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(54) **LOW-FREQUENCY COUPLING SOUND ABSORBING STRUCTURE**

(57) A low-frequency coupling sound-absorbing structure includes a peripheral chamber, a resonance chamber arranged inside the peripheral chamber, and an extension tube structure arranged inside the resonance chamber, wherein one end of the extension tube structure is connected to a chamber wall of the resonance chamber through a corresponding through hole; and the peripheral chamber includes the micro-perforated plate, the back plate, the first side plate, and the second side plate, wherein the micro-perforated plate is provided with multiple micro-hole structures, the micro-perforated plate is opposite to the back plate, and the first side plate is

opposite to the second side plate. The low-frequency coupling sound-absorbing structure in this application can increase the acoustic impedance of the sound-absorbing structure by providing the resonance chamber with the extension tube structure in the peripheral chamber with the micro-hole structure, which improves the sound-absorption coefficient, widens the sound-absorption frequency band, and shifts the sound-absorption frequency band to the low frequency, thereby realizing low-frequency sound absorption and improving the product performance.

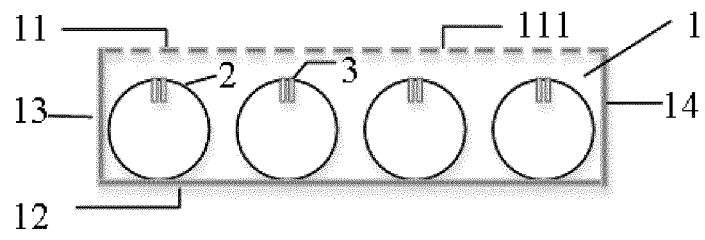


Figure 1

Description

[0001] The present application claims priority to Chinese Patent Application No. 201811359437.9, titled "LOW-FREQUENCY COUPLING SOUND-ABSORBING STRUCTURE", filed with the China National Intellectual Property Administration on November 15, 2018 which is incorporated herein by reference in its entirety.

FIELD

[0002] The embodiments of the present application relate to the technical field of noise reduction, and in particular to a low-frequency coupling sound-absorbing structure.

BACKGROUND

[0003] At present, sound-absorbing materials can be roughly divided into porous sound-absorbing materials and resonance sound-absorbing materials according to the principle of sound absorption, wherein the thin-plate resonance sound-absorbing structure, the thin-film resonance sound-absorbing structure, the micro-perforated-plate resonance sound-absorbing structure, and the micro-perforated-plate and micro-slitted-plate sound-absorbing structure all belong to resonance sound absorption-structure. Compared with the porous sound-absorption materials, the micro-perforated-plate resonance, the micro-perforated-plate sound-absorbing structure, and the double-layer micro-perforated-plate sound-absorbing structure have many advantages in terms of sound-absorption characteristics, flow resistance, moisture resistance, corrosion resistance, sanitation, and so on. However, these structures still cannot meet some practical needs of noise control especially in the occasions where the sound-absorbing space is strictly limited, and can hardly control low-frequency noise.

[0004] Since sound waves with large wavelengths in the low-frequency range cannot be effectively controlled, and low-frequency sound waves are not easily attenuated in the air, have a long propagation distance, and have a large influence range, the thickness of the sound-absorption material or the depth of the chamber of the sound-absorbing structure must be greatly increased to effectively reduce the low-frequency noise according to the prior art, which increases the volume of the sound-absorbing structure and is not conducive to the miniaturization of the product. In addition, the increase in the depth of the chamber of the sound-absorbing structure may further narrow the sound-absorption frequency band to a certain extent, reducing the product performance.

[0005] In view of this, how to provide a low-frequency coupling sound-absorbing structure that solves the above technical problems has become a problem that those skilled in the art need to solve.

SUMMARY

[0006] An object of the embodiments of the present application is to provide a low-frequency coupling sound-absorbing structure, which improves the sound-absorption coefficient, widens the sound-absorption frequency band during usage, and shifts the sound-absorption frequency band to the low frequency, thereby realizing low-frequency sound absorption and improving the product performance.

[0007] To solve the above technical problems, a low-frequency coupling sound-absorbing structure is provided according to the embodiments of the present application, which includes:

a peripheral chamber, a resonance chamber arranged inside the peripheral chamber, and an extension tube structure arranged inside the resonance chamber, wherein one end of the extension tube structure is connected to a chamber wall of the resonance chamber through a corresponding through hole; and

the peripheral chamber includes a micro-perforated plate, a back plate, a first side plate, and a second side plate, wherein the micro-perforated plate is provided with multiple micro-hole structures, the micro-perforated plate is opposite to the back plate, and the first side plate is opposite to the second side plate.

[0008] Optionally, multiple resonance chambers are provided, and each of the resonance chambers is arranged on the back plate.

[0009] Optionally, the extension tube structures on the resonance chambers direct toward the same direction.

[0010] Optionally, the extension tube structure on each of the resonance chamber includes multiple extension tubes.

[0011] Optionally, lengths of the extension tube structures on the resonance chambers are different.

[0012] Optionally, the low-frequency coupling sound-absorbing structure further includes an isolation layer arranged between two adjacent resonance chambers.

[0013] Optionally, the isolation layer is made of melamine foam.

[0014] Optionally, the isolation layer is made of metal.

[0015] Optionally, the resonance chamber is spherical.

[0016] Optionally, the parameters of the low-frequency coupling sound-absorbing structure are set according to a preset method. The preset method includes:

establishing an objective function according to parameters of the low-frequency coupling sound-absorbing structure;

optimizing the objective function by a simulated annealing optimization algorithm to obtain an optimal solution of the objective function; and

taking each element in the optimal solution as the corresponding parameter.

[0017] The low-frequency coupling sound-absorbing structure provided by the embodiments of the present application includes the peripheral chamber, the resonance chamber arranged inside the peripheral chamber, and the extension tube structure arranged inside the resonance chamber, wherein one end of the extension tube structure is connected to the chamber wall of the resonance chamber through the corresponding through hole; and the peripheral chamber includes the micro-perforated plate, the back plate, the first side plate, and the second side plate, wherein the micro-perforated plate is provided with multiple micro-hole structures, the micro-perforated plate is opposite to the back plate, and the first side plate is opposite to the second side plate.

[0018] It can be seen that the low-frequency coupling sound-absorbing structure in this application can increase the acoustic impedance of the sound-absorbing structure by providing the resonance chamber with the extension tube structure in the peripheral chamber with the micro-hole structure, which increases the acoustic impedance of the sound-absorbing structure, improves the sound-absorption coefficient, widens the sound-absorption frequency band, and shifts the sound-absorption frequency band to the low frequency, thereby realizing low-frequency sound absorption and improving the product performance.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] To illustrate the technical solutions in the embodiments of the present application more clearly, drawings required in description of the conventional technology and embodiments will be introduced simply in the following. It is obvious that the drawings in the following description are only some embodiments of the present application, and other drawings may be obtained by those skilled in the art based on the drawings without creative efforts.

Figure 1 is a schematic structural view of a low-frequency coupling sound-absorbing structure according to a first embodiment of the present application;

Figure 2 is a schematic structural view of the low-frequency coupling sound-absorbing structure according to a second embodiment of the present application;

Figure 3 is a schematic structural view of the low-frequency coupling sound-absorbing structure according to a third embodiment of the present application;

Figure 4 is a schematic structural view of the low-frequency coupling sound-absorbing structure according to a fourth embodiment of the present application;

Figure 5 is a schematic structural view of the low-frequency coupling sound-absorbing structure according to a fifth embodiment of the present application;

Figure 6 is a schematic flowchart of a simulated annealing optimization algorithm according to an embodiment of the present application;

Figure 7 is a curve diagram of frequency - sound-absorption coefficient corresponding to a conventional micro-perforated plate sound-absorbing structure and the low-frequency coupling sound-absorbing structure provided by an embodiment of the present application;

Figure 8 is a curve diagram of frequency - sound-absorption coefficient corresponding to the conventional micro-perforated plate sound-absorbing structure and the low-frequency coupling sound-absorbing structure provided by another embodiment of the present application; and

Figure 9 is a curve diagram of frequency - sound-absorption coefficient corresponding to the low-frequency coupling sound-absorbing structure provided by yet another embodiment of the present application.

DETAILED DESCRIPTION OF EMBODIMENTS

[0020] A low-frequency coupling sound-absorbing structure is provided according to the embodiments of the present application, which improves the sound-absorption coefficient, widens the sound-absorption frequency band during usage, and shifts the sound-absorption frequency band to the low frequency, thereby realizing low-frequency sound absorption and improving the product performance.

[0021] In order to make the objectives, technical solutions and advantages of embodiments of the present application clearer, the technical solutions according to the embodiments of the present application will be described clearly and completely as follows in conjunction with the drawings. It is apparent that the described embodiments are only a few rather than all of the embodiments according to the present application. Based on the embodiments of the present application, all other embodiments, made by those skilled in the art without any creative efforts, fall into the scope of the present application.

[0022] Referring to Figure 1, Figure 1 is a schematic structural view of a low-frequency coupling sound-absorbing structure according to a first embodiment of the present application.

[0023] The low-frequency coupling sound-absorbing structure includes:

a peripheral chamber 1, a resonance chamber 2 arranged inside the peripheral chamber 1, and an extension tube structure 3 arranged inside the resonance chamber 2, wherein one end of the extension tube structure 3 is connected to a chamber wall of the resonance chamber 2 through a corresponding through hole; and

the peripheral chamber 1 includes a micro-perforated plate 11, a back plate 12, a first side plate 13, and a second side plate 14, wherein the micro-perforated plate 11 is provided with multiple micro-hole structures 111, the micro-perforated plate 11 is opposite to the back plate 12, and the first side plate 13 is opposite to the second side plate 14.

[0024] It should be noted that, according to the embodiments of the present application, the acoustic impedance of an empty chamber is optimized by arranging the resonance chamber 2 in the empty chamber surrounded by the peripheral chamber 1 and arranging the extension tube structure 3 on the resonance chamber 2, such that the low-frequency coupling sound-absorbing structure in the present application can realize the absorption of low-frequency sound waves. In the present application, the space behind the micro-perforated plate 11 is fully used, and low-frequency sound waves can be absorbed without increasing the length of the peripheral chamber or the thickness of the material. Specifically, by adjusting parameters such as the tube length, tube diameter, and perforation ratio of the extension tube in the extension tube structure, the acoustic impedance of the sound-absorbing structure in the present application can be increased, the sound-absorption coefficient can be improved, the sound-absorption frequency band can be widened and shifted to the low frequency, thereby realizing low-frequency sound absorption.

[0025] The combination of the resonance chamber 2 and the extension tube structure 3 is referred to as an extension-tube resonance structure. The extension tube structure 3 is provided with an extension tube, and one end of the extension tube passes through the through hole of the resonance chamber 2 and is connected to the chamber wall of the resonance chamber 2. The micro-perforated plate 11, the back plate 12, the first side plate 13 and the second side plate 14 in the embodiments of the present application may all be made of stainless steel, aluminum plate, plastic plate and other materials, which is not particularly limited in the present application. Further, multiple resonance chambers 2 are provided, and each of the resonance chambers 2 is arranged on the back plate 12.

[0026] It is conceivable that, multiple resonance chambers 2 with the extension tube structure 3 are provided in the peripheral chamber 1. As shown in Figures 1 to 3, four resonance chambers 2 are provided, that is, multiple extension-tube resonance structures are provided in the peripheral chamber 1, so that the empty chamber is divided into multiple extension-tube resonance systems to further improve the absorption efficiency for the low frequency sounds. In the embodiments of the present application, the micro-perforated plate 11 and the multiple extension-tube resonance structures together form coupling resonance. From the equivalent circuit of "electricity-force-sound", it can be determined that the arrangement of the micro-perforated plate 11 and the extension-tube resonance structure belongs to series-connection noise reduction, achieving noise reduction with a double-layer structure. The multiple extension tube structures form a parallel resonance circuit. The low-frequency coupling sound-absorbing structure in the embodiments of the present application adopts a composite sound-absorbing structure of parallel-connection and series-connection, thereby realizing the control of wide frequency noise. In addition, specific parameters of the resonance chamber 2 and the extension tube structure 3 in the embodiments of the present application can be set according to the frequency of the noise source, so as to achieve accurate noise reduction.

[0027] Specifically, based on the micro-perforated plate 11 and the extension-tube resonance structure, a sound-

absorbing matching layer of the micro-perforated plate 11 allows medium and low frequency sound waves to enter the extension-tube resonance structure without reflection. Due to the sound scattering by the surface of the resonance chamber 2, sound waves can reach the resonance chamber 2 of each extension tube structure 3, and can push the air column in the extension tube to perform reciprocating vibration, and in the process of reciprocating vibration, low-frequency resonance sound absorption is achieved via viscous damping dissipation. Moreover, the micro-perforated plate 11 and the multiple extension-tube resonance structures further widen the dissipation of medium and high frequency sound waves in the combined structure.

[0028] That is, when the sound wave is radiated into the low-frequency coupling sound-absorbing structure in the present embodiment, the sound wave first reaches the surface of the micro-perforated plate 11, and pushes the air columns in the holes on the peripheral chamber 1 to perform reciprocating vibration. Due to the viscous damping effect of the micro-hole structures 111, part of the sound energy is converted into heat energy and consumed when passing through the micro-hole structures 111. Then, the sound wave continues to propagate along the empty chamber to form sound scattering on the surface of the extension-tube resonance structure, the air column in the extension-tube resonance structure also performs reciprocating vibration under the excitation of the sound wave, and the composite structure can efficiently absorb low-frequency sound waves by optimizing the acoustic impedance of the extension-tube resonance structure.

[0029] Furthermore, the extension tube structures 3 on the resonance chambers 2 direct toward the same direction.

[0030] Specifically, as shown in Figures 1 to 3, the extension tube structures 3 on the resonance chambers 2 of the embodiments direct toward the same direction. Apparently, the specific orientation of the extension tube structure 3 on each resonance chamber 2 can be designed according to the incident direction of sound wave in practical applications, which is not specifically limited in the present application.

[0031] For example, as shown in Figure 1 and Figure 2, the extension tube structures 3 of the resonance chambers 2 right face the through holes of the micro-perforated plate 11. As shown in Figure 3, the extension tube structures 3 of the resonance chambers 2 are parallel to the micro-perforated plate 11.

[0032] Furthermore, the extension tube structure 3 on each resonance chamber 2 includes multiple extension tubes.

[0033] As shown in Figure 1, the extension tube structure 3 on each resonance chamber 2 includes two extension tubes. Each extension tube structure 3 in Figure 2 has different numbers of extension tubes. The extension tube structure 3 in the third resonance chamber 2 includes three extension tubes. The length of the extension tube in each extension tube structure 3 may be identical or not, which can be set according to practical needs.

[0034] Specifically, the diameter of the resonance chamber 2 in the embodiments of the present application may be 60mm, the hole diameter of the extension tube may be 2mm to 8mm, and the perforation ratio of the extension tube may be 1% to 5%. Apparently, specific parameters of the extension tube can be set according to the practical situation, which is not particularly limited in the present application.

[0035] Apparently, lengths of the extension tube structures 3 on the resonance chambers 2 are different. For example, for a sound-absorbing structure including four resonance chambers 2, lengths of the extension tube structures of the first resonance chamber, the second resonance chamber, and the third resonance chamber may be different from each other. Apparently, lengths of the extension tubes in the extension tube structure of a single resonance chamber may be the same or not. As shown in Figure 2, the length of the extension tube structure 3 in the first resonance chamber and the length of the extension tube structure 3 in the third resonance chamber may be 3cm, and the lengths of the extension tube structures 3 in the other two resonance chambers may be 2cm. In practical applications, the length of the extension tube structure should be determined according to the practical situation, and the specific value thereof is not particularly limited in the present application.

[0036] Further, the low-frequency coupling sound-absorbing structure in the embodiments of the present application may further include an isolation layer provided between two adjacent resonance chambers.

[0037] Specifically, in order to further improve the absorption of high-frequency sound waves, the isolation layer in the embodiments of the present application may be made of melamine foam.

[0038] As shown in Figure 4, a melamine foam layer 41 with a thickness of 10mm is provided between two adjacent resonance chambers 2 to separate the two adjacent resonance chambers 2.

[0039] In addition, in order to further improve the absorption efficiency of low-frequency sound waves and effectively absorb irregularly incident sound waves, the isolation layer in the embodiments of the present application may be made of metal to separate the resonance chambers 2 from each other, forming multiple independent working units.

[0040] As shown in Figure 5, a metal partition plate 42 with a thickness of 2mm is provided between two adjacent resonance chambers 2 to separate the two adjacent resonance chambers 2 to form a pair of independent working units. The resonance chamber 2 in each working unit works independently and does not interfere with each other.

[0041] Apparently, the thickness of the isolation layer in the embodiments of the present application can be set according to the practical situation, which is not particularly limited in the present application.

[0042] Further, the resonance chamber 2 is spherical.

[0043] Specifically, the diameter of the resonance chamber 2 may be 60mm, and the thickness of the chamber wall

of the resonance chamber 2 may be 1mm. Apparently, the specific parameters should be set according to the practical situation, which are not particularly limited in the present application.

[0044] Further, the micro-hole structures 11 are uniformly distributed.

[0045] Specifically, the depth of the peripheral chamber 1 (that is, the distance between the micro-perforated plate 11 and the back plate 2) in the embodiments of the present application may be 70mm, the micro-perforated plate 11 may be a square with a side length of 100mm and the thickness of the micro-perforated plate 11 may be 0.5mm to 1mm, the diameter of the micro-hole structure 111 may be 0.4mm to 0.9mm, the perforation ratio of the micro-hole structure 111 is 1% to 4%, and the micro-hole structures 111 on the micro-perforated plate 11 may be distributed uniformly, for example, distributed in a regular square, which is conducive to improving the absorption efficiency of sound waves.

[0046] Furthermore, the parameters of the low-frequency coupling sound-absorbing structure are set according to a preset method. The preset method includes:

establishing an objective function according to parameters of the low-frequency coupling sound-absorbing structure;

optimizing the objective function by a simulated annealing optimization algorithm to obtain an optimal solution of the objective function; and

taking each element in the optimal solution as the corresponding parameter.

[0047] It should be noted that the process of optimizing the objective function by the simulated annealing optimization algorithm is shown in Figure 6, wherein $f(X)$ is the objective function and X is the variable. After the algorithm starts, the initial temperature is set to $T=0$, the initial solution is set to X . During each iteration, a set of possible solutions X' is randomly generated in the current domain X . If the condition $\Delta f = f(X') - f(X) \leq 0$ is met, the new solution X' is accepted as the current solution. Otherwise, if the condition $\Delta f = f(X') - f(X) > 0$ is met, the new solution X' may be accepted as the new current solution with a certain probability $Pb(X') = \exp(-\Delta f / CT) > \varphi$. C and T respectively are the Boltzmann constant and the temperature value of the current iteration, and the $\varphi = rand(0,1)$ is a random number between 0 and 1. That is, if the condition $\Delta f = f(X') - f(X) > 0$ is true, it is judged whether this condition $rand(0,1) \leq \exp(-\Delta f / CT)$ is true, and when it is true, the X' is accepted as the new current solution. In the simulated annealing process, temperature T is an important parameter for controlling iterations to find the optimal solution. If $T = 0$ and $\Delta f = f(X') - f(X) > 0$, then $Pb(X') = \exp(-\Delta f / CT) = 0$, and the probability is always less than φ , so the new solution will never be accepted. If $\Delta f \leq 0$, the new solution X' is always accepted, while $\Delta f > 0$ can prevent the objective function from being limited to the local optimal value. The termination condition of the inner loop of the algorithm is to go through L_P routines of iteration, and after each inner loop ends, it will be accompanied by a cooling process $T_{i+1} = \varepsilon T_i$, where $\varepsilon \in (0,1)$ is a cooling constant, and the termination condition of the algorithm is that the termination temperature T_{min} has been reached and another new solution has not been found through the outer loop after ω_{max} routines of iteration search, thereby finding the optimal solution X of the objective function.

[0048] The low-frequency coupling sound-absorbing structure in the embodiment of the present application is described in detail by way of an example and with reference to Figure 2.

[0049] Parameters of the low-frequency coupling sound-absorbing structure in Figure 2 are optimized by the simulated annealing optimization algorithm shown in Figure 6. First, an objective function corresponding to the parameters of the low-frequency coupling sound-absorbing structure is established, wherein, in the case of normal incidence of the sound wave, the Helmholtz equation of the sound wave propagating inside the low-frequency coupling sound-absorbing structure is established:

$$\Delta p + \omega^2 \frac{\rho_{eq}}{K_{eq}} p = 0, \quad \text{wherein } p \text{ represents the sound pressure on the surface of the structure, } \omega \text{ represents the}$$

angular frequency, ρ_{eq} represents the equivalent density of the structure, and K_{eq} represents the equivalent bulk modulus of the structure.

[0050] According to the sound wave equation, the acoustic impedance Z_{mpp} of a single layer of the micro-hole structure is obtained, $Z_{mpp} = \rho c(r_p + j\omega m_p)$.

$$r_p = \frac{32\eta t}{p\rho c d^2} k_r, \quad k_r = \left(1 + \frac{k^2}{32}\right)^{\frac{1}{2}} + \frac{\sqrt{2}}{8} k \frac{d}{t}; \quad m_p = \frac{t}{pc} k_m, \quad k_m = 1 + \left(9 + \frac{k^2}{2}\right)^{-1/2} + 0.85 \frac{d}{t};$$

wherein, the micro-perforated plate constant is $k = d / 2\sqrt{2\pi f_0 \rho / \eta}$, r represents the relative specific acoustic resistance, m represents the relative acoustic mass, ρc represents the specific acoustic resistance of air, ω represents the angular frequency, t represents the thickness of the micro-perforated plate, d represents the diameter of the perforation, p represents the perforation ratio, and f_0 represents the frequency of the sound wave.

[0051] The sound wave equation inside the extension-tube resonance structure can also be solved, and the surface acoustic resistances of the four extension tube resonators in Figure 2, that is Z_{P1} , Z_{P2} , Z_{P3} , and Z_{P4} , can further be obtained. According to the theory of the equivalent circuit of the parallel structure, the surface specific acoustic resistance of the parallel composite structure of the four extension-tube resonance structures and the surrounding air layer is:

$$Z_p = \left(\frac{\phi_1}{Z_{p1}} + \frac{\phi_2}{Z_{p2}} + \frac{\phi_3}{Z_{p3}} + \frac{\phi_4}{Z_{p4}} + \frac{\phi_5}{Z_{a1}} \right)^{-1}$$

wherein $\phi_1, \phi_2, \phi_3, \phi_4, \phi_5$ represent the ratio of the area occupied by each unit, and Z_{a1} represents the acoustic impedance of the air layer surrounding the extension-tube resonance structure. According to the impedance transfer theory, the impedance transfer value Z_p' from the surface of the extension-tube resonance structure to the surface of the micro-perforated plate can be obtained:

$$Z_p' = Z_a \frac{Z_p + jZ_a \tan(k_a t')}{Z_a + jZ_p \tan(k_a t')}, \text{ where } Z_a = \rho c \text{ represents the characteristic acoustic impedance of the air, } k_a \text{ represents the propagation constant of the sound wave in the air, and } t' \text{ represents the thickness of the air layer between the resonator and the micro-perforated plate.}$$

[0052] Then the total surface specific acoustic resistance of the low-frequency coupling sound-absorbing structure in Figure 2 is $Z = Z_{mpp} + Z_p'$, and the reflection coefficient of the material according to the surface specific acoustic resistance of the material is $R = \frac{Z - \rho c}{Z + \rho c}$.

[0053] Therefore, the sound-absorption coefficient of the low-frequency coupling sound-absorbing structure in Figure 2 is obtained, $\alpha = 1 - |R|^2$, which is the objective function corresponding to the parameters of the low-frequency coupling sound-absorbing structure.

[0054] The sound-absorption coefficient is determined by the parameters of the micro-perforated plate layer, the air layer, and the resonance structure. Combined with the simulated annealing optimization algorithm, the approximate global optimization parameters of the low-frequency coupling sound-absorbing structure can be found, thereby realizing the optimal design of the composite structure. In the low-frequency coupling sound-absorbing structure shown in Figure 2, a sound-absorbing layer of the micro-perforated plate 11 has (d, t, D, p) four parameters (D represents the depth of the peripheral chamber 1, that is, the thickness of the low-frequency coupling sound-absorbing structure), and each extension-tube resonance structure has four variables, and the four extension-tube resonance structures have a total of sixteen variables, so the objective function includes twenty variables. After obtaining the optimal solution of the objective function by the simulated annealing optimization algorithm, the parameters of the variables are determined according to the optimal solution, that is, the specific values corresponding to the parameters are determined, and the low-frequency coupling sound-absorbing structure is configured according to the specific values of the parameters. The objective function in the practical optimization problem is to obtain a set of parameter solutions which maximize the average sound-absorption coefficient of the objective function in the frequency range of 80HZ to 2000Hz:

$$Max: \langle \alpha \rangle = \frac{\sum_{i=1}^N \alpha(f_i, X)}{N}, i = 1, 2, 3, \dots, N$$

[0055] α in the above formula represents the sound-absorption coefficient, $\langle \alpha \rangle$ represents the average sound-absorption coefficient, N represents the number of different sound wave frequencies in the frequency interval to be optimized, i is the subscript of the sound wave frequency, and f_i represents the i th sound wave frequency.

[0056] It should be noted that, other low-frequency coupling sound-absorbing structures in the embodiments of the

present application (as shown in Figures 3 to 5) can also use the above method to calculate the sound-absorption coefficient relationship equation (that is, the objective function) corresponding to each low-frequency coupling sound-absorbing structure, and then optimize the objective function by the simulated annealing optimization algorithm to find out the optimal parameters corresponding to the corresponding low-frequency coupling sound-absorbing structure, and then the low-frequency coupling sound-absorbing structure with the best sound-absorption effect can be obtained.

[0057] It should be further noted that, the above structural parameter optimization algorithm in the embodiments of the present application allows the low-frequency coupling sound-absorbing structure to have a low-frequency broad-band noise reduction effect in the low-frequency band of 80Hz to 2000Hz and realize the efficient reduction of low-frequency broad-band noise of rail transportation equipment and high-speed delivery platforms.

[0058] In addition, with reference to Figures 7 to 9, the curve 61 in Figure 7 represents a frequency - sound-absorption coefficient curve corresponding to a conventional micro-perforated plate sound-absorbing structure, and the curve 62 represents a frequency - sound-absorption coefficient curve corresponding to the low-frequency coupling sound-absorbing structure in an embodiment of the present application, that is, a frequency - sound-absorption coefficient curve corresponding to the sound-absorbing structure with the extension-tube resonance structure provided in the peripheral chamber. As can be seen from Figure 7, under the same limitation of the chamber depth (that is, the depth of the peripheral chamber 1) of 70mm, the sound-absorption coefficient of the conventional micro-perforated plate structure is not greater than 0.15 in the frequency range of 100Hz to 250Hz, and the sound-absorption effect is poor, while the sound-absorption coefficient of the formant of the sound-absorbing structure with the extension-tube resonance structure provided in the peripheral chamber according to the embodiment of the present application reaches 0.91 at 170Hz, and the sound-absorption coefficient keeps beyond 0.5 in the frequency range of 150Hz to 200Hz. Apparently, the sound-absorption effect of the sound-absorbing structure provided in the present application is obviously superior to that of the conventional sound-absorbing structure.

[0059] In addition, the curve 71 in Figure 8 represents a frequency-sound-absorption coefficient curve corresponding to a conventional micro-perforated plate sound-absorbing structure with a chamber depth of 150mm, and the curve 72 represents a frequency-sound-absorption coefficient curve corresponding to the low-frequency coupling sound-absorbing structure with a chamber depth of 150mm according to an embodiment of the present application. As shown in the figure, the sound-absorption effect of the sound-absorbing structure in the embodiment of the present application is obviously superior to that of the conventional sound-absorbing structure, and as can be seen from Figures 7 and 8, the size of the entire sound-absorbing structure in the embodiment of the present application is only 1/28 of the wavelength of the control sound wave.

[0060] When the depth of the chamber of the low-frequency coupling sound-absorbing structure is fixed, the sound-absorption effect varies according to the number of the extension-tube resonance structures inside the low-frequency-coupling sound-absorbing structure. Referring to Figure 9, the curve 81 represents a frequency-sound-absorption coefficient curve corresponding to a sound-absorbing structure with four extension-tube resonance structures provided in the peripheral wall, and the curve 82 represents a frequency-sound-absorption coefficient curve corresponding to a sound-absorbing structure with three extension-tube resonance structures provided in the peripheral wall. Specifically, the chamber depths of the two sound-absorbing structures are both 150mm. As can be seen from Figure 8, the sound-absorption frequency band of the sound-absorbing structure with four extension-tube resonance structures is wider than that of the sound-absorbing structure with three extension-tube resonance structures, and the sound-absorption coefficients at the formants of the sound-absorbing structure with four extension-tube resonance structures all exceed 0.8, which shows that the more the extension-tube resonance structures provided in the peripheral chamber 1, the better the low-frequency and broad-band sound-absorption performance of the entire sound-absorbing structure.

[0061] The low-frequency coupling sound-absorbing structure provided by the embodiments of the present application includes the peripheral chamber, the resonance chamber arranged inside the peripheral chamber, and the extension tube structure arranged inside the resonance chamber, wherein one end of the extension tube structure is connected to the chamber wall of the resonance chamber through the corresponding through hole; and the peripheral chamber includes the micro-perforated plate, the back plate, the first side plate, and the second side plate, wherein the micro-perforated plate is provided with multiple micro-hole structures, the micro-perforated plate is opposite to the back plate, and the first side plate is opposite to the second side plate.

[0062] It can be seen that the low-frequency coupling sound-absorbing structure in the embodiments of the present application can increase the acoustic impedance of the sound-absorbing structure by providing the resonance chamber with the extension tube structure in the peripheral chamber with the micro-hole structure, which increases the acoustic impedance of the sound-absorbing structure, improves the sound-absorption coefficient, widens the sound-absorption frequency band, and shifts the sound-absorption frequency band to the low frequency, thereby realizing low-frequency sound absorption and improving the product performance.

[0063] It should be noted that the relationship terminologies such as "first", "second" and the like are only used herein to distinguish one entity or operation from another, rather than to necessitate or imply that a practical relationship or order exists between the entities or operations. Moreover, terms such as "include", "have" or any other variants thereof

are meant to cover non-exclusive inclusion, so that the process, method, item or apparatus including a series of elements is not limited to those elements, and may include other elements that are not specifically listed or that are inherent in the process, method, item or apparatus. With no other limitations, an element restricted by the phrase "include a ..." does not exclude the existence of other identical elements in the process, method, item or apparatus including the element.

[0064] Based on the above description of the disclosed embodiments, those skilled in the art can implement or deploy the present application. Various modifications to these embodiments are obvious to a person skilled in the art. The general principles defined herein may be implemented in other embodiments without departing from the spirit and scope of the present application. Therefore, the present application is not limited to these embodiments illustrated herein, but should be defined by the broadest scope consistent with the principles and novel features disclosed herein.

Claims

1. A low-frequency coupling sound-absorbing structure, comprising:

a peripheral chamber,
 a resonance chamber arranged inside the peripheral chamber, and
 an extension tube structure arranged inside the resonance chamber, wherein
 one end of the extension tube structure is connected to a chamber wall of the resonance chamber through a
 corresponding through hole; and
 the peripheral chamber comprises a micro-perforated plate, a back plate, a first side plate, and a second side
 plate, wherein the micro-perforated plate is provided with a plurality of micro-hole structures, the micro-perforated
 plate is opposite to the back plate, and the first side plate is opposite to the second side plate.

2. The low-frequency coupling sound-absorbing structure according to claim 1, wherein a plurality of resonance cham-
 bers is provided, and each of the resonance chambers is arranged on the back plate.

3. The low-frequency coupling sound-absorbing structure according to claim 2, wherein the extension tube structures
 on the plurality of resonance chambers direct toward a same direction.

4. The low-frequency coupling sound-absorbing structure according to claim 3, wherein each extension tube structure
 on the corresponding resonance chamber comprises a plurality of extension tubes.

5. The low-frequency coupling sound-absorbing structure according to claim 3, wherein lengths of the extension tube
 structures on the plurality of resonance chambers are different.

6. The low-frequency coupling sound-absorbing structure according to any one of claims 2 to 5, further comprising an
 isolation layer arranged between two adjacent resonance chambers.

7. The low-frequency coupling sound-absorbing structure according to claim 6, wherein the isolation layer is made of
 melamine foam.

8. The low-frequency coupling sound-absorbing structure according to claim 6, wherein the isolation layer is made of
 metal.

9. The low-frequency coupling sound-absorbing structure according to any one of claims 1 to 5, wherein the resonance
 chamber is spherical.

10. The low-frequency coupling sound-absorbing structure according to claim 9, wherein parameters of the low-fre-
 quency coupling sound-absorbing structure are set according to a preset method which comprises:

establishing an objective function according to parameters of the low-frequency coupling sound-absorbing
 structure;
 optimizing the objective function by a simulated annealing optimization algorithm to obtain an optimal solution
 of the objective function; and
 taking each element in the optimal solution as the corresponding parameter.

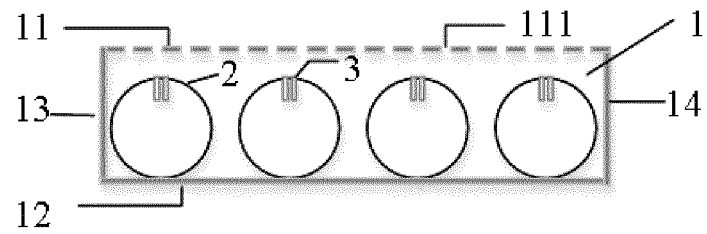


Figure 1

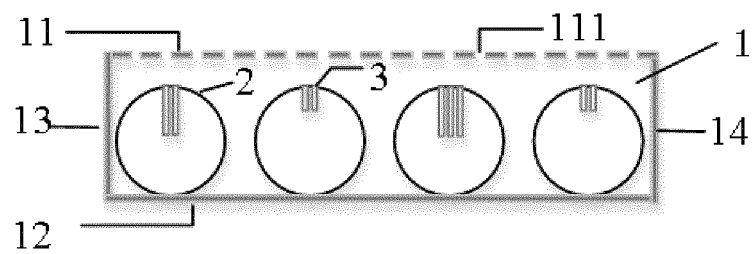


Figure 2

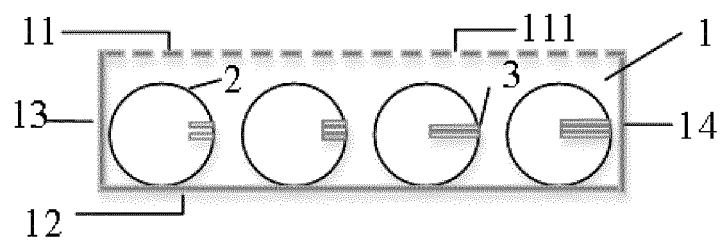


Figure 3

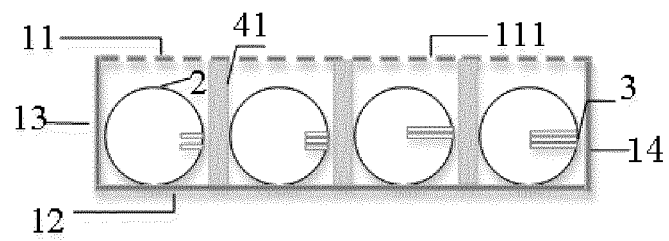


Figure 4

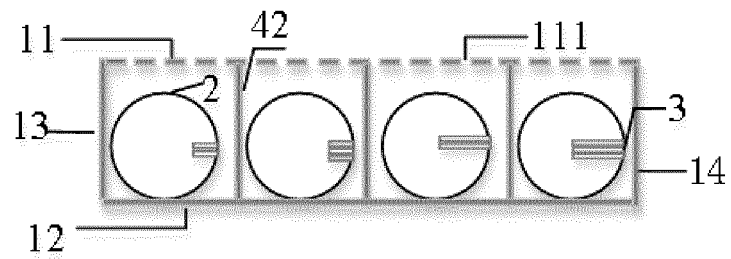
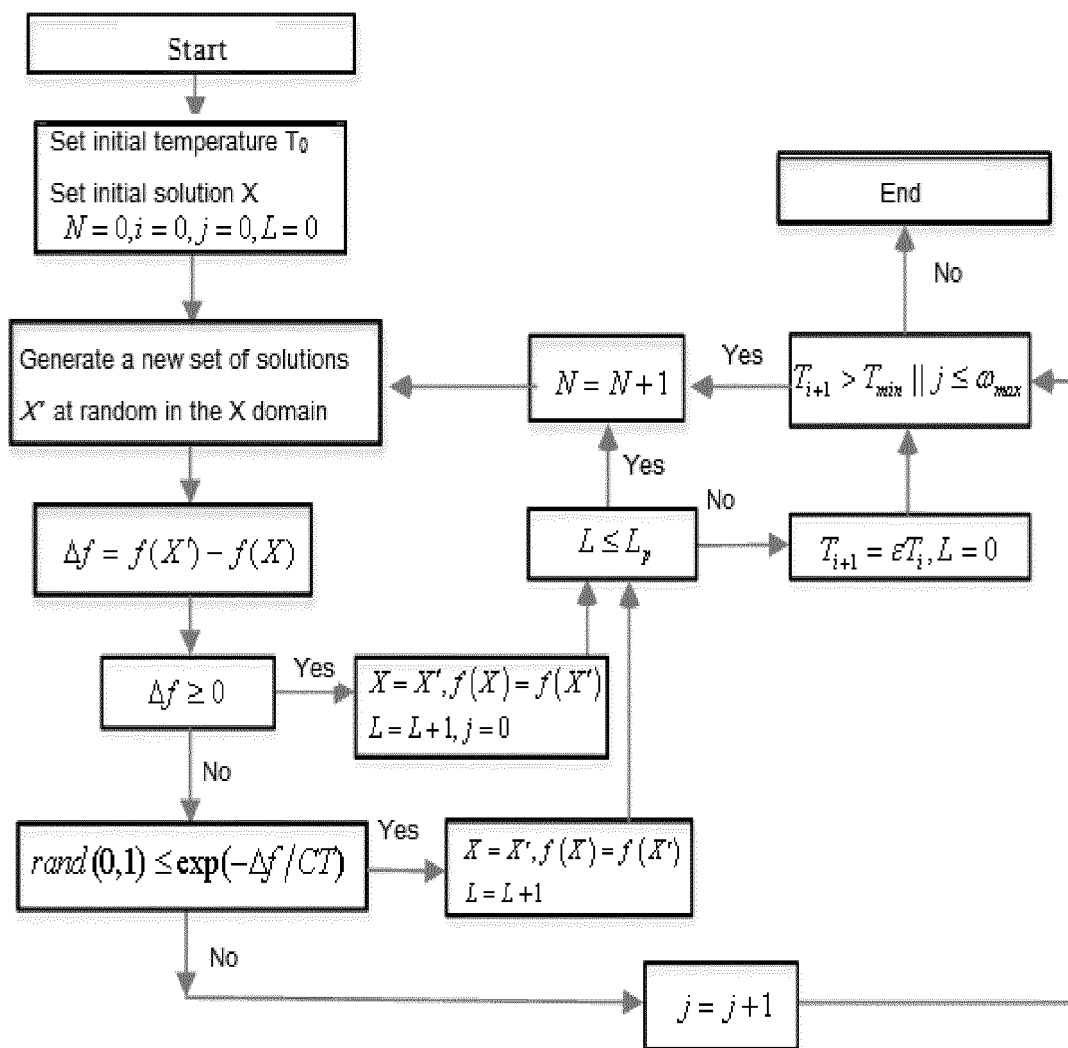


Figure 5

**Figure 6**

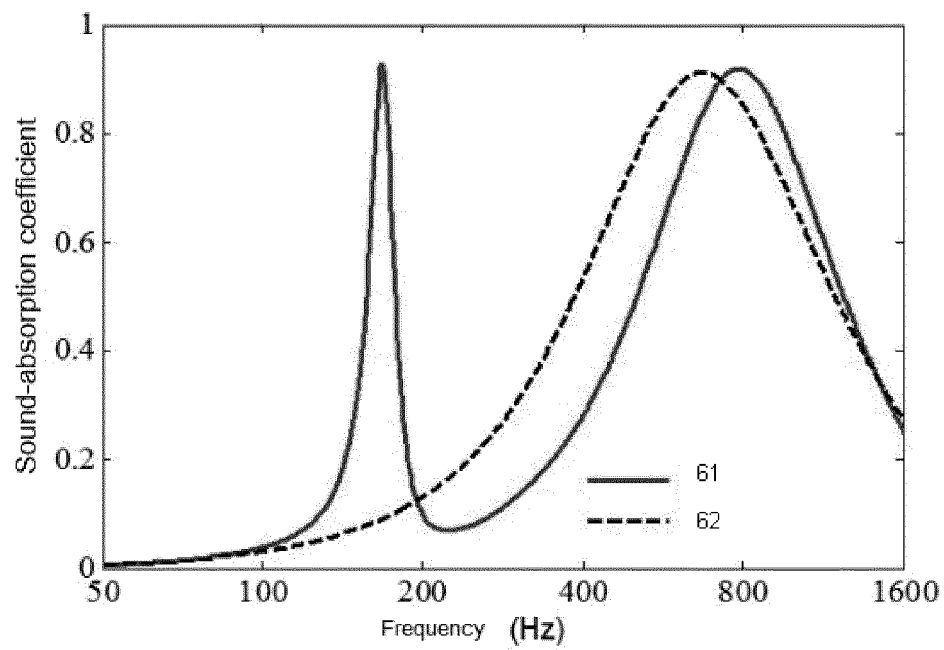


Figure 7

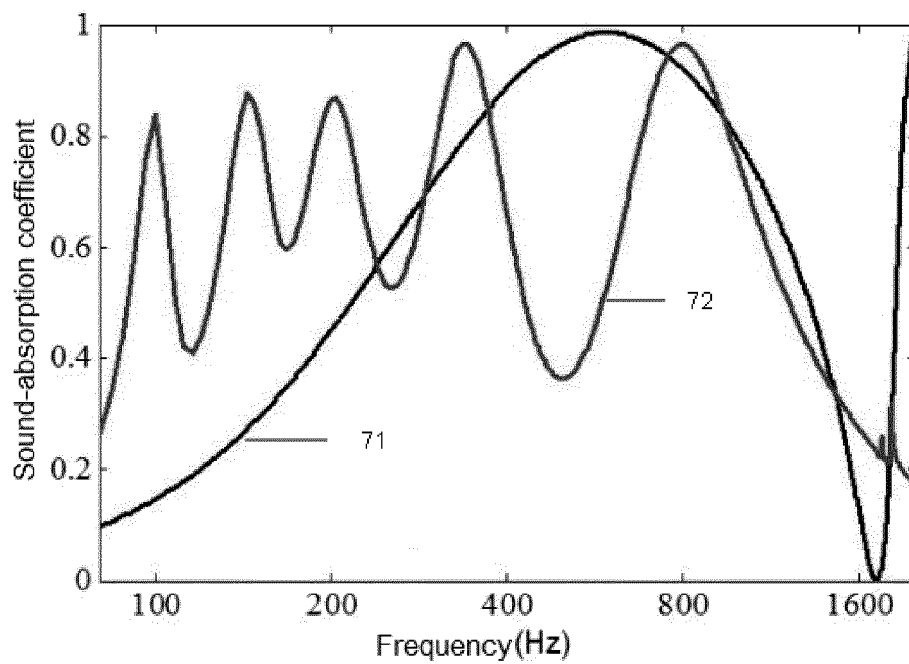


Figure 8

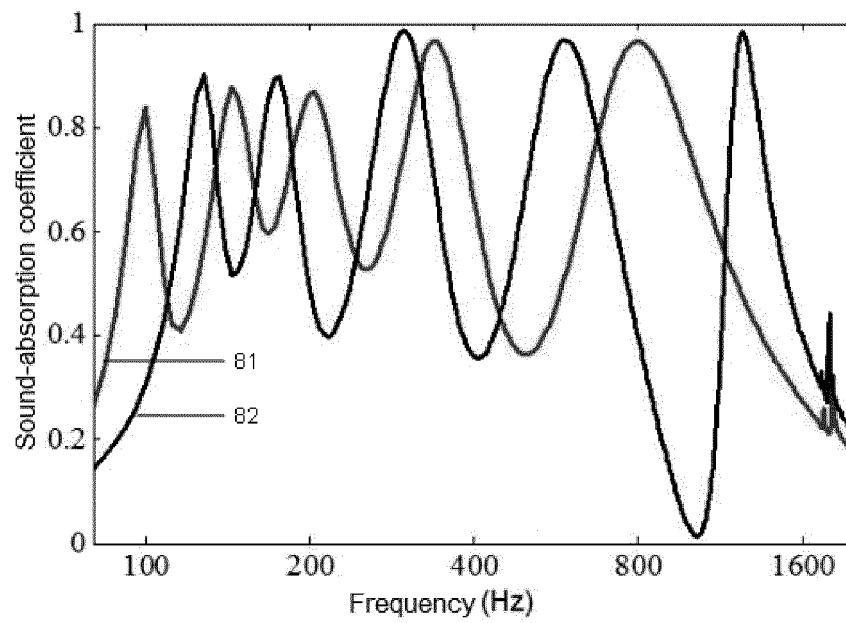


Figure 9

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2019/113918

A. CLASSIFICATION OF SUBJECT MATTER G10K 11/162(2006.01)i; G10K 11/172(2006.01)i 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) G10K11 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) CNPAT, CNKI, WPI, EPODOC: 低频, 延长, 亥姆霍兹, 吸声, 消声, 共振, 小孔, 双层, 混合, 微孔, acoustic, panel, flat, plate, structure, structural, honeycomb, sandwich, cellular, silencing, silencer, sound, soundproof, insulate, dissipation, absorption, absorbent, cell, hole.																		
C. DOCUMENTS CONSIDERED TO BE RELEVANT <table border="1"> <thead> <tr> <th>Category*</th> <th>Citation of document, with indication, where appropriate, of the relevant passages</th> <th>Relevant to claim No.</th> </tr> </thead> <tbody> <tr> <td>PX</td> <td>CN 109147750 A (CRRC ZHUZHOU LOCOMOTIVE CO., LTD.) 04 January 2019 (2019-01-04) claims 1-10</td> <td>1-10</td> </tr> <tr> <td>Y</td> <td>CN 107437411 A (BEIJING MUNICIPAL INSTITUTE OF LABOUR PROTECTION) 05 December 2017 (2017-12-05) description, paragraphs [0017]-[0036], and figure 1</td> <td>1-10</td> </tr> <tr> <td>Y</td> <td>US 2015090526 A1 (3M INNOVATIVE PROPERTIES COMPANY) 02 April 2015 (2015-04-02) description, paragraphs [0020]-[0062], and figures 1-5</td> <td>1-10</td> </tr> <tr> <td>A</td> <td>US 6069840 A (THE UNITED STATES OF AMERICA AS REPRESENTED BY THE SECRETARY OF THE AIR FORCE) 30 May 2000 (2000-05-30) entire document</td> <td>1-10</td> </tr> <tr> <td>A</td> <td>CN 108399911 A (BEIJING MUNICIPAL INSTITUTE OF LABOUR PROTECTION) 14 August 2018 (2018-08-14) entire document</td> <td>1-10</td> </tr> </tbody> </table>	Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.	PX	CN 109147750 A (CRRC ZHUZHOU LOCOMOTIVE CO., LTD.) 04 January 2019 (2019-01-04) claims 1-10	1-10	Y	CN 107437411 A (BEIJING MUNICIPAL INSTITUTE OF LABOUR PROTECTION) 05 December 2017 (2017-12-05) description, paragraphs [0017]-[0036], and figure 1	1-10	Y	US 2015090526 A1 (3M INNOVATIVE PROPERTIES COMPANY) 02 April 2015 (2015-04-02) description, paragraphs [0020]-[0062], and figures 1-5	1-10	A	US 6069840 A (THE UNITED STATES OF AMERICA AS REPRESENTED BY THE SECRETARY OF THE AIR FORCE) 30 May 2000 (2000-05-30) entire document	1-10	A	CN 108399911 A (BEIJING MUNICIPAL INSTITUTE OF LABOUR PROTECTION) 14 August 2018 (2018-08-14) entire document	1-10
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Date of the actual completion of the international search 02 January 2020	Date of mailing of the international search report 31 January 2020																	
Name and mailing address of the ISA/CN China National Intellectual Property Administration (ISA/ CN) No. 6, Xitucheng Road, Jimenqiao Haidian District, Beijing 100088 China Facsimile No. (86-10)62019451	Authorized officer Telephone No.																	

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INTERNATIONAL SEARCH REPORT

International application No.

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2008233793 A (YAMAHA CORP.) 02 October 2008 (2008-10-02) entire document	1-10

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

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Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
CN	109147750	A	04 January 2019	None	
CN	107437411	A	05 December 2017	None	
US	2015090526	A1	02 April 2015	JP 2013250501	A 12 December 2013
				WO 2013184370	A2 12 December 2013
US	6069840	A	30 May 2000	None	
CN	108399911	A	14 August 2018	None	
JP	2008233793	A	02 October 2008	None	

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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- CN 201811359437 [0001]