form PCT/ISA/210 (patent family annex) (July 2009)

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2010/001613

A. CLASSIFICATION OF SUBJECT MATTER

G10K 11/172 (2006.01) i

G10K 11/16 (2006.01) i

E04B 1/84 (2006.01) i

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- CN ZL00100641X [0003]
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Non-patent literature cited in the description

- **DAH-YOU MAA.** Theory and Design of Microperforated board Sound-absorbing Structure. *Science in China*, 1975 [0002]
- Theory of Micro slit Absorbers. *Chinese Journal of Acoustics*, 2000 [0002]