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(54) **ACOUSTIC METAMATERIAL-BASED MUFFLER FOR BROADBAND EXHAUST NOISE REDUCTION OF INTERNAL COMBUSTION ENGINES**

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(57) **ABSTRACT**

The present disclosure provides an acoustic metamaterial-based muffler for broadband exhaust noise reduction of internal combustion engines is mounted on an exhaust pipe of an internal combustion engine, and includes an exhaust flow pipe that is formed of an inlet on one side through which exhaust of the internal combustion engine flows in, an outlet on the other side through which the exhaust flows out, and a flow passage on the inside through which the exhaust flows from one side to the other side; and a plurality of noise reduction units that are provided inside along a longitudinal direction of the exhaust flow pipe to attenuate noise in the corresponding frequency band among the exhaust noises flowing along the exhaust flow pipe.

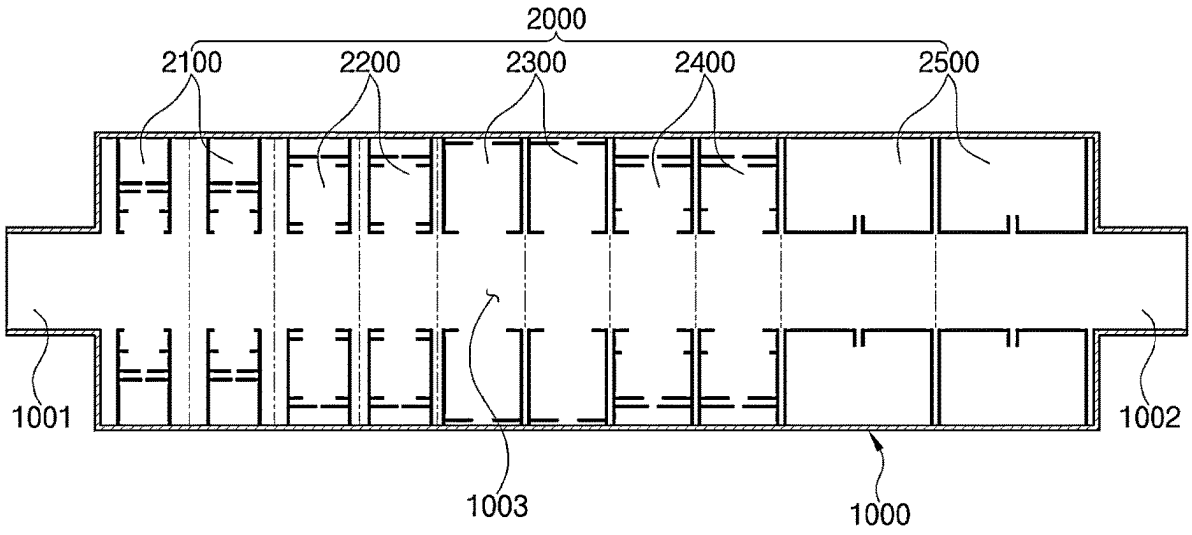


FIG. 1

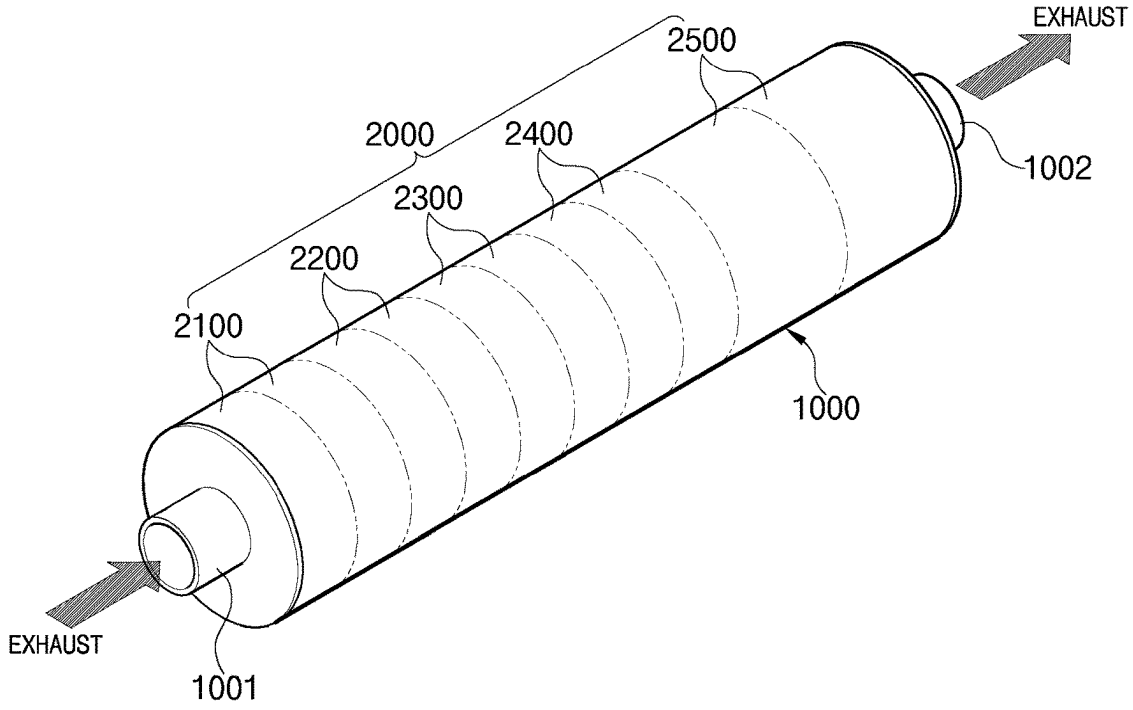

EXHAUST
2500
2000
2400
1002
2300
2200
2100
1000
EXHAUST
1001

FIG. 2

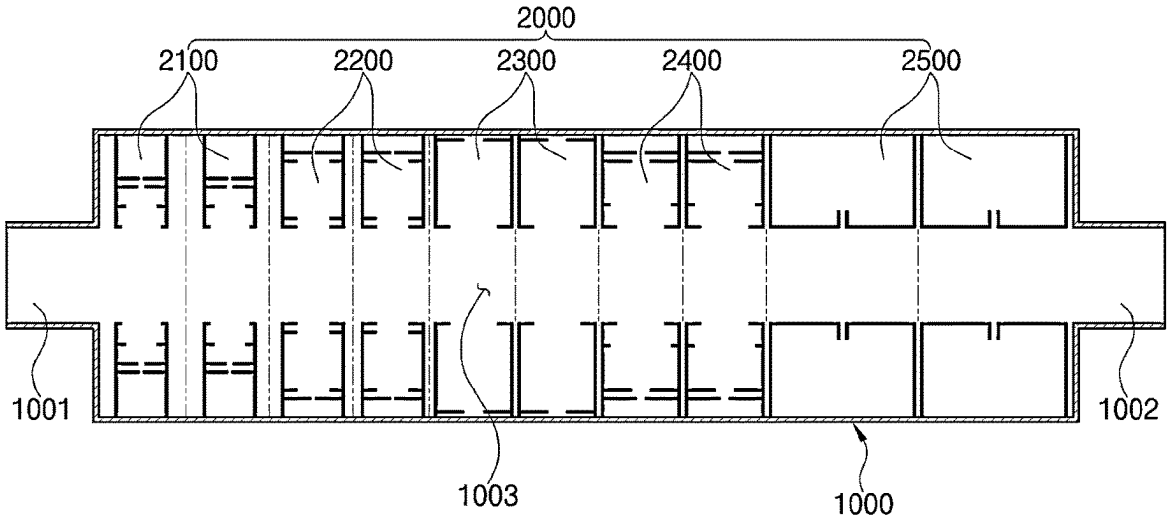

2000
2100
2200
2300
2400
2500
1001
1002
1003
1000

FIG. 3

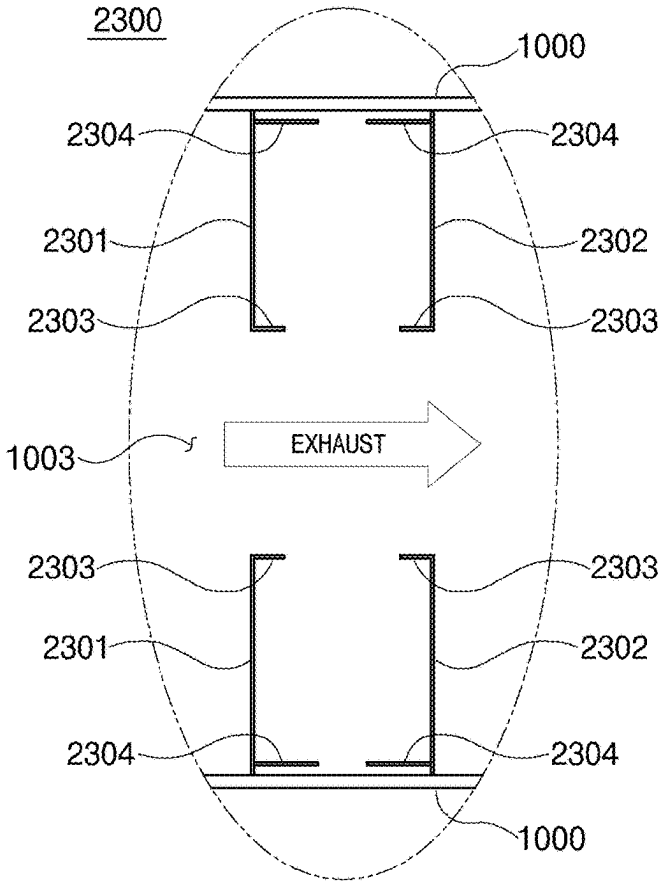

2300
1000
2304
2304
2301
2302
2303
2303
1003
EXHAUST
2303
2303
2301
2302
2304
2304
1000

FIG. 4

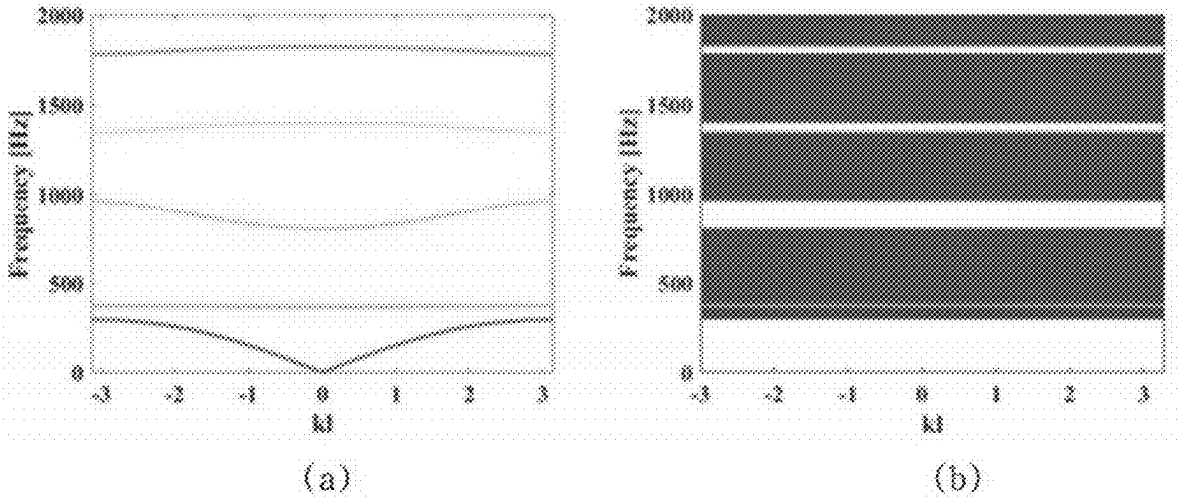

Frequency [Hz]
2000
1500
1000
500
0
-3
-2
-1
0
1
2
3
kd
(a)
(b)

FIG. 5

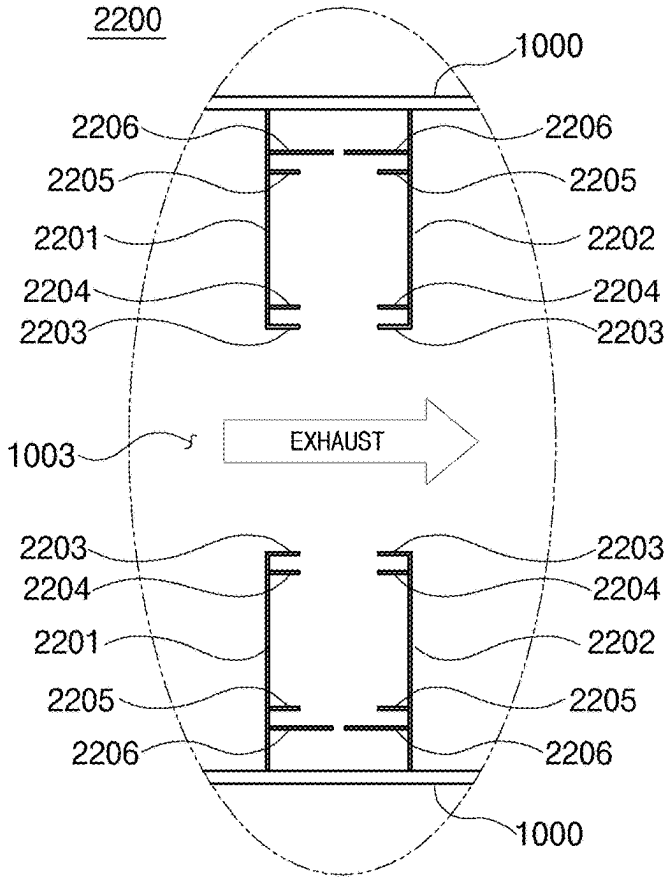

2200
1000
2206
2206
2205
2205
2201
2202
2204
2204
2203
2203
1003
EXHAUST
2203
2203
2204
2204
2201
2202
2205
2205
2206
2206
1000

FIG. 6

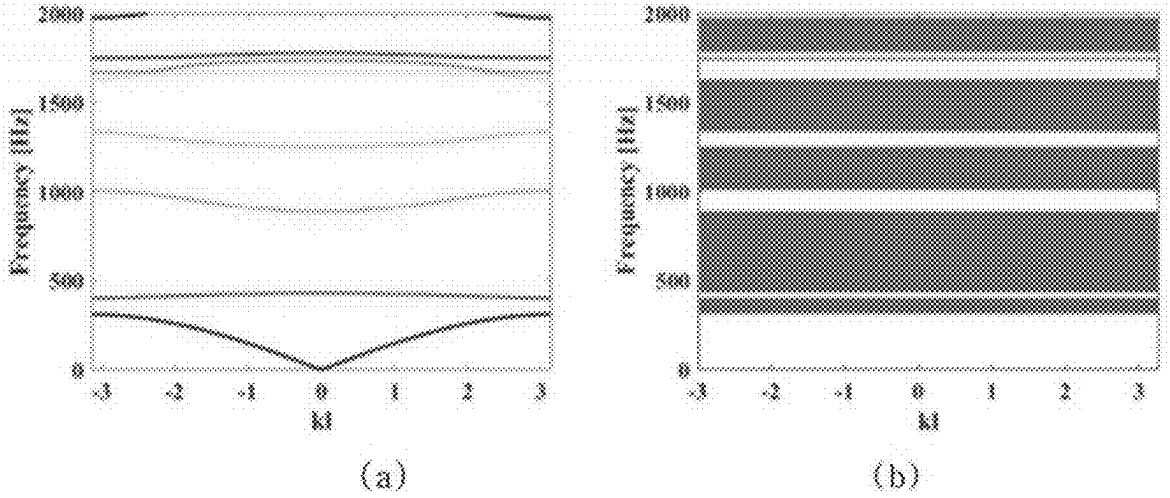

2000
1500
1000
500
0
Frequency [Hz]
-3
-2
-1
0
1
2
3
kl
(a)
(b)

FIG. 7

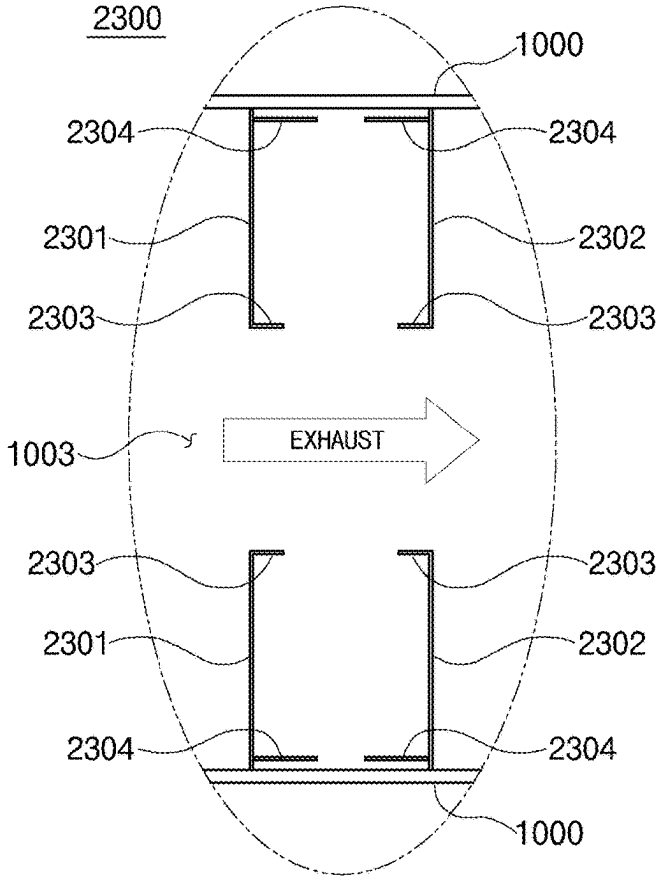

2300
1000
2304
2304
2301
2302
2303
2303
1003
EXHAUST
2303
2303
2301
2302
2304
2304
1000

FIG. 8

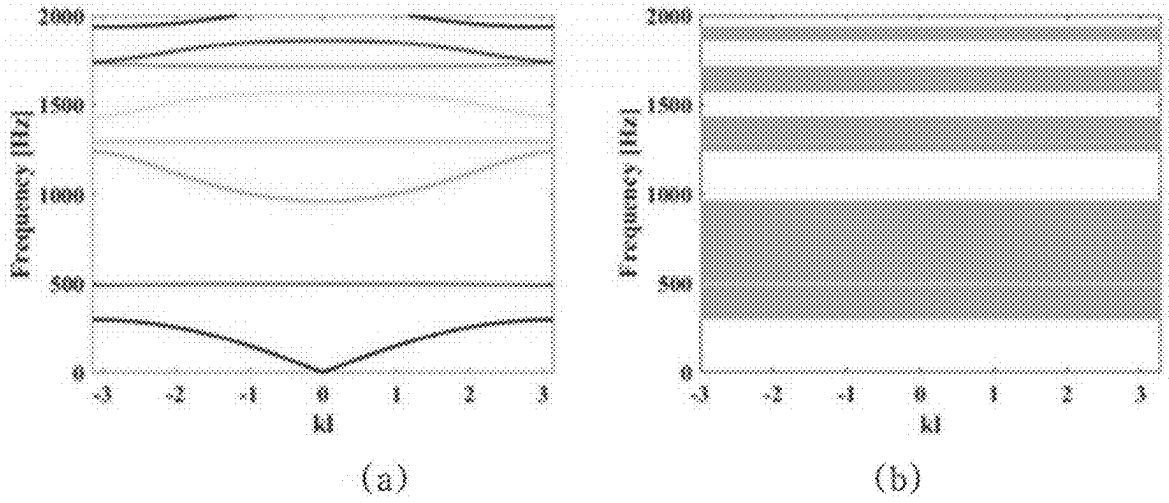

Frequency [Hz]
2000
1500
1000
500
0
-3
-2
-1
0
1
2
3
kl
(a)
(b)

FIG. 9

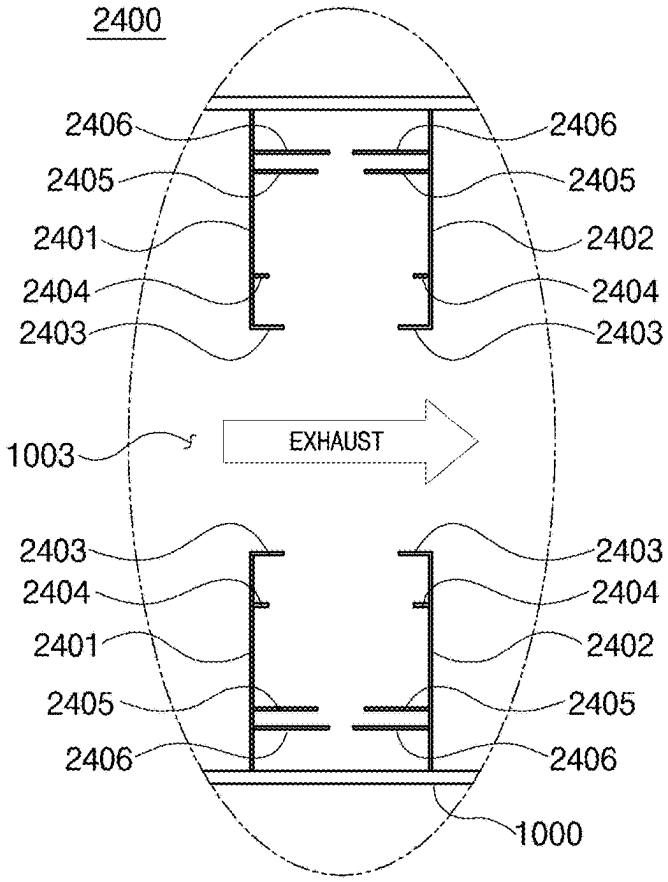

2400
2406
2405
2401
2404
2403
2406
2405
2402
2404
2403
1003
EXHAUST
2403
2404
2401
2405
2406
2403
2404
2402
2405
2406
1000

FIG. 10

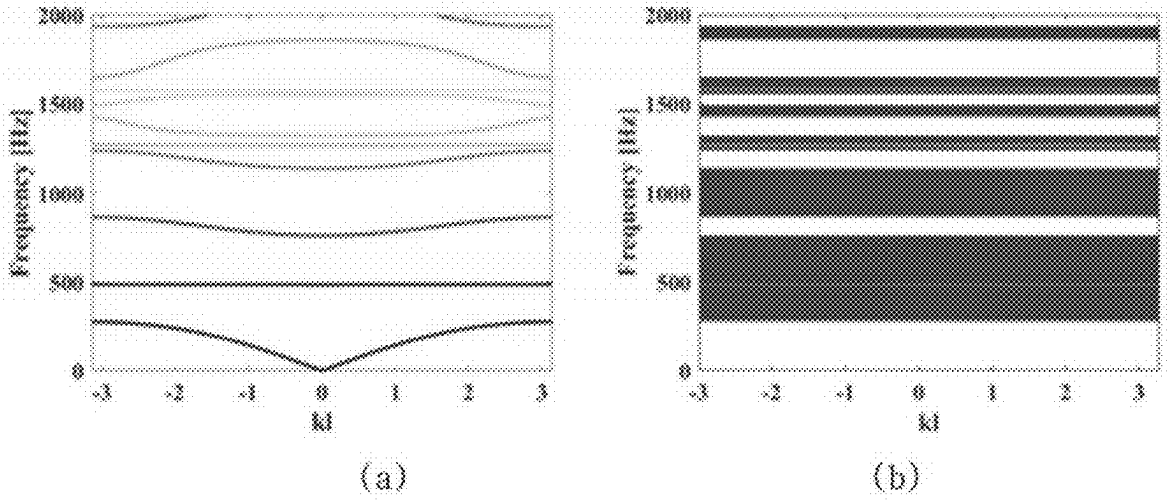

Frequency [Hz]
kl
(a)
(b)

FIG. 11

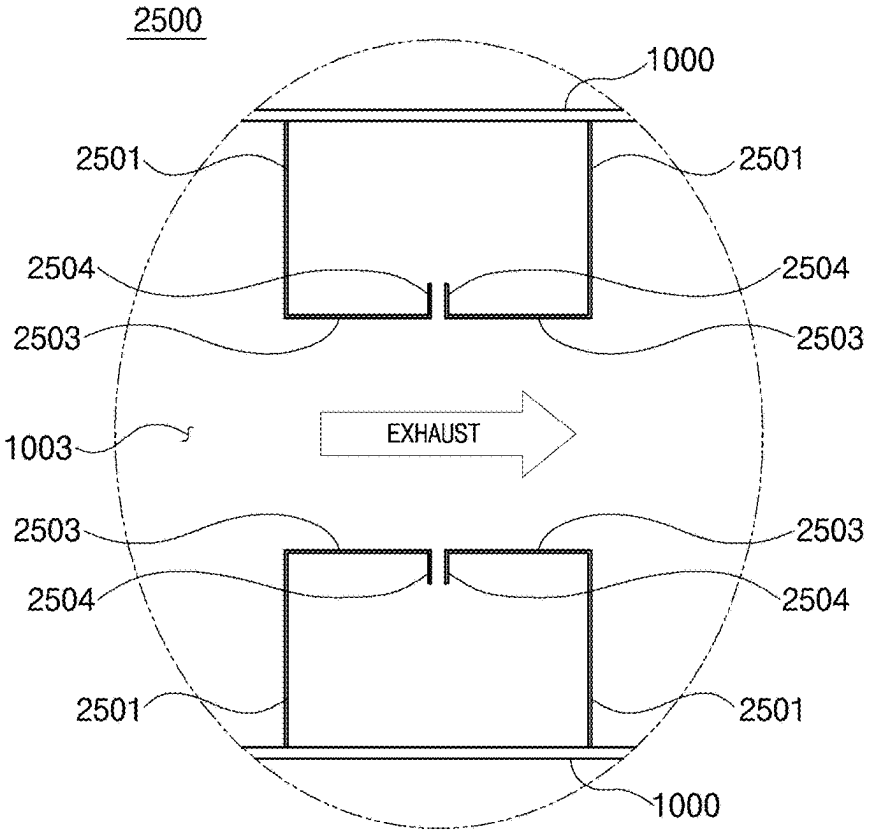

2500
1000
2501
2501
2504
2504
2503
2503
1003
EXHAUST
2503
2503
2504
2504
2501
2501
1000

FIG. 12

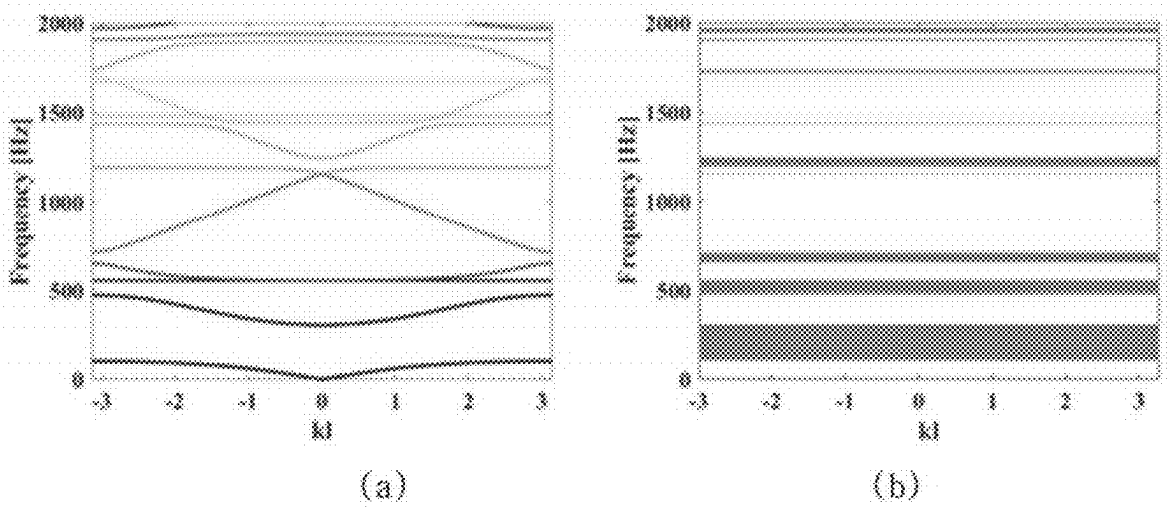

Frequency [Hz]
kl
(a)
(b)

FIG. 13

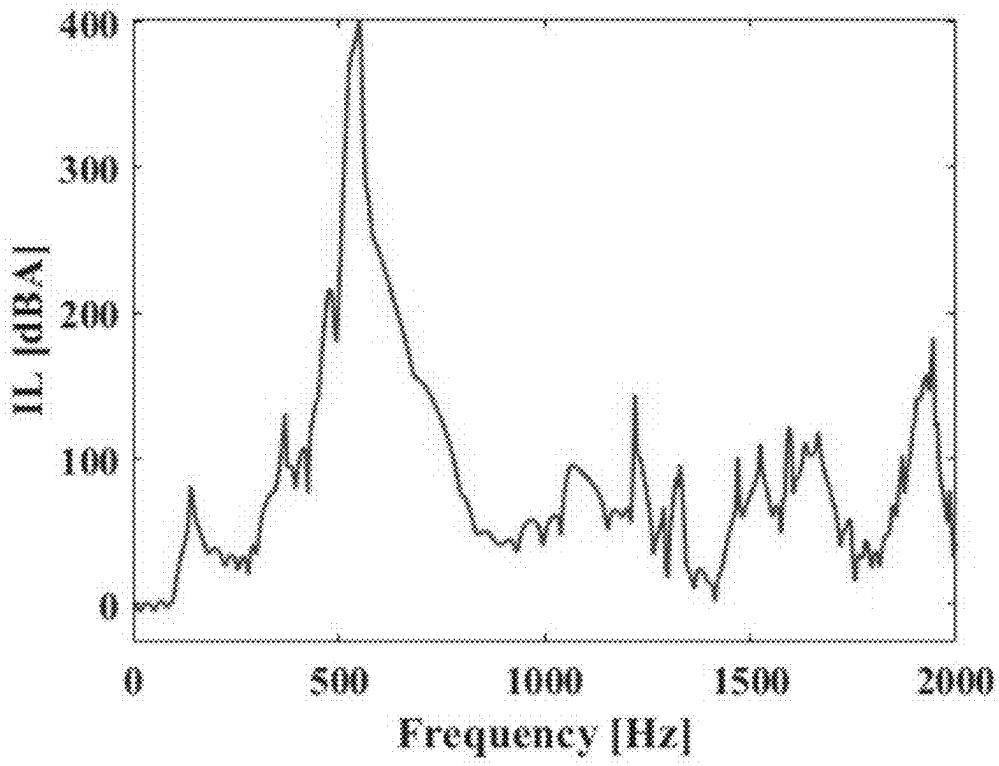
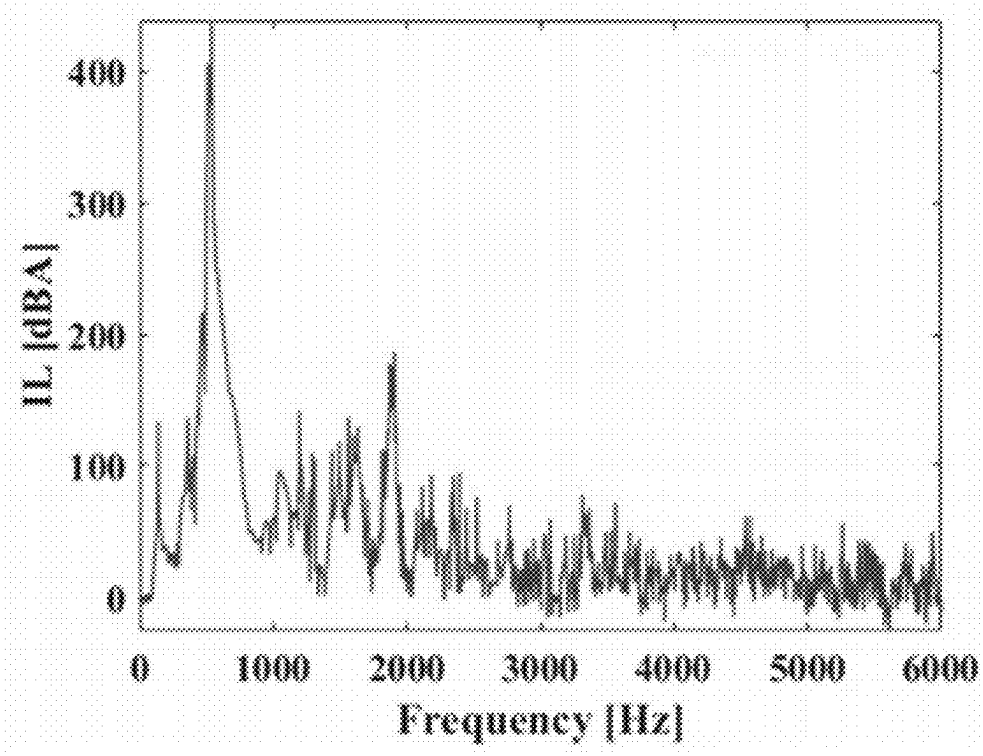

400
300
200
100
0
IL [dBA]
0
500
1000
1500
2000
Frequency [Hz]

FIG. 14


400
300
200
100
0
IL [dBA]
0
1000
2000
3000
4000
5000
6000
Frequency [Hz]

ACOUSTIC METAMATERIAL-BASED MUFFLER FOR BROADBAND EXHAUST NOISE REDUCTION OF INTERNAL COMBUSTION ENGINES

BACKGROUND

1. Field

[0001] The present disclosure relates to an acoustic metamaterial-based muffler for broadband exhaust noise reduction of internal combustion engines, and more specifically, to an acoustic metamaterial-based muffler for broadband exhaust noise reduction of internal combustion engines in which a plurality of noise reduction units that attenuate exhaust noise in the corresponding frequency band are arranged in a straight pipe structure where centers of an inlet through which exhaust flows in and an outlet through which exhaust flows out coincide, and a plurality of walls forming the noise reduction units attenuate exhaust noise in the corresponding frequency band to reduce exhaust noise without interfering the flow of exhaust.

2. Description of the Related Art

[0002] In general, exhaust sound from a mechanical device powered by an internal combustion engine, such as a vehicle, is a source of noise in everyday life.

[0003] For the purpose of reducing exhaust noise generated from the power device of the internal combustion engine, a muffler is used to reduce noise.

[0004] Conventionally, many companies and organizations have reported research results on noise reduction devices for engines with a displacement equivalent to that of commercial vehicles.

[0005] On the other hand, development of an exhaust noise reduction device related to a mechanical device that uses a large internal combustion engine such as a large diesel generator and a combat vehicle as a power source is insufficient.

[0006] Most exhaust noise reduction devices of commercial vehicles on the market have complex internal structures, and a decrease in engine efficiency due to a pressure drop caused by the noise reduction device having such a structure is inevitable.

[0007] In this case, the higher the displacement of the mechanical device, the more sensitive it is to the pressure drop due to the complex internal structure of the exhaust noise reduction device, and requires a large diameter pipe size is required compared to passenger vehicles.

[0008] The muffler of the passenger vehicle uses a pipe with a diameter of about 5 cm due to exhaust characteristics, and a high-displacement mechanical device using a large engine such as a generator and a combat vehicle requires a pipe several times larger than this.

[0009] Generally, as the size of the pipe increases, the size of the installed muffler also increases, which may cause installation space problems.

[0010] In addition, the size of an outer cylinder must be small due to constraints related to installation space, and in such a structure, it is difficult to implement a wide noise reduction band with a single unit structure.

[0011] For prior art, refer to Korean Patent Application Laid-open Publication No. 10-2013-0064299 (Jun. 18, 2013).

SUMMARY

[0012] The present disclosure provides an acoustic metamaterial-based muffler for broadband exhaust noise reduction of internal combustion engines in which a plurality of noise reduction units that attenuate exhaust noise in the corresponding frequency band form a straight pipe structure where centers of an inlet through which exhaust flows in and an outlet through which exhaust flows out coincide to be arranged in a structure in which a plurality of Helmholtz resonators are connected in series and a ¼ wave tube structure, and thereby a plurality of walls forming the noise reduction units attenuate exhaust noise in the corresponding frequency band to have an exhaust noise reduction band wider than that of the prior art without interfering the flow of exhaust.

[0013] An acoustic metamaterial-based muffler for broadband exhaust noise reduction of internal combustion engines according to the present disclosure is mounted on an exhaust pipe of an internal combustion engine, and includes an exhaust flow pipe that is formed of an inlet on one side through which exhaust of the internal combustion engine flows in, an outlet on the other side through which the exhaust flows out, and a flow passage on the inside through which the exhaust flows from one side to the other side; and a plurality of noise reduction units that are provided inside along a longitudinal direction of the exhaust flow pipe to attenuate noise in the corresponding frequency band among the exhaust noises flowing along the exhaust flow pipe.

[0014] In this case, the plurality of noise reduction units according to the present disclosure includes a first noise reduction unit that attenuates exhaust noise in the frequency bands of 296 to 367 Hz, 374 to 804 Hz, 962 to 1349 Hz, 1401 to 1784 Hz, and 1824 to 2000 Hz among the frequency ranges of 1 to 2000 Hz, a second noise reduction unit that attenuates exhaust noise in the frequency bands of 368 to 373 Hz, 805 to 882 Hz, 1350 to 1400 Hz, and 1785 to 1823 Hz among the frequency bands in which the noise reduction band of the first noise reduction unit is not formed, a third noise reduction unit that attenuates exhaust noise in the frequency band of 883 to 961 Hz among the frequency bands in which the noise reduction bands of the first and second noise reduction units are not formed, a fourth noise reduction unit that attenuates exhaust noise in the frequency band of 277 to 295 Hz among the frequency bands in which the noise reduction bands of the first, second, and third noise reduction units are not formed, and a fifth noise reduction unit that attenuates exhaust noise in the frequency band of 102 to 276 Hz among the frequency bands in which the noise reduction bands of the first, second, third, and fourth noise reduction units are not formed.

[0015] Here, the first noise reduction unit according to the present disclosure includes a first front outer wall that is formed orthogonal to a longitudinal direction of the exhaust flow pipe, a first rear outer wall that is spaced apart from the first front outer wall at a certain distance, and formed orthogonal to the longitudinal direction of the exhaust flow pipe, a 1-1 inner wall that is formed at ends of the first front outer wall and the first rear outer wall to have a length toward an inner center between the first front outer wall and the first rear outer wall, and of which length is parallel to the longitudinal direction of the exhaust flow pipe, a 1-2 inner wall that is spaced apart from the 1-1 inner wall at a corresponding distance in an outer circumferential direction on the inside between the first front outer wall and the first

rear outer wall, and is formed to have a length toward an inner center between the first front outer wall and the first rear outer wall, and of which length is parallel to a length of the 1-1 inner wall, a 1-3 inner wall that is spaced apart from the 1-2 inner wall at a corresponding distance in the outer circumferential direction on the inside between the first front outer wall and the first rear outer wall, and is formed to have a length toward the inner center between the first front outer wall and the first rear outer wall, and of which length is parallel to the length of the 1-1 inner wall, and a 1-4 inner wall that is spaced apart from the 1-3 inner wall at a corresponding distance in the outer circumferential direction on the inside between the first front outer wall and the first rear outer wall, and is formed to have a length toward the inner center of the first front outer wall and the first rear outer wall, and of which length is parallel to the length of the 1-1 inner wall.

[0016] In this case, the separation distance between the first front outer wall and the first rear outer wall according to the present disclosure is 104 mm, and the length of the 1-1 inner wall is 8 mm, the length of the 1-2 inner wall is 14 mm and the separation distance from the 1-1 inner wall is 26 mm based on the 1-1 inner wall, the length of the 1-3 inner wall is 42 mm and the separation distance from the 1-1 inner wall is 62 mm based on the 1-1 inner wall, and the length of the 1-4 inner wall is 46 mm and the separation distance from the 1-1 inner wall is 76 mm based on the 1-1 inner wall.

[0017] In addition, the second noise reduction unit according to the present disclosure includes a second front outer wall that is formed orthogonal to a longitudinal direction of the exhaust flow pipe, a second rear outer wall that is spaced apart from the second front outer wall at a certain distance, and formed orthogonal to the longitudinal direction of the exhaust flow pipe, a 2-1 inner wall that is formed at ends of the second front outer wall and the second rear outer wall to have a length toward an inner center between the second front outer wall and the second rear outer wall, and of which length is parallel to the longitudinal direction of the exhaust flow pipe, a 2-2 inner wall that is spaced apart from the 2-1 inner wall at a corresponding distance in an outer circumferential direction on the inside between the second front outer wall and the second rear outer wall, and is formed to have a length toward an inner center between the second front outer wall and the second rear outer wall, and of which length is parallel to the length of the 2-1 inner wall, a 2-3 inner wall that is spaced apart from the 2-2 inner wall at a corresponding distance in the outer circumferential direction on the inside between the second front outer wall and the second rear outer wall, and is formed to have a length toward the inner center between the second front outer wall and the second rear outer wall, and of which length is parallel to the length of the 2-1 inner wall, and a 2-4 inner wall that is spaced apart from the 2-3 inner wall at a corresponding distance in the outer circumferential direction on the inside between the second front outer wall and the second rear outer wall, and is formed to have a length toward the inner center of the second front outer wall and the second rear outer wall, and of which length is parallel to the length of the 2-1 inner wall.

[0018] In this case, the separation distance between the second front outer wall and the second rear outer wall according to the present disclosure is 144 mm, and the length of the 2-1 inner wall is 24 mm, the length of the 2-2 inner wall is 20 mm and the separation distance from the 2-1 inner wall is 16 mm based on the 2-1 inner wall, the length of the 2-3 inner wall is 20 mm and the separation distance from the 2-1 inner wall is 112 mm based on the 2-1 inner wall, and the length of the 2-4 inner wall is 56 mm and the separation distance from the 2-1 inner wall is 124 mm based on the 2-1 inner wall.

[0019] In addition, the third noise reduction unit according to the present disclosure includes a third front outer wall that is formed orthogonal to a longitudinal direction of the exhaust flow pipe, a third rear outer wall that is spaced apart from the third front outer wall at a certain distance, and formed orthogonal to the longitudinal direction of the exhaust flow pipe, a 3-1 inner wall that is formed at ends of the third front outer wall and the third rear outer wall to have a length toward an inner center between the third front outer wall and the third rear outer wall, and of which length is parallel to the longitudinal direction of the exhaust flow pipe, and a 3-2 inner wall that is spaced apart from the 3-1 inner wall at a corresponding distance in an outer circumferential direction on the inside between the third front outer wall and the third rear outer wall, and is formed to have a length toward an inner center between the third front outer wall and the third rear outer wall, and of which length is parallel to the length of the 3-1 inner wall.

[0020] In this case, it is preferable that the separation distance between the third front outer wall and the third rear outer wall according to the present disclosure is 184 mm, and the length of the 3-1 inner wall is 34 mm, and the length of the 3-2 inner wall is 52 mm and the separation distance from the 3-1 inner wall is 154 mm based on the 3-1 inner wall.

[0021] In addition, the fourth noise reduction unit according to the present disclosure includes a fourth front outer wall that is formed orthogonal to a longitudinal direction of the exhaust flow pipe, a fourth rear outer wall that is spaced apart from the fourth front outer wall at a certain distance, and formed orthogonal to the longitudinal direction of the exhaust flow pipe, a 4-1 inner wall that is formed at ends of the fourth front outer wall and the fourth rear outer wall to have a length toward an inner center between the fourth front outer wall and the fourth rear outer wall, and of which length is parallel to the longitudinal direction of the exhaust flow pipe, a 4-2 inner wall that is spaced apart from the 4-1 inner wall at a corresponding distance in an outer circumferential direction on the inside between the fourth front outer wall and the fourth rear outer wall, and is formed to have a length toward an inner center between the fourth front outer wall and the fourth rear outer wall, and of which length is parallel to the length of the 4-1 inner wall, a 4-3 inner wall that is spaced apart from the 4-2 inner wall at a corresponding distance in the outer circumferential direction on the inside between the fourth front outer wall and the fourth rear outer wall, and is formed to have a length toward the inner center between the fourth front outer wall and the fourth rear outer wall, and of which length is parallel to the length of the 4-1 inner wall, and a 4-4 inner wall that is spaced apart from the 4-3 inner wall at a corresponding distance in the outer circumferential direction on the inside between the fourth front outer wall and the fourth rear outer wall, and is formed to have a length toward the inner center of the fourth front outer wall and the fourth rear outer wall, and of which length is parallel to the length of the 4-1 inner wall.

[0022] In this case, it is preferable that the separation distance between the fourth front outer wall and the fourth

rear outer wall according to the present disclosure is 188 mm, and the length of the 4-1 inner wall is 42 mm, the length of the 4-2 inner wall is 18 mm and the separation distance from the 4-1 inner wall is 68 mm based on the 4-1 inner wall, the length of the 4-3 inner wall is 66 mm and the separation distance from the 4-1 inner wall is 120 mm based on the 4-1 inner wall, and the length of the 4-4 inner wall is 78 mm and the separation distance from the 4-1 inner wall is 128 mm based on the 4-1 inner wall.

[0023] In addition, the fifth noise reduction unit according to the present disclosure includes a fifth front outer wall that is formed orthogonal to a longitudinal direction of the exhaust flow pipe, a fifth rear outer wall that is spaced apart from the fifth front outer wall at a certain distance, and formed orthogonal to the longitudinal direction of the exhaust flow pipe, a 5-1 inner wall that is formed at ends of the fifth front outer wall and the fifth rear outer wall to have a length toward an inner center between the fifth front outer wall and the fifth rear outer wall, and of which length is parallel to the longitudinal direction of the exhaust flow pipe, and a 5-2 inner wall that is formed at the end of the 5-1 inner wall to have a length toward the inside between the fifth front outer wall and the fifth rear outer wall, and of which length is parallel to the lengths of the fifth front outer wall and the fifth rear outer wall.

[0024] In this case, it is preferable that the separation distance between the fifth front outer wall and the fifth rear outer wall according to the present disclosure is 392 mm, and the length of the 5-1 inner wall is 182 mm, and the length of the 5-2 inner wall is 54 mm.

[0025] In addition, each of the first to fifth noise reduction units according to the present disclosure may be provided as a pair.

[0026] In addition, the first noise reduction unit, the second noise reduction unit, the third noise reduction unit, the fourth noise reduction unit, and the fifth noise reduction unit according to the present disclosure may be provided in that order.

[0027] In addition, the noise reduction unit according to the present disclosure may be provided with only one noise reduction unit selected from the first to fifth noise reduction units.

[0028] In addition, the noise reduction unit according to the present disclosure may be provided with only two or more noise reduction units selected from the first to fifth noise reduction units.

[0029] The effects exhibited by the acoustic metamaterial-based muffler for broadband exhaust noise reduction of internal combustion engines according to the present disclosure are as follows.

[0030] A plurality of noise reduction units that attenuate exhaust noise in the corresponding frequency band form a straight pipe structure where centers of an inlet through which exhaust flows in and an outlet through which exhaust flows out coincide to be arranged in a structure in which a plurality of Helmholtz resonators are connected in series and a ¼ wave tube structure, and thereby a plurality of walls forming the noise reduction units attenuate exhaust noise in the corresponding frequency band to have an exhaust noise reduction band wider than that of the prior art without interfering the flow of exhaust.

BRIEF DESCRIPTION OF THE DRAWINGS

[0031] The above and other aspects, features, and advantages of certain embodiments of the disclosure will be more apparent from the following description taken in conjunction with the accompanying drawings, in which:

[0032] FIG. **1** is a perspective view illustrating an acoustic metamaterial-based muffler for broadband exhaust noise reduction of internal combustion engines according to an embodiment of the present disclosure;

[0033] FIG. **2** is a sectional view illustrating the acoustic metamaterial-based muffler for broadband exhaust noise reduction of internal combustion engines according to an embodiment of the present disclosure;

[0034] FIG. **3** is a sectional view illustrating a cross-section of a first noise reduction unit according to an embodiment of the present disclosure;

[0035] FIG. **4** is a graph illustrating analysis results of a dispersion curve (a) and a band cap (b) of the first noise reduction unit according to an embodiment of the present disclosure;

[0036] FIG. **5** is a sectional view illustrating a cross-section of a second noise reduction unit according to an embodiment of the present disclosure;

[0037] FIG. **6** is a graph illustrating analysis results of a dispersion curve (a) and a band cap (b) of the second noise reduction unit according to an embodiment of the present disclosure;

[0038] FIG. **7** is a sectional view illustrating a cross-section of a third noise reduction unit according to an embodiment of the present disclosure;

[0039] FIG. **8** is a graph illustrating analysis results of a dispersion curve (a) and a band cap (b) of the third noise reduction unit according to an embodiment of the present disclosure;

[0040] FIG. **9** is a sectional view illustrating a fourth noise reduction unit according to an embodiment of the present disclosure;

[0041] FIG. **10** is a graph illustrating analysis results of a dispersion curve (a) and a band cap (b) of the fourth noise reduction unit according to an embodiment of the present disclosure;

[0042] FIG. **11** is a sectional view illustrating a cross-section of a fifth noise reduction unit according to an embodiment of the present disclosure;

[0043] FIG. **12** is a graph illustrating analysis results of a dispersion curve (a) and a band cap (b) of the fifth noise reduction unit according to an embodiment of the present disclosure;

[0044] FIG. **13** is a graph illustrating an insertion loss curve obtained in a frequency band of 1 to 2000 Hz by an acoustic metamaterial-based muffler for broadband exhaust noise reduction of internal combustion engines according to an embodiment of the present disclosure; and

[0045] FIG. **14** is a graph illustrating an insertion loss curve obtained in a frequency band of 1 to 6000 Hz by an acoustic metamaterial-based muffler for broadband exhaust noise reduction of internal combustion engines according to an embodiment of the present disclosure.

DETAILED DESCRIPTION

[0046] Hereinafter, preferred embodiments according to the present disclosure will be described in detail with reference to the attached drawings. Prior to this, the terms or

words used in this specification and claims should not be construed as limited to their usual or dictionary meanings, and the inventor should appropriately define the concept of terms in order to explain his or her invention in the best way. Based on the principle of definability, it must be interpreted with meaning and concept consistent with the technical idea of the present disclosure.

[0047] Therefore, the embodiments described in this specification and the configurations illustrated in the drawings are only the most preferred embodiments of the present disclosure, and do not represent the entire technical idea of the present disclosure, so it should be understood that at the time of filing this application, there may be equivalent variations that may be replaced.

[0048] First, a metamaterial is a material artificially designed to have unique properties that cannot be found in the natural world, and the metamaterial is composed of a repeating arrangement of units.

[0049] An acoustic metamaterial may control wave energy such as sound waves, and acoustic properties of the acoustic metamaterial may be known from a dispersion curve obtained through acoustic analysis of the unit, and a band gap, which is a section where the wave number becomes an imaginary number, coincides with a noise reduction band.

[0050] In other words, the band gap section becomes a frequency section where transmitted noise is reduced compared to incident noise when implementing the acoustic metamaterial by repeating the arrangement of the units.

[0051] The present disclosure relates to an acoustic metamaterial-based muffler for broadband exhaust noise reduction of internal combustion engines in which a plurality of noise reduction units that attenuate exhaust noise in the corresponding frequency band are arranged in a straight pipe structure where centers of an inlet through which exhaust flows in and an outlet through which exhaust flows out coincide, and a plurality of walls forming the noise reduction units attenuate exhaust noise in the corresponding frequency band to reduce exhaust noise without interfering the flow of exhaust, and is described with reference to the drawings as follows.

[0052] The acoustic metamaterial-based muffler for broadband exhaust noise reduction of internal combustion engines according to an embodiment of the present disclosure with reference to FIGS. **1** to **14** is mounted on an exhaust pipe of a large internal combustion engine, and includes an exhaust flow pipe **1000** and a plurality of noise reduction units **2000**, in which the exhaust flow pipe **1000** is formed of an inlet **1001** on one side through which exhaust of the internal combustion engine flows in, an outlet **1002** on the other side through which the exhaust flows out, and a flow passage **1003** on the inside through which the exhaust flows from one side to the other side.

[0053] In this case, the exhaust flow pipe **1000** has a straight pipe shape with a circular circumference, and diameters of the inlet **1001** through which the exhaust flows in and the outlet **1002** through which the exhaust flows out are desirably smaller than a diameter of the exhaust flow pipe **1000**.

[0054] In addition, the plurality of noise reduction units **2000** are provided along a longitudinal direction of the exhaust flow pipe **1000** to attenuate noise in the corresponding frequency band among the exhaust noises flowing along the exhaust flow pipe **1000**.

[0055] The noise reduction unit **2000** includes a total of 5 types of a first noise reduction unit **2100**, a second noise reduction unit **2200**, a third noise reduction unit **2300**, a fourth noise reduction unit **2400**, and a fifth noise reduction unit **2500**, and each pair is arranged to form a muffler.

[0056] In this case, internal structural dimensions of the five types of noise reduction units **2100**, **2200**, **2300**, **2400**, and **2500** may be set differently to each other so that band gaps of the respective noise reduction units **2100**, **2200**, **2300**, **2400**, and **2500** do not coincide.

[0057] In addition, the above-mentioned noise reduction units **2000** do not necessarily need to be of the five types, and even if the noise reduction units **2000** are provided with two or more types which are selected from the five types of the noise reduction units **2100**, **2200**, **2300**, **2400**, and **2500**, the broadband noise reduction band may be achieved by providing the noise reduction units **2000** with differently set band gaps.

[0058] With reference to FIGS. **3** to **12**, each of the noise reduction units **2100**, **2200**, **2300**, **2400**, and **2500** according to an embodiment of the present disclosure will be described in more detail as follows.

[0059] First, the first noise reduction unit **2100** with reference to FIGS. **3** and **4** attenuates exhaust noise in frequency bands of 296 to 367 Hz, 374 to 804 Hz, 962 to 1349 Hz, 1401 to 1784 Hz, and 1824 to 2000 Hz among the frequency ranges of 1 to 2000 Hz.

[0060] In this case, the first noise reduction unit **2100** includes a first front outer wall **2101**, a first rear outer wall **2102**, a 1-1 inner wall **2103**, a 1-2 inner wall **2104**, a 1-3 inner wall **2105**, and a 1-4 inner wall **2106**. The number, position, and length of the inner walls are only examples, and the number of inner walls is not limited to 4 according to design conditions of the muffler, and may be adjusted in various ways to be more or less than that.

[0061] As an example of the first noise reduction unit **2100**, it is preferable that the first front outer wall **2101** is formed orthogonal to a longitudinal direction of the exhaust flow pipe **1000**, the first rear outer wall **2102** is formed to be spaced apart from the first front outer wall **2101** at a certain distance, and the first rear outer wall **2102** is also formed orthogonal to the longitudinal direction of the exhaust flow pipe **1000**.

[0062] In this case, it is preferable that the separation distance between the first front outer wall **2101** and the first rear outer wall **2102** is 104 mm, and an annular disk is formed at the center of the first front outer wall **2101** and the first rear outer wall **2102** to allow the exhaust to flow.

[0063] In addition, the 1-1 inner wall **2103** is formed at the ends of the first front outer wall **2101** and the first rear outer wall **2102** to have a length toward the inner center of the first front outer wall **2101** and the first rear outer wall **2102**, and its length is parallel to the longitudinal direction of the exhaust flow pipe **1000**.

[0064] In this case, it is preferable that the length of the 1-1 inner wall **2103** is 8 mm, and wave energy such as sound waves of exhaust flowing along the exhaust passage is incident between the 1-1 inner walls **2103** formed at the ends of the first front outer wall **2101** and the first rear outer wall **2102**, respectively.

[0065] The 1-2 inner wall **2104** is spaced apart from the 1-1 inner wall **2103** at a corresponding distance in the outer circumferential direction on the inside between the first front outer wall **2101** and the first rear outer wall **2102**, and is

formed to have a length toward the inner center of the first front outer wall **2101** and the first rear outer wall **2102**, and its length is parallel to the length of the 1-1 inner wall **2103**.

[0066] In this case, it is preferable that the length of the 1-2 inner wall **2104** is 14 mm, the separation distance from the 1-1 inner wall **2103** is 26 mm based on the 1-1 inner wall **2103**, and wave energy such as sound waves of exhaust passing between the 1-1 inner walls **2103** is incident between the 1-2 inner walls **2104** formed on the inner surfaces of the first front outer wall **2101** and the first rear outer wall **2102**, respectively.

[0067] The 1-3 inner wall **2105** is spaced apart from the 1-2 inner wall **2104** at a corresponding distance in the outer circumferential direction on the inside between the first front outer wall **2101** and the first rear outer wall **2102**, and is formed to have a length toward the inner center of the first front outer wall **2101** and the first rear outer wall **2102**, and its length is parallel to the length of the 1-1 inner wall **2103**.

[0068] In this case, it is preferable that the length of the 1-3 inner wall **2105** is 42 mm, the separation distance from the 1-1 inner wall **2103** is 62 mm based on the 1-1 inner wall **2103**, and wave energy such as sound waves of exhaust passing between the 1-3 inner walls **2105** is incident between the 1-3 inner walls **2105** formed on the inner surfaces of the first front outer wall **2101** and the first rear outer wall **2102**, respectively.

[0069] The 1-4 inner wall **2106** is spaced apart from the 1-3 inner wall **2105** at a corresponding distance in the outer circumferential direction on the inside between the first front outer wall **2101** and the first rear outer wall **2102**, and is formed to have a length toward the inner center of the first front outer wall **2101** and the first rear outer wall **2102**, and its length is parallel to the length of the 1-1 inner wall **2103**.

[0070] In this case, it is preferable that the length of the 1-4 inner wall **2106** is 46 mm, the separation distance from the 1-1 inner wall **2103** is 76 mm based on the 1-1 inner wall **2103**, and wave energy such as sound waves of exhaust passing between the 1-3 inner walls **2105** is incident between the 1-4 inner walls **2106** formed on the inner surfaces of the first front outer wall **2101** and the first rear outer wall **2102**, respectively.

[0071] Therefore, the lengths of the 1-1 inner wall **2103**, the 1-2 inner wall **2104**, the 1-3 inner wall **2105**, and the 1-4 inner wall **2106** are parallel to each other, and the above-described inner walls are formed on the first front outer wall **2101** and the first rear outer wall **2102**, respectively, and are bilaterally symmetrical based on the inner center of the first front outer wall **2101** and the first rear outer wall **2102**.

[0072] In addition, as described above, it is preferable that the 1-1 inner wall **2103**, the 1-2 inner wall **2104**, the 1-3 inner wall **2105**, and the 1-4 inner wall **2106** of the first noise reduction unit **2100** are axially symmetrical having a shape rotated about the central axis of the exhaust flow pipe **1000**.

[0073] In addition, the cavity divided by the 1-1 inner wall **2103**, the 1-2 inner wall **2104**, the 1-3 inner wall **2105**, and the 1-4 inner wall **2106** may be formed of a structure in which a plurality of Helmholtz resonators are connected in series and a ¼ wave tube structure to reduce exhaust noise.

[0074] Therefore, FIG. **4** illustrates a dispersion curve and a band gap section according to the first noise reduction unit **2100**, and the first noise reduction unit **2100** forms noise reduction bands in the ranges of 296 to 367 Hz, 374 to 804 Hz, 962 to 1349 Hz, 1401 to 1784 Hz, and 1824 to 2000 Hz among the frequency bands of 1 to 2000 Hz, thereby reducing exhaust noise by attenuating the exhaust noise in the corresponding frequency bands.

[0075] In addition, the second noise reduction unit **2200** with reference to FIGS. **5** and **6** attenuates exhaust noise in the frequency bands of 368 to 373 Hz, 805 to 882 Hz, 1350 to 1400 Hz, and 1785 to 1823 Hz among the frequency bands in which the noise reduction band of the first noise reduction unit **2100** is not formed.

[0076] In this case, the second noise reduction unit **2200** includes a second front outer wall **2201**, a second rear outer wall **2202**, a 2-1 inner wall **2203**, a 2-2 inner wall **2204**, a 2-3 inner wall **2205**, and a 2-4 inner wall **2206**. The number, position, and length of the inner walls are only examples, and the number of inner walls is not limited to 4 according to design conditions of the muffler, and may be adjusted in various ways to be more or less than that.

[0077] As an example of the second noise reduction unit **2200**, it is preferable that the second front outer wall **2201** is formed orthogonal to the longitudinal direction of the exhaust flow pipe **1000**, the second rear outer wall **2202** is formed to be spaced apart from the second front outer wall **2201** at a certain distance, and the second rear outer wall **2202** is also formed orthogonal to the longitudinal direction of the exhaust flow pipe **1000**.

[0078] In this case, it is preferable that the separation distance between the second front outer wall **2201** and the second rear outer wall **2202** is 144 mm, and an annular disk is formed at the center of the second front outer wall **2201** and the second rear outer wall **2202** to allow the exhaust to flow.

[0079] In addition, the 2-1 inner wall **2203** is formed at the ends of the second front outer wall **2201** and the second rear outer wall **2202** to have a length toward the inner center of the second front outer wall **2201** and the second rear outer wall **2202**, and its length is parallel to the longitudinal direction of the exhaust flow pipe **1000**.

[0080] In this case, it is preferable that the length of the 2-1 inner wall **2203** is 20 mm, and wave energy such as sound waves of exhaust flowing along the exhaust passage is incident between the 2-1 inner walls **2203** formed at the ends of the second front outer wall **2201** and the second rear outer wall **2202**, respectively.

[0081] The 2-2 inner wall **2204** is spaced apart from the 2-1 inner wall **2203** at a corresponding distance in the outer circumferential direction on the inside between the second front outer wall **2201** and the second rear outer wall **2202**, and is formed to have a length toward the inner center of the second front outer wall **2201** and the second rear outer wall **2202**, and its length is parallel to the length of the 2-1 inner wall **2203**.

[0082] In this case, it is preferable that the length of the 2-2 inner wall **2204** is 20 mm, the separation distance from the 2-1 inner wall **2203** is 16 mm based on the 2-1 inner wall **2203**, and wave energy such as sound waves of exhaust passing between the 2-1 inner walls **2203** is incident between the 2-2 inner walls **2204** formed on the inner surfaces of the second front outer wall **2201** and the second rear outer wall **2202**, respectively.

[0083] The 2-3 inner wall **2205** is spaced apart from the 2-2 inner wall **2204** at a corresponding distance in the outer circumferential direction on the inside between the second front outer wall **2201** and the second rear outer wall **2202** and is formed to have a length toward the inner center of the

second front outer wall **2201** and the second rear outer wall **2202**, and its length is parallel to the length of the 2-1 inner wall **2203**.

[0084] In this case, it is preferable that the length of the 2-3 inner wall **2205** is 20 mm, the separation distance from the 2-1 inner wall **2203** is 62 mm based on the 2-1 inner wall **2203**, and wave energy such as sound waves of exhaust passing between the 2-3 inner walls **2205** is incident between the 2-3 inner walls **2205** formed on the inner surfaces of the second front outer wall **2201** and the second rear outer wall **2202**, respectively.

[0085] The 2-4 inner wall **2206** is spaced apart from the 2-3 inner wall **2205** at a corresponding distance in the outer circumferential direction on the inside between the second front outer wall **2201** and the second rear outer wall **2202** and is formed to have a length toward the inner center of the second front outer wall **2201** and the second rear outer wall **2202**, and its length is parallel to the length of the 2-1 inner wall **2203**.

[0086] In this case, it is preferable that the length of the 2-4 inner wall **2206** is 56 mm, the separation distance from the 2-1 inner wall **2203** is 124 mm based on the 2-1 inner wall **2203**, and wave energy such as sound waves of exhaust passing between the 2-3 inner walls **2205** is incident between the 2-4 inner walls **2206** formed on the inner surfaces of the second front outer wall **2201** and the second rear outer wall **2202**, respectively.

[0087] Therefore, the lengths of the 2-1 inner wall **2203**, the 2-2 inner wall **2204**, the 2-3 inner wall **2205**, and the 2-4 inner wall **2206** are parallel to each other, and the above-described inner walls are formed on the second front outer wall **2201** and the second rear outer wall **2202**, respectively, and are bilaterally symmetrical based on the inner center of the second front outer wall **2201** and the second rear outer wall **2202**.

[0088] In addition, as described above, it is preferable that the 2-1 inner wall **2203**, the 2-2 inner wall **2204**, the 2-3 inner wall **2205**, and the 2-4 inner wall **2206** of the second noise reduction unit **2200** are axially symmetrical having a shape rotated about the central axis of the exhaust flow pipe **1000**.

[0089] In addition, the cavity divided by the 2-1 inner wall **2203**, the 2-2 inner wall **2204**, the 2-3 inner wall **2205**, and the 2-4 inner wall **2206** may be formed of a structure in which a plurality of Helmholtz resonators are connected in series and a ¼ wave tube structure to reduce exhaust noise.

[0090] Therefore, FIG. **6** illustrates a dispersion curve and a band gap section according to the second noise reduction unit **2200**, and the second noise reduction unit **2200** forms noise reduction bands in the ranges of 309 to 399 Hz, 427 to 882 Hz, 1010 to 1255 Hz, 1338 to 1630 Hz, and 1669 to 1670 Hz among the frequency bands of 1 to 2000 Hz, thereby reducing exhaust noise by attenuating the exhaust noise in the corresponding frequency bands.

[0091] Here, the second noise reduction unit **2200** has the noise reduction bands in 368 to 373 Hz, 805 to 882 Hz, 1350 to 1400 Hz, and 1785 to 1823 Hz among the frequency bands in which the noise reduction band of the first noise reduction unit **2100** is not formed, and in a case where the first noise reduction unit **2100** and the second noise reduction unit **2200** are used together, wide noise reduction bands of 296 to 882 Hz and 962 to 2000 Hz may be obtained.

[0092] In addition, the third noise reduction unit **2300** with reference to FIGS. **7** and **8** attenuates exhaust noise in the frequency band of 883 to 961 Hz among the frequency bands in which the noise reduction bands of the first and second noise reduction units **2100** and **2200** are not formed.

[0093] In this case, the third noise reduction unit **2300** includes a third front outer wall **2301**, a third rear outer wall **2302**, a 3-1 inner wall **2303**, and a 3-2 inner wall **2304**. The number, position, and length of the inner walls are only examples, and the number of inner walls is not limited to 2 according to design conditions of the muffler, and may be adjusted in various ways to be more or less than that.

[0094] As an example of the third noise reduction unit **2300**, it is preferable that the third front outer wall **2301** is formed orthogonal to the longitudinal direction of the exhaust flow pipe **1000**, the third rear outer wall **2302** is formed to be spaced apart from the third front outer wall **2301** at a certain distance, and the third rear outer wall **2302** is also formed orthogonal to the longitudinal direction of the exhaust flow pipe **1000**.

[0095] In this case, it is preferable that the separation distance between the third front outer wall **2301** and the third rear outer wall **2302** is 184 mm, and an annular disk is formed at the center of the third front outer wall **2301** and the third rear outer wall **2302** to allow the exhaust to flow.

[0096] In addition, the 3-1 inner wall **2303** is formed at the ends of the third front outer wall **2301** and the third rear outer wall **2302** to have a length toward the inner center of the third front outer wall **2301** and the third rear outer wall **2302**, and its length is parallel to the longitudinal direction of the exhaust flow pipe **1000**.

[0097] In this case, it is preferable that the length of the 3-1 inner wall **2303** is 34 mm, and wave energy such as sound waves of exhaust flowing along the exhaust passage is incident between the 3-1 inner walls **2303** formed at the ends of the third front outer wall **2301** and the third rear outer wall **2302**, respectively.

[0098] The 3-2 inner wall **2304** is spaced apart from the 3-1 inner wall **2303** at a corresponding distance in the outer circumferential direction on the inside between the third front outer wall **2301** and the third rear outer wall **2302**, and is formed to have a length toward the inner center of the third front outer wall **2301** and the third rear outer wall **2302**, and its length is parallel to the length of the 3-1 inner wall **2303**.

[0099] In this case, it is preferable that the length of the 3-2 inner wall **2304** is 52 mm, the separation distance from the 3-1 inner wall **2303** is 144 mm based on the 3-1 inner wall **2303**, and wave energy such as sound waves of exhaust passing between the 3-1 inner walls **2303** is incident between the 3-2 inner walls **2304** formed on the inner surfaces of the third front outer wall **2301** and the third rear outer wall **2302**, respectively.

[0100] Therefore, the lengths of the 3-1 inner wall **2303** and the 3-2 inner wall **2304** are parallel to each other, and the above-described inner walls are formed on the third front outer wall **2301** and the third rear outer wall **2302**, respectively, and are bilaterally symmetrical based on the inner center of the third front outer wall **2301** and the third rear outer wall **2302**.

[0101] In addition, as described above, it is preferable that the 3-1 inner wall **2303** and the 3-2 inner wall **2304** of the third noise reduction unit **2300** are axially symmetrical having a shape rotated about the central axis of the exhaust flow pipe **1000**.

[0102] In addition, the cavity divided by the 3-1 inner wall **2303** and the 3-2 inner wall **2304** may be formed of a

structure in which a plurality of Helmholtz resonators are connected in series and a ¼ wave tube structure to reduce exhaust noise.

[0103] Therefore, FIG. **8** illustrates a dispersion curve and a band gap section according to the third noise reduction unit **2300**, and the third noise reduction unit **2300** forms noise reduction bands in the ranges of 297 to 489 Hz, 496 to 964 Hz, 1240 to 1292 Hz, 1295 to 1432 Hz, 1568 to 1714 Hz, 1735 to 1737 Hz, and 1860 to 1936 Hz among the frequency bands of 1 to 2000 Hz, thereby reducing exhaust noise by attenuating the exhaust noise in the corresponding frequency bands.

[0104] Here, the third noise reduction unit **2300** has the noise reduction bands in 883 to 961 Hz among the frequency bands in which the noise reduction bands of the first noise reduction unit **2100** and the second noise reduction unit **2200** are not formed, and in a case where the first noise reduction unit **2100**, the second noise reduction unit **2200**, and the third noise reduction unit **2300** are used together, wide noise reduction bands of 296 to 2000 Hz may be obtained.

[0105] In addition, the fourth noise reduction unit **2400** with reference to FIGS. **9** and **10** attenuates exhaust noise in the frequency band of 277 to 295 Hz among the frequency bands in which the noise reduction bands of the first, second, and third noise reduction units **2100**, **2200**, and **2300** are not formed.

[0106] In this case, the fourth noise reduction unit **2400** includes a fourth front outer wall **2401**, a fourth rear outer wall **2402**, a 4-1 inner wall **2403**, a 4-2 inner wall **2404**, a 4-3 inner wall **2405**, and a 4-4 inner wall **2406**. The number, position, and length of the inner walls are only examples, and the number of inner walls is not limited to 4 according to design conditions of the muffler, and may be adjusted in various ways to be more or less than that.

[0107] As an example of the fourth noise reduction unit **2400**, it is preferable that the fourth front outer wall **2401** is formed orthogonal to the longitudinal direction of the exhaust flow pipe **1000**, the fourth rear outer wall **2402** is formed to be spaced apart from the fourth front outer wall **2401** at a certain distance, and the fourth rear outer wall **2402** is also formed orthogonal to the longitudinal direction of the exhaust flow pipe **1000**.

[0108] In this case, it is preferable that the separation distance between the fourth front outer wall **2401** and the fourth rear outer wall **2402** is 188 mm, and an annular disk is formed at the center of the fourth front outer wall **2401** and the fourth rear outer wall **2402** to allow the exhaust to flow.

[0109] In addition, the 4-1 inner wall **2403** is formed at the ends of the fourth front outer wall **2401** and the fourth rear outer wall **2402** to have a length toward the inner center of the fourth front outer wall **2401** and the fourth rear outer wall **2402**, and its length is parallel to the longitudinal direction of the exhaust flow pipe **1000**.

[0110] In this case, it is preferable that the length of the 4-1 inner wall **2403** is 42 mm, and wave energy such as sound waves of exhaust flowing along the exhaust passage is incident between the 4-1 inner walls **2403** formed at the ends of the fourth front outer wall **2401** and the fourth rear outer wall **2402**, respectively.

[0111] The 4-2 inner wall **2404** is spaced apart from the 4-1 inner wall **2403** at a corresponding distance in the outer circumferential direction on the inside between the fourth front outer wall **2401** and the fourth rear outer wall **2402**, and is formed to have a length toward the inner center of the fourth front outer wall **2401** and the fourth rear outer wall **2402**, and its length is parallel to the length of the 4-1 inner wall **2403**.

[0112] In this case, it is preferable that the length of the 4-2 inner wall **2404** is 18 mm, the separation distance from the 4-1 inner wall **2403** is 68 mm based on the 4-1 inner wall **2403**, and wave energy such as sound waves of exhaust passing between the 4-1 inner walls **2403** is incident between the 4-2 inner walls **2404** formed on the inner surfaces of the fourth front outer wall **2401** and the fourth rear outer wall **2402**, respectively.

[0113] The 4-3 inner wall **2405** is spaced apart from the 4-2 inner wall **2404** at a corresponding distance in the outer circumferential direction on the inside between the fourth front outer wall **2401** and the fourth rear outer wall **2402**, and is formed to have a length toward the inner center of the fourth front outer wall **2401** and the fourth rear outer wall **2402**, and its length is parallel to the length of the 4-1 inner wall **2403**.

[0114] In this case, it is preferable that the length of the 4-3 inner wall **2405** is 66 mm, the separation distance from the 4-1 inner wall **2403** is 120 mm based on the 4-1 inner wall **2403**, and wave energy such as sound waves of exhaust passing between the 4-2 inner walls **2404** is incident between the 4-3 inner walls **2405** formed on the inner surfaces of the fourth front outer wall **2401** and the fourth rear outer wall **2402**, respectively.

[0115] The 4-4 inner wall **2406** is spaced apart from the 4-3 inner wall **2405** at a corresponding distance in the outer circumferential direction on the inside between the fourth front outer wall **2401** and the fourth rear outer wall **2402**, and is formed to have a length toward the inner center of the fourth front outer wall **2401** and the fourth rear outer wall **2402**, and its length is parallel to the length of the 4-1 inner wall **2403**.

[0116] In this case, it is preferable that the length of the 4-4 inner wall **2406** is 78 mm, the separation distance from the 4-1 inner wall **2403** is 128 mm based on the 4-1 inner wall **2403**, and wave energy such as sound waves of exhaust passing between the 4-3 inner walls **2405** is incident between the 4-4 inner walls **2406** formed on the inner surfaces of the fourth front outer wall **2401** and the fourth rear outer wall **2402**, respectively.

[0117] Therefore, the lengths of the 4-1 inner wall **2403**, the 4-2 inner wall **2404**, the 4-3 inner wall **2405**, and the 4-4 inner wall **2406** are parallel to each other, and the above-described inner walls are formed on the fourth front outer wall **2401** and the fourth rear outer wall **2402**, respectively, and are bilaterally symmetrical based on the inner center of the fourth front outer wall **2401** and the fourth rear outer wall **2402**.

[0118] In addition, as described above, it is preferable that the 4-1 inner wall **2403**, the 4-2 inner wall **2404**, the 4-3 inner wall **2405**, and the 4-4 inner wall **2406** of the fourth noise reduction unit **2400** are axially symmetrical having a shape rotated about the central axis of the exhaust flow pipe **1000**.

[0119] In addition, the cavity divided by the 4-1 inner wall **2403**, the 4-2 inner wall **2404**, the 4-3 inner wall **2405**, and the 4-4 inner wall **2406** may be formed of a structure in which a plurality of Helmholtz resonators are connected in series and a ¼ wave tube structure to reduce exhaust noise.

[0120] Therefore, FIG. **10** illustrates a dispersion curve and a band gap section according to the fourth noise reduction unit **2400**, and the fourth noise reduction unit **2400** forms noise reduction bands in the ranges of 277 to 484 Hz, 487 to 757 Hz, 861 to 1141 Hz, 1240 to 1267 Hz, 1273 to 1321 Hz, 1425 to 1490 Hz, 1522 to 1573 Hz, and 1579 to 1647 Hz among the frequency bands of 1 to 2000 Hz, thereby reducing exhaust noise by attenuating the exhaust noise in the corresponding frequency bands.

[0121] Here, the fourth noise reduction unit **2400** has the noise reduction bands in 277 to 295 Hz among the frequency bands in which the noise reduction bands of the first noise reduction unit **2100** to the third noise reduction unit **2300** are not formed, and in a case where the first noise reduction unit **2100** to the fourth noise reduction unit **2400** are used together, wide noise reduction bands of 277 to 2000 Hz may be obtained.

[0122] In addition, the fifth noise reduction unit **2500** with reference to FIGS. **11** and **12** attenuates exhaust noise in the frequency band of 102 to 276 Hz among the frequency bands in which the noise reduction bands of the first, second, third, and fourth noise reduction units **2100**, **2200**, **2300**, and **1400** are not formed.

[0123] In this case, the fifth noise reduction unit **2500** includes a fifth front outer wall **2501**, a fifth rear outer wall **2502**, a 5-1 inner wall **2503**, and a 5-2 inner wall **2504**. The number, position, and length of the inner walls are only examples, and the number of inner walls is not limited to 2 according to design conditions of the muffler, and may be adjusted in various ways to be more or less than that.

[0124] As an example of the fifth noise reduction unit **2500**, it is preferable that the fifth front outer wall **2501** is formed orthogonal to the longitudinal direction of the exhaust flow pipe **1000**, the fifth rear outer wall **2502** is formed to be spaced apart from the fifth front outer wall **2501** at a certain distance, and the fifth rear outer wall **2502** is also formed orthogonal to the longitudinal direction of the exhaust flow pipe **1000**.

[0125] In this case, it is preferable that the separation distance between the fifth front outer wall **2501** and the fifth rear outer wall **2502** is 392 mm, and an annular disk is formed at the center of the fifth front outer wall **2501** and the fifth rear outer wall **2502** to allow the exhaust to flow.

[0126] In addition, the 5-1 inner wall **2503** is formed at the ends of the fifth front outer wall **2501** and the fifth rear outer wall **2502** to have a length toward the inner center of the fifth front outer wall **2501** and the fifth rear outer wall **2502**, and its length is parallel to the longitudinal direction of the exhaust flow pipe **1000**.

[0127] In this case, it is preferable that the length of the 5-1 inner wall **2503** is 182 mm, and wave energy such as sound waves of exhaust flowing along the exhaust passage **1003** is incident between the 5-1 inner walls **2503** formed on the ends of the fifth front outer wall **2501** and the fifth rear outer wall **2502**, respectively.

[0128] The 5-2 inner wall **2504** is formed at the end of the 5-1 inner wall **2503** to have a length toward the inside between the fifth front outer wall **2501** and the fifth rear outer wall **2502**, and its length is parallel to the lengths of the fifth front outer wall **2501** and the fifth rear outer wall **2502**.

[0129] In this case, it is preferable that the length of the 5-2 inner wall **25034** is 54 mm, and wave energy such as sound waves of exhaust flowing along the exhaust passage **1003** is incident between the 5-2 inner walls **2504** formed on the ends of the 5-1 inner walls **2503**, respectively.

[0130] Therefore, the 5-1 inner wall **2503** and the 5-2 inner wall **2504** orthogonal to each other are formed in the fifth front outer wall **2501** and the fifth rear outer wall **2502**, respectively, and are bilaterally symmetrical based on the inner center of the fifth front outer wall **2501** and the fifth rear outer wall **2502**.

[0131] In addition, as described above, it is preferable that the 5-1 inner wall **2503** and the 5-2 inner wall **2504** are axially symmetrical having a shape rotated about the central axis of the exhaust flow pipe **1000**.

[0132] In addition, the cavity formed by the 5-1 inner wall **2503** and the 5-2 inner wall **2504** may be formed of a Helmholtz resonator structure and a ¼ wave tube structure to reduce exhaust noise.

[0133] Therefore, FIG. **12** illustrates a dispersion curve and a band gap section according to the fifth noise reduction unit **2500**, and the fifth noise reduction unit **2500** forms noise reduction bands in the ranges of 102 to 303 Hz, 470 to 552 Hz, 650 to 708 Hz, 1156 to 1160 Hz, 1195 to 1247 Hz, 1438 to 1442 Hz, 1718 to 1734 Hz, 1897 to 1908 Hz, and 1940 to 1970 Hz among the frequency bands of 1 to 2000 Hz, thereby reducing exhaust noise by attenuating the exhaust noise in the corresponding frequency bands.

[0134] Here, the fifth noise reduction unit **2500** has the noise reduction bands in 102 to 276 Hz among the frequency bands in which the noise reduction bands of the first noise reduction unit **2100** to the fourth noise reduction unit **2400** are not formed, and in a case where the first noise reduction unit **2100** to the fifth noise reduction unit **2500** are used together, wide noise reduction bands of 102 to 2000 Hz may be obtained.

[0135] FIG. **13** is a graph illustrating an insertion loss curve obtained in a frequency band of 1 to 2000 Hz by an acoustic metamaterial-based muffler for broadband exhaust noise reduction of internal combustion engines according to an embodiment of the present disclosure, and it may be seen that exhaust noise is effectively reduced by the present disclosure.

[0136] FIG. **14** is a graph illustrating an insertion loss curve obtained in a frequency band of 1 to 6000 Hz by an acoustic metamaterial-based muffler for broadband exhaust noise reduction of internal combustion engines according to an embodiment of the present disclosure, and it may be seen that exhaust noise is effectively reduced by the present disclosure.

[0137] The present disclosure has been described with reference to the embodiments illustrated in the drawings, but these are merely exemplary, and those skilled in the art will understand that various modifications and equivalent other embodiments are possible therefrom. Therefore, the true scope of technical protection of the present disclosure should be determined by the technical spirit of the attached claims.

What is claimed is:

1. An acoustic metamaterial-based muffler for broadband exhaust noise reduction of internal combustion engines that is mounted on an exhaust pipe of an internal combustion engine, comprising:

an exhaust flow pipe that is formed of an inlet on one side through which exhaust of the internal combustion engine flows in, an outlet on the other side through

which the exhaust flows out, and a flow passage on the inside through which the exhaust flows from one side to the other side; and

a plurality of noise reduction units that are provided inside along a longitudinal direction of the exhaust flow pipe to attenuate noise in the corresponding frequency band among the exhaust noises flowing along the exhaust flow pipe.

2. The acoustic metamaterial-based muffler for broadband exhaust noise reduction of internal combustion engines according to claim **1**, wherein the plurality of noise reduction units includes

a first noise reduction unit that attenuates exhaust noise in the frequency bands of 296 to 367 Hz, 374 to 804 Hz, 962 to 1349 Hz, 1401 to 1784 Hz, and 1824 to 2000 Hz among the frequency ranges of 1 to 2000 Hz,

a second noise reduction unit that attenuates exhaust noise in the frequency bands of 368 to 373 Hz, 805 to 882 Hz, 1350 to 1400 Hz, and 1785 to 1823 Hz among the frequency bands in which the noise reduction band of the first noise reduction unit is not formed,

a third noise reduction unit that attenuates exhaust noise in the frequency band of 883 to 961 Hz among the frequency bands in which the noise reduction bands of the first and second noise reduction units are not formed,

a fourth noise reduction unit that attenuates exhaust noise in the frequency band of 277 to 295 Hz among the frequency bands in which the noise reduction bands of the first, second, and third noise reduction units are not formed, and

a fifth noise reduction unit that attenuates exhaust noise in the frequency band of 102 to 276 Hz among the frequency bands in which the noise reduction bands of the first, second, third, and fourth noise reduction units are not formed.

3. The acoustic metamaterial-based muffler for broadband exhaust noise reduction of internal combustion engines according to claim **2**, wherein the first noise reduction unit includes

a first front outer wall that is formed orthogonal to a longitudinal direction of the exhaust flow pipe,

a first rear outer wall that is spaced apart from the first front outer wall at a certain distance, and formed orthogonal to the longitudinal direction of the exhaust flow pipe,

a 1-1 inner wall that is formed at ends of the first front outer wall and the first rear outer wall to have a length toward an inner center between the first front outer wall and the first rear outer wall, and of which length is parallel to the longitudinal direction of the exhaust flow pipe,

a 1-2 inner wall that is spaced apart from the 1-1 inner wall at a corresponding distance in an outer circumferential direction on the inside between the first front outer wall and the first rear outer wall, and is formed to have a length toward an inner center between the first front outer wall and the first rear outer wall, and of which length is parallel to a length of the 1-1 inner wall,

a 1-3 inner wall that is spaced apart from the 1-2 inner wall at a corresponding distance in the outer circumferential direction on the inside between the first front outer wall and the first rear outer wall, and is formed to have a length toward the inner center between the first front outer wall and the first rear outer wall, and of which length is parallel to the length of the 1-1 inner wall, and

a 1-4 inner wall that is spaced apart from the 1-3 inner wall at a corresponding distance in the outer circumferential direction on the inside between the first front outer wall and the first rear outer wall, and is formed to have a length toward the inner center of the first front outer wall and the first rear outer wall, and of which length is parallel to the length of the 1-1 inner wall.

4. The acoustic metamaterial-based muffler for broadband exhaust noise reduction of internal combustion engines according to claim **3**, wherein the separation distance between the first front outer wall and the first rear outer wall is 104 mm, and the length of the 1-1 inner wall is 8 mm,

the length of the 1-2 inner wall is 14 mm and the separation distance from the 1-1 inner wall is 26 mm based on the 1-1 inner wall,

the length of the 1-3 inner wall is 42 mm and the separation distance from the 1-1 inner wall is 62 mm based on the 1-1 inner wall, and

the length of the 1-4 inner wall is 46 mm and the separation distance from the 1-1 inner wall is 76 mm based on the 1-1 inner wall.

5. The acoustic metamaterial-based muffler for broadband exhaust noise reduction of internal combustion engines according to claim **2**, wherein the second noise reduction unit includes

a second front outer wall that is formed orthogonal to a longitudinal direction of the exhaust flow pipe,

a second rear outer wall that is spaced apart from the second front outer wall at a certain distance, and formed orthogonal to the longitudinal direction of the exhaust flow pipe,

a 2-1 inner wall that is formed at ends of the second front outer wall and the second rear outer wall to have a length toward an inner center between the second front outer wall and the second rear outer wall, and of which length is parallel to the longitudinal direction of the exhaust flow pipe,

a 2-2 inner wall that is spaced apart from the 2-1 inner wall at a corresponding distance in an outer circumferential direction on the inside between the second front outer wall and the second rear outer wall, and is formed to have a length toward an inner center between the second front outer wall and the second rear outer wall, and of which length is parallel to the length of the 2-1 inner wall,

a 2-3 inner wall that is spaced apart from the 2-2 inner wall at a corresponding distance in the outer circumferential direction on the inside between the second front outer wall and the second rear outer wall, and is formed to have a length toward the inner center between the second front outer wall and the second rear outer wall, and of which length is parallel to the length of the 2-1 inner wall, and

a 2-4 inner wall that is spaced apart from the 2-3 inner wall at a corresponding distance in the outer circumferential direction on the inside between the second front outer wall and the second rear outer wall, and is formed to have a length toward the inner center of the second front outer wall and the second rear outer wall, and of which length is parallel to the length of the 2-1 inner wall.

6. The acoustic metamaterial-based muffler for broadband exhaust noise reduction of internal combustion engines according to claim **5**, wherein the separation distance between the second front outer wall and the second rear outer wall is 144 mm, and the length of the 2-1 inner wall is 24 mm,

the length of the 2-2 inner wall is 20 mm and the separation distance from the 2-1 inner wall is 16 mm based on the 2-1 inner wall,

the length of the 2-3 inner wall is 20 mm and the separation distance from the 2-1 inner wall is 112 mm based on the 2-1 inner wall, and

the length of the 2-4 inner wall is 56 mm and the separation distance from the 2-1 inner wall is 124 mm based on the 2-1 inner wall.

7. The acoustic metamaterial-based muffler for broadband exhaust noise reduction of internal combustion engines according to claim **2**, wherein the third noise reduction unit includes

a third front outer wall that is formed orthogonal to a longitudinal direction of the exhaust flow pipe,

a third rear outer wall that is spaced apart from the third front outer wall at a certain distance, and formed orthogonal to the longitudinal direction of the exhaust flow pipe,

a 3-1 inner wall that is formed at ends of the third front outer wall and the third rear outer wall to have a length toward an inner center between the third front outer wall and the third rear outer wall, and of which length is parallel to the longitudinal direction of the exhaust flow pipe, and

a 3-2 inner wall that is spaced apart from the 3-1 inner wall at a corresponding distance in an outer circumferential direction on the inside between the third front outer wall and the third rear outer wall, and is formed to have a length toward an inner center between the third front outer wall and the third rear outer wall, and of which length is parallel to the length of the 3-1 inner wall.

8. The acoustic metamaterial-based muffler for broadband exhaust noise reduction of internal combustion engines according to claim **7**, wherein the separation distance between the third front outer wall and the third rear outer wall is 184 mm, and the length of the 3-1 inner wall is 34 mm, and

the length of the 3-2 inner wall is 52 mm and the separation distance from the 3-1 inner wall is 154 mm based on the 3-1 inner wall.

9. The acoustic metamaterial-based muffler for broadband exhaust noise reduction of internal combustion engines according to claim **2**, wherein the fourth noise reduction unit includes

a fourth front outer wall that is formed orthogonal to a longitudinal direction of the exhaust flow pipe,

a fourth rear outer wall that is spaced apart from the fourth front outer wall at a certain distance, and formed orthogonal to the longitudinal direction of the exhaust flow pipe,

a 4-1 inner wall that is formed at ends of the fourth front outer wall and the fourth rear outer wall to have a length toward an inner center between the fourth front outer wall and the fourth rear outer wall, and of which length is parallel to the longitudinal direction of the exhaust flow pipe,

a 4-2 inner wall that is spaced apart from the 4-1 inner wall at a corresponding distance in an outer circumferential direction on the inside between the fourth front outer wall and the fourth rear outer wall, and is formed to have a length toward an inner center between the fourth front outer wall and the fourth rear outer wall, and of which length is parallel to the length of the 4-1 inner wall,

a 4-3 inner wall that is spaced apart from the 4-2 inner wall at a corresponding distance in the outer circumferential direction on the inside between the fourth front outer wall and the fourth rear outer wall, and is formed to have a length toward the inner center between the fourth front outer wall and the fourth rear outer wall, and of which length is parallel to the length of the 4-1 inner wall, and

a 4-4 inner wall that is spaced apart from the 4-3 inner wall at a corresponding distance in the outer circumferential direction on the inside between the fourth front outer wall and the fourth rear outer wall, and is formed to have a length toward the inner center of the fourth front outer wall and the fourth rear outer wall, and of which length is parallel to the length of the 4-1 inner wall.

10. The acoustic metamaterial-based muffler for broadband exhaust noise reduction of internal combustion engines according to claim **9**, wherein the separation distance between the fourth front outer wall and the fourth rear outer wall is 188 mm, and the length of the 4-1 inner wall is 42 mm,

the length of the 4-2 inner wall is 18 mm and the separation distance from the 4-1 inner wall is 68 mm based on the 4-1 inner wall,

the length of the 4-3 inner wall is 66 mm and the separation distance from the 4-1 inner wall is 120 mm based on the 4-1 inner wall, and

the length of the 4-4 inner wall is 78 mm and the separation distance from the 4-1 inner wall is 128 mm based on the 4-1 inner wall.

11. The acoustic metamaterial-based muffler for broadband exhaust noise reduction of internal combustion engines according to claim **2**, wherein the fifth noise reduction unit includes

a fifth front outer wall that is formed orthogonal to a longitudinal direction of the exhaust flow pipe,

a fifth rear outer wall that is spaced apart from the fifth front outer wall at a certain distance, and formed orthogonal to the longitudinal direction of the exhaust flow pipe,

a 5-1 inner wall that is formed at ends of the fifth front outer wall and the fifth rear outer wall to have a length toward an inner center between the fifth front outer wall and the fifth rear outer wall, and of which length is parallel to the longitudinal direction of the exhaust flow pipe, and

a 5-2 inner wall that is formed at the end of the 5-1 inner wall to have a length toward the inside between the fifth front outer wall and the fifth rear outer wall, and of which length is parallel to the lengths of the fifth front outer wall and the fifth rear outer wall.

12. The acoustic metamaterial-based muffler for broadband exhaust noise reduction of internal combustion engines according to claim **11**, wherein the separation distance

between the fifth front outer wall and the fifth rear outer wall is 392 mm, and the length of the 5-1 inner wall is 182 mm, and

the length of the 5-2 inner wall is 54 mm.

13. The acoustic metamaterial-based muffler for broadband exhaust noise reduction of internal combustion engines according to claim **2**, wherein each of the first to fifth noise reduction units is provided as a pair.

14. The acoustic metamaterial-based muffler for broadband exhaust noise reduction of internal combustion engines according to claim **13**, wherein the first noise reduction unit, the second noise reduction unit, the third noise reduction unit, the fourth noise reduction unit, and the fifth noise reduction unit are provided in that order.

15. The acoustic metamaterial-based muffler for broadband exhaust noise reduction of internal combustion engines according to claim **13**, wherein the noise reduction unit is provided with only one noise reduction unit selected from the first to fifth noise reduction units.

16. The acoustic metamaterial-based muffler for broadband exhaust noise reduction of internal combustion engines according to claim **13**, wherein the noise reduction unit is provided with only two or more noise reduction units selected from the first to fifth noise reduction units.

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