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Thin-layer low-frequency underwater sound insulation metamaterial

Abstract

The present disclosure provides a thin-layer low-frequency underwater sound insulation metamaterial, including two cover plates and a sound insulation layer. The sound insulation layer is composed of sound insulation components arranged in an array periodically. The sound insulation components each include a sound insulation unit and four connecting units. The sound insulation unit is of a hollow rectangular column structure. The four connecting units are arranged at four corners of the sound insulation unit. Every two adjacent sound insulation units are connected through the connecting units. A long side wall of the sound insulation unit and the corresponding cover plate have an included angle of 0-90°. The metamaterial can obtain a smaller equivalent acoustic impedance in propagation direction of acoustic waves, and compared with a sound insulation material of a square honeycomb structure with the same thickness, the metamaterial has greatly improved sound insulation performance.

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Background/Summary

CROSS REFERENCE TO RELATED APPLICATION

(1) The present application is a U.S. National Phase application of PCT International Application

Number PCT/CN2022/088212, filed on Apr. 21, 2022, which claims priority to the Chinese Patent Application No. CN202110464415.4, filed with China National Intellectual Property Administration (CNIPA) on Apr. 28, 2021, and entitled “THIN-LAYER LOW-FREQUENCY UNDERWATER SOUND INSULATION METAMATERIAL”, which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

(2) The present disclosure relates to the technical field of vibration and noise control of underwater equipment, and in particular, to a thin-layer low-frequency underwater sound insulation metamaterial.

BACKGROUND ART

(3) Applying sound insulation materials on the surface of underwater equipment is an important technology that can suppress the radiated noise of the equipment and improve its acoustic stealth performance. The sound insulation mechanism of the sound insulation materials mainly includes the following two aspects: (1) Damping dissipation sound insulation: The energy of the equipment radiating acoustic waves to the outside is reduced by means of the vibration damping dissipation inside the material or the absorption of scattered acoustic waves. (2) Impedance mismatch sound insulation: by designing the acoustic structure, the internal noise of the equipment is strongly reflected on the surface of the sound insulation material, thereby reducing the transmitted acoustic wave energy.

(4) The sound insulation material laid on the surface of the underwater equipment can effectively block the outward propagation path of the internal noise of the equipment, and reduce the radiated noise of the equipment itself, so as to achieve “quietness”. With the continuous development of the working frequency of a detection sonar to low frequency, the effective working frequency of existing sound insulation materials is high, which cannot meet the needs of low-frequency applications. Designing sound insulation materials that can effectively block low-frequency (200-2,000 Hz) underwater acoustic waves is of great significance to the development of acoustic stealth technology for the underwater equipment.

SUMMARY

(5) In view of the above-mentioned deficiencies of the low-frequency performance of the existing underwater sound insulation materials, based on the quasi-static impedance mismatch mechanism and the density-based topology optimization method, the present disclosure designs a thin-layer low-frequency underwater sound insulation metamaterial, which can effectively improve the sound insulation in a low-frequency band of 200-2,000 Hz.

(6) To achieve the above objectives, the present disclosure provides a thin-layer low-frequency underwater sound insulation metamaterial, including two cover plates and a sound insulation layer located between the two cover plates.

(7) The two cover plates are parallel to each other, and the sound insulation layer is composed of $m \times n$ sound insulation components arranged in an array periodically, where $m \geq 1$, and $n \geq 1$.

(8) The sound insulation components each include a sound insulation unit and four connecting units. The sound insulation unit is of a hollow rectangular column structure. The four connecting units are arranged at four corners of the sound insulation unit. Every two adjacent sound insulation units are connected through the connecting units.

(9) A long side wall of the sound insulation unit and the corresponding cover plate have an included angle of 0-90°.

(10) In one of the embodiments, the connecting units may each include an extension portion and a connecting portion. One end of the extension portion may be connected to the sound insulation unit. The connecting portion may be provided at the other end of the extension portion.

(11) Every two adjacent sound insulation units may be connected by the connecting portions, and the extension portion, the connecting portion, and the long side wall of the sound insulation unit may constitute a “Z”-shaped structure.

(12) In one of the embodiments, an outer profile of the long side wall of the sound insulation unit may be a first profile, and an outer profile of a short side wall of the sound insulation unit may be the second profile.
(13) The extension portion may have a third profile and a fourth profile. The first profile may be connected to one end of the third profile through a first transition profile. The second profile may be connected to one end of the fourth profile through the second transition profile.
(14) The first profile and the third profile may have a topological angle of α3, and the second profile and the fourth profile may have a topological angle of α1, where
(15) $\alpha 3 = \frac{1}{2}\alpha 1$.
(16) In one of the embodiments, the connecting portion may have a fifth profile, a sixth profile, a seventh profile, an eighth profile, and a ninth profile that are connected in sequence.
(17) The fifth profile may be connected to the other end of the third profile, and the ninth profile may be connected to the other end of the fourth profile through a third transition profile.
(18) The sixth profile may be perpendicular to the fifth profile. The seventh profile may be perpendicular to the sixth profile. The eighth profile may be perpendicular to the seventh profile.
(19) The ninth profile and the sixth profile may have a topological angle of α2, where
(20) $\alpha 2 = \frac{1}{4}\alpha 1$.
(21) In one of the embodiments, a section of the sound insulation unit parallel to the long side wall and passing through the axis of the sound insulation unit may be a first section, and a section of the sound insulation unit parallel to the short side wall and passing through the axis of the sound insulation unit may be a second section.
(22) A distance between the first section and the sixth profile may be a1. The seventh profile may have a width of a2, and the fifth profile may have a width of a3, where
(23) $a2 = \frac{1}{5}a1$,
and 0≤a3≤0.25 mm.
(24) A distance between the second section and the seventh profile may be b1. The sixth profile may have a length of b2, and the eighth profile may have a length of b3, where
(25) $b2\frac{4}{5}b1$, and $b3 = \frac{1}{5}b1$.
(26) In one of the embodiments, the long side wall of the sound insulation unit may have a thickness of a4 and the short side wall of the sound insulation unit may have a thickness of b4, where
(27) $a4 = \frac{1}{10}a1$, and $b4 = \frac{1}{10}b1$.
(28) In one of the embodiments, the cover plates may each have a thickness greater than or equal to 0.1 mm.
(29) In one of the embodiments, the cover plates and the sound insulation layer may be made of metal or non-metal materials with physical parameters as follows: a range of an elastic modulus E satisfies 0.1 GPa≤E≤220 GPa, a range of a Poisson's ratio η satisfies 0.2≤η≤0.5, and a range of a density ρ satisfies 800 kg/m.sup.3≤ρ≤12,000 kg/m.sup.3.
(30) The thin-layer low-frequency underwater sound insulation metamaterial provided by the present disclosure is designed based on the quasi-static impedance mismatch mechanism and the density-based topology optimization method, which can effectively solve the sound insulation problem in a low-frequency band of 200-2,000 Hz. The internal microstructure of the metamaterial has the characteristic of negative Poisson's ratio. Under the condition of a thickness not greater than 20 mm, the low-frequency broadband sound insulation performance of acoustic wave at 200-2,000 Hz can be realized. The metamaterial can be applied to noise control in underwater equipment and other fields, and has an excellent engineering application prospect.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) To describe the technical solutions in the embodiments of the present disclosure or in the prior art more clearly, the following briefly describes the accompanying drawings required for describing the embodiments or the prior art. Apparently, the accompanying drawings in the following description show some embodiments of the present disclosure, and those of ordinary skill in the art may still derive other drawings from these accompanying drawings without creative efforts.

(2) FIG. **1** shows an overall structure of a thin-layer low-frequency underwater sound insulation metamaterial in an embodiment of the present disclosure;

(3) FIG. **2** shows a structure of a sound insulation component in the embodiment of the present disclosure;

(4) FIG. **3** shows a structure of ¼ of the sound insulation component in the embodiment of the present disclosure;

(5) FIG. **4** shows a structure of a rectangular cover plate in the embodiment of the present disclosure;

(6) FIG. **5** shows a traditional sound insulation material of a square honeycomb structure in the simulation example of the embodiment of the present disclosure;

(7) FIG. **6** shows a partial structure of a thin-layer low-frequency underwater sound insulation metamaterial in the simulation example of the embodiment of the present disclosure;

(8) FIG. **7** is a comparison diagram of a sound insulation coefficients of the traditional sound insulation material of a square honeycomb structure and the thin-layer low-frequency underwater sound insulation metamaterial in the embodiment of the present disclosure in a frequency range of 200-2,000 Hz.

(9) Reference Numerals: cover plate **10**, sound insulation layer **20**, sound insulation unit **201**, connecting unit **202**, extension portion **2021**, connecting portion **2022**, first profile **301**, second profile **302**, third profile **303**, fourth profile **304**, fifth profile **305**, sixth profile **306**, seventh profile **307**, eighth profile **308**, ninth profile **309**, first transition profile **401**, second transition profile **402**, third transition profile **403**, first section **501**, and second section **502**.

(10) The implementation of objectives, functional features, and advantages of the present disclosure will be further described with reference to the accompanying drawings and the embodiments.

DETAILED DESCRIPTION OF THE EMBODIMENTS

(11) The following clearly and completely describes the technical solutions in the embodiments of the present disclosure with reference to the accompanying drawings in the embodiments of the present disclosure. Apparently, the described embodiments are merely a part rather than all of the embodiments of the present disclosure. All other embodiments obtained by those of ordinary skill in the art based on the embodiments of the present disclosure without creative efforts shall fall within the protection scope of the present disclosure.

(12) It should be noted that all the directional indications (such as upper, lower, left, right, front, and rear) in the embodiments of the present disclosure are merely used to explain relative position relationships, motion situations, and the like of the components in a specific gesture (as shown in the figures). If the specific gesture changes, the directional indication also changes accordingly.

(13) Moreover, the terms such as “first” and “second” used herein are only for the purpose of description and are not intended to indicate or imply relative importance, or implicitly indicate the number of the indicated technical features. Thus, features limited by “first” and “second” may expressly or implicitly include at least one of that feature. In description of the present disclosure, “a plurality of” means at least two, for example, two or three, unless otherwise clearly and specifically limited.

(14) In the present disclosure, unless otherwise specified and defined, the terms such as “connection” and “fixation” should be comprehended in a broad sense. For example, “fixation”

may be a fixed connection, a detachable connection, or an integral formation; or a direct connection, or an indirect connection through an intermediate medium, or internal communication between two elements, or an interactive relationship between two elements, unless otherwise clearly and specifically limited. Those of ordinary skill in the art may understand specific meanings of the above terms in the present disclosure based on a specific situation.
(15) Furthermore, the technical solutions between the various embodiments of the present disclosure may be combined with each other, but must be on the basis that the combination thereof can be implemented by those of ordinary skill in the art. In case of a contradiction with the combination of the technical solutions or a failure to implement the combination, it should be considered that the combination of the technical solutions does not exist, and is not within the protection scope of the present disclosure.
(16) FIG. **1** to FIG. **4** show a thin-layer low-frequency underwater sound insulation metamaterial disclosed by the embodiment of the present disclosure, which specifically includes two cover plates **10** and a sound insulation layer **20** located between the two cover plates **10**. The two cover plates **10** are parallel to each other, and the sound insulation layer **20** is composed of m×n sound insulation components arranged in an array periodically, where m≥1, and n≥1. Specifically, the sound insulation components each include a sound insulation unit **201** and four connecting units **202**. The sound insulation unit **201** is of a hollow rectangular column structure. The four connecting units **202** are arranged at four corners of the sound insulation unit **201**. The four connecting units **202** are distributed symmetrically in a cross on the sound insulation unit **201**. Every two adjacent sound insulation units **201** are connected through the connecting units **202**. A long side wall of the sound insulation unit **201** and the corresponding cover plate **10** have an included angle of 0-90°. The long side wall of the sound insulation unit **201** refers to a side wall where a long side of the sound insulation unit **201** is located.
(17) In the present embodiment, the connecting units **202** each include an extension portion **2021** and a connecting portion **2022**. One end of the extension portion **2021** is connected to the sound insulation unit **201**. The connecting portion **2022** is provided at the other end of the extension portion **2021**. When two adjacent sound insulation units **201** are connected, their corresponding connecting portions **2022** are fixedly connected, that is, every two adjacent sound insulation units **201** are connected by the connecting portions **2022**, and the extension portion **2021**, the connecting portion **2022**, and the long side wall of the sound insulation unit **201** constitute a “Z”-shaped structure.
(18) Further, specifically, an outer profile of the long side wall of the sound insulation unit **201** is the first profile **301**. An outer profile of a short side wall of the sound insulation unit **201** is the second profile **302**. The short side wall of the sound insulation unit **201** refers to a side wall where a short side of the sound insulation unit **201** is located. The extension portion **2021** has a third profile **303** and a fourth profile **304**. The first profile **301** is connected to one end of the third profile **303** through a first transition profile **401**. The second profile **302** is connected to one end of the fourth profile **304** through a second transition profile **402**. The first profile **301** and the third profile **303** have a topological angle of α3, and the second profile **302** and the fourth profile **304** have a topological angle of α1, where
(19) $\alpha 3=\frac{1}{2}\alpha 1$.
The connecting portion **2022** has a fifth profile **305**, a sixth profile **306**, a seventh profile **307**, an eighth profile **308**, and a ninth profile **309** that are connected in sequence. The fifth profile **305** is connected to the other end of the third profile **303**. The ninth profile **309** is connected to the other end of the fourth profile **304** through a third transition profile **403**. The sixth profile **306** is perpendicular to the fifth profile **305**. The seventh profile **307** is perpendicular to the sixth profile **306**. The eighth profile **308** is perpendicular to the seventh profile **307**. The ninth profile **309** and the sixth profile **306** has a topological angle of α2, where
(20) $\alpha 2=\frac{1}{4}\alpha 1$.

Preferably, all of the first transition profile **401**, the second transition profile **402**, and the third transition profile **403** are arc transition surfaces. When two adjacent sound insulation units **201** are connected, the two sixth profiles **306** or the two seventh profiles **307** in their corresponding connecting portions **2022** are connected, that is, one connecting portion is connected to at most two other connecting portions, and one sound insulation component is connected to at most eight adjacent sound insulation components.

(21) In the present embodiment, a section of the sound insulation unit **201** parallel to the long side wall and passing through an axis of the sound insulation unit **201** is a first section **501**, and a section of the sound insulation unit **201** parallel to the short side wall and passing through the axis of the sound insulation unit **201** is a second section **502**. A distance between the first section **501** and the sixth profile **306** is a1, the seventh profile **307** has a width of α2, and the fifth profile **305** has a width of a3, where

(22) $a2 = \frac{1}{5}a1$,

and 0≤a3≤0.25 mm. A distance between the second section **502** and the fifth profile **307** is b1, the sixth profile **306** has a length of b2, and the eighth profile **308** has a length of b3, where

(23) b2 = $\frac{4}{5}b1$, and $b3 = \frac{1}{5}b1$.

The long side wall of the sound insulation unit **201** has a thickness of a4, and the short side wall of the sound insulation unit **201** has a thickness of b4, where

(24) 0$a4 = \frac{1}{10}a1$, and $b4 = \frac{1}{10}b1$.

(25) In the present embodiment, the cover plate **10** is a rectangular plate structure, and its length and width are equal to those of the sound insulation layer **20**. The cover plates **10** each have a thickness greater than or equal to 0.1 mm.

(26) In the present embodiment, the cover plates **10** and the sound insulation layer **20** are made of metal materials or non-metal materials. The metal materials may be selected from aluminum, carbon steel, and alloy steel, and the non-metal materials may be selected from polylactic acid or acrylonitrile butadiene styrene (ABS). The materials have physical parameters as follows: a range of an elastic modulus E satisfies 0.1 GPa≤E≤220 GPa, a range of a Poisson's ratio η satisfies 0.2≤η≤0.5, and a range of a density ρ satisfies 800 kg/m.sup.3≤ρ≤12,000 kg/m.sup.3.

(27) In the present embodiment, the cover plates **10** and the sound insulation layer **20** may be integrally printed and manufactured using a three-dimensional (3D) printing technology, or may be manufactured by machining modes such as wire cut electrical discharge machining (WEDM).

(28) Combined with a specific simulation example, the thin-layer low-frequency underwater sound insulation metamaterial in the present embodiment is compared with a traditional sound insulation material of a square honeycomb structure in FIG. **5**, so as to further explain the thin-layer low-frequency underwater sound insulation metamaterial in the present embodiment.

(29) In this example, both a cover plate **10** and a sound insulation layer **20** are made of polylactic acid. The material has parameters as follows: a Young's modulus of 0.8 GPa, a Poisson's ratio of 0.38, and a density of 1,200 kg/m.sup.3. A long side wall of the sound insulation unit **201** and the corresponding cover plate **10** have an included angle θ of **450** as shown in FIG. **6**. The cover plate **10** has a length of b=10 cm, a width of h=10 cm, and a thickness of c=0.5 mm. The thin-layer low-frequency underwater sound insulation metamaterial has a total thickness of a=20 mm, a width of b=10 cm, and a height of h=10 cm. A sound insulation component has a length of a′=5 mm, a width of b′=5 mm, and n height of h=10 mm. A distance between the above 1 first section **501** and the sixth profile **306** is

(30) $a1 = \frac{1}{2}a' = 2.5\text{mm}$.

The seventh profile **307** has a width of

(31) $a2 = \frac{1}{5}a1 = 0.5\text{mm}$.

The fifth profile **305** has a width of a3=0.1 mm. The long side wall of the sound insulation unit **201** has a thickness of

(32) $a4 = \frac{1}{10}a1 = 0.25\text{mm}$.

A distance between the second section **502** and the fifth profile **307** is

(33) $b1=\frac{1}{2}b'=2.5\text{mm}$.

The sixth profile **306** has a length of

(34) $b2=\frac{4}{5}b1=2\text{mm}$.

The eighth profile **308** has a length of

(35) $b3=\frac{1}{5}b1=0.5\text{mm}$.

The short side wall of the sound insulation unit **201** has a thickness of

(36) $b4=\frac{1}{10}b1=0.25\text{mm}$.

The first profile **301** and the third profile **303** have a topological angle of α3=55°. The second profile **302** and the fourth profile **304** have a topological angle of α1=2α3=110°. The ninth profile **309** and the sixth profile **306** have a topological angle of

(37) $\alpha 2=\frac{1}{4}\alpha 1=27.5°$

(38) According to the above dimensional parameters, a finite element analysis model of the sound insulation performance of the material is established, and a sound insulation coefficient obtained from the simulation is shown in FIG. **7**. FIG. **7** compares the sound insulation coefficients of the traditional sound insulation material of a square honeycomb structure and the thin-layer low-frequency underwater sound insulation metamaterial in the present embodiment under the same material and overall thickness. It can be seen from FIG. **7** that in the embodiment of the present disclosure, the metamaterial has an average sound insulation greater than 20 dB in the frequency range of 200-2,000 Hz under the condition that the overall thickness is only 20 mm, and has excellent sound insulation. Compared with the traditional sound insulation material of a square honeycomb structure, the thin-layer underwater sound insulation metamaterial in the present embodiment has greatly improved sound insulation performance.

(39) To sum up, the technical effects of the thin-layer low-frequency underwater sound insulation metamaterial in the present embodiment are as follows: 1. It has excellent low-frequency sound insulation performance. Compared with the traditional sound insulation material of a square honeycomb structure, the thin-layer low-frequency underwater sound insulation metamaterial has an average sound insulation greater than 20 dB in the frequency range of 200-2,000 Hz under the condition that the overall thickness is only 20 mm, achieving low-frequency high-efficient sound insulation. 2. It has excellent mechanical properties and lightweight properties. The thin-layer low-frequency underwater sound insulation metamaterial has negative Poisson's ratio and excellent bending resistance, and the thin-layer low-frequency underwater sound insulation metamaterial in the embodiment is a lightweight structure with an overall average density of less than 350 kg/m.sup.3. 3. The sound insulation material in the present embodiment has excellent structural design. By optimizing and adjusting the length, width and height of the sound insulation component, as well as the topological angle and manufacturing materials, it can meet the requirements of sound insulation and mechanical properties in different practical applications.

(40) The foregoing are merely preferred embodiments of the present disclosure, and the scope of the present disclosure is not limited thereto. Any equivalent structure change made using the content of the specification of the present disclosure and the accompanying drawings under the inventive concept of the present disclosure, or direct/indirect application thereof in other related technical fields, shall fall within the protection scope of the present disclosure.

Claims

1. A thin-layer low-frequency underwater sound insulation metamaterial, comprising two cover plates and a sound insulation layer located between the two cover plates, wherein: the two cover plates are parallel to each other, and the sound insulation layer is composed of m×n sound insulation components arranged in an array periodically, wherein m≥1, and n≥1; the sound

insulation components each comprise a sound insulation unit and four connecting units, wherein the sound insulation unit is of a hollow rectangular column structure, the four connecting units are arranged at four corners of the sound insulation unit, and every two adjacent sound insulation units are connected through the connecting units; a long side wall of the sound insulation unit and the corresponding cover plate have an included angle of 0-90°, and wherein each of the connecting units comprises an extension portion and a connecting portion, wherein a first end of the extension portion is connected to the sound insulation unit, and the connecting portion is provided at a second end of the extension portion; and the every two adjacent sound insulation units are connected by the connecting portions and the extension portion, wherein the connecting portion and the long side wall of the sound insulation unit constitute a “Z”-shaped structure.

2. The thin-layer low-frequency underwater sound insulation metamaterial according to claim 1, wherein the four connecting units are distributed symmetrically in a cross on the sound insulation unit.

3. The thin-layer low-frequency underwater sound insulation metamaterial according to claim 1, wherein an outer profile of the long side wall of the sound insulation unit is a first profile, and an outer profile of a short side wall of the sound insulation unit is a second profile; the extension portion has a third profile and a fourth profile, the first profile is connected to one end of the third profile through a first transition profile, and the second profile is connected to one end of the fourth profile through a second transition profile; and the first profile and the third profile have a topological angle of α3, and the second profile and the fourth profile have a topological angle of α1, wherein $\alpha 3=\frac{1}{2}\alpha 1$.

4. The thin-layer low-frequency underwater sound insulation metamaterial according to claim 3, wherein the connecting portion has a fifth profile, a sixth profile, a seventh profile, an eighth profile, and a ninth profile that are connected in sequence; the fifth profile is connected to the other end of the third profile, and the ninth profile is connected to the other end of the fourth profile through a third transition profile; the sixth profile is perpendicular to the fifth profile, the seventh profile is perpendicular to the sixth profile, and the eighth profile is perpendicular to the seventh profile; and the ninth profile and the sixth profile have a topological angle of α2, wherein $\alpha 2=\frac{1}{4}\alpha 1$.

5. The thin-layer low-frequency underwater sound insulation metamaterial according to claim 4, wherein the first transition profile, the second transition profile, and the third transition profile are arc transition surfaces.

6. The thin-layer low-frequency underwater sound insulation metamaterial according to claim 4, wherein a section of the sound insulation unit parallel to the long side wall and passing through an axis of the sound insulation unit is a first section, and a section of the sound insulation unit parallel to the short side wall and passing through the axis of the sound insulation unit is a second section; a distance between the first section and the sixth profile is a1, the seventh profile has a width of a2, and the fifth profile has a width of a3, wherein $a2=\frac{1}{5}a1$, and 0≤a3≤0.25 mm; and a distance between the second section and the seventh profile is b1, the sixth profile has a length of b2, and the eighth profile has a length of b3, wherein $b2=\frac{4}{5}b1$, and $b3=\frac{1}{5}b1$.

7. The thin-layer low-frequency underwater sound insulation metamaterial according to claim 6, wherein the long side wall of the sound insulation unit has a thickness of a4, and the short side wall of the sound insulation unit has a thickness of b4, wherein a4= 1/10a1, and b4= 1/10b1.

8. The thin-layer low-frequency underwater sound insulation metamaterial according to claim 1, wherein the cover plates each have a thickness greater than or equal to 0.1 mm.

9. The thin-layer low-frequency underwater sound insulation metamaterial according to claim 2, wherein the cover plates each have a thickness greater than or equal to 0.1 mm.

10. The thin-layer low-frequency underwater sound insulation metamaterial according to claim 1, wherein the cover plates each have a thickness greater than or equal to 0.1 mm.

11. The thin-layer low-frequency underwater sound insulation metamaterial according to claim 3,

wherein the cover plates each have a thickness greater than or equal to 0.1 mm.
12. The thin-layer low-frequency underwater sound insulation metamaterial according to claim 4, wherein the cover plates each have a thickness greater than or equal to 0.1 mm.
13. The thin-layer low-frequency underwater sound insulation metamaterial according to claim 5, wherein the cover plates each have a thickness greater than or equal to 0.1 mm.
14. The thin-layer low-frequency underwater sound insulation metamaterial according to claim 6, wherein the cover plates each have a thickness greater than or equal to 0.1 mm.
15. The thin-layer low-frequency underwater sound insulation metamaterial according to claim 7, wherein the cover plates each have a thickness greater than or equal to 0.1 mm.
16. The thin-layer low-frequency underwater sound insulation metamaterial according to claim 1, wherein the cover plates and the sound insulation layer are made of metal materials or non-metal materials with physical parameters as follows: a range of an elastic modulus E satisfies 0.1 GPa≤E≤220 GPa, a range of a Poisson's ratio η satisfies 0.25≤η≤0.5, and a range of a density ρ satisfies 800 kg/m.sup.3≤ρ≤12,000 kg/m.sup.3.
17. The thin-layer low-frequency underwater sound insulation metamaterial according to claim 16, wherein the metal materials comprise aluminum, carbon steel, or alloy steel; and the non-metal materials comprise polylactic acid or acrylonitrile butadiene styrene (ABS).
18. The thin-layer low-frequency underwater sound insulation metamaterial according to claim 1, wherein the cover plates and the sound insulation layer are integrally printed and manufactured using a three-dimensional (3D) printing technology.
19. The thin-layer low-frequency underwater sound insulation metamaterial according to claim 1, wherein the cover plates and the sound insulation layer are manufactured by wire cut electrical discharge machining (WEDM).