(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 4 303 866 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
10.01.2024 Bulletin 2024/02

(21) Application number: **22275087.9**

(22) Date of filing: **04.07.2022**

(51) International Patent Classification (IPC):
G10K 11/16 *(2006.01)* ***G10K 11/162*** *(2006.01)*

(52) Cooperative Patent Classification (CPC):
G10K 11/162; G10K 11/161

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

(71) Applicant: **BAE SYSTEMS plc**
London SW1Y 5AD (GB)

(72) Inventor: **The designation of the inventor has not yet been filed**

(74) Representative: **BAE SYSTEMS plc**
Group IP Department
Warwick House
P.O. Box 87
Farnborough Aerospace Centre
Farnborough Hampshire GU14 6YU (GB)

(54) DAMPER DEVICE, STRUCTURALLY DAMPED STRUCTURE, AND METHOD

(57) According to the present disclosure, there is provided a damper device for providing damping of primary structure, the damper device comprising: a body comprising a first surface and a second surface; a first acoustic black hole, ABH, provided at the first surface of the body, wherein the first surface of the body is adapted to contact, in a facing manner, a surface of the primary structure.

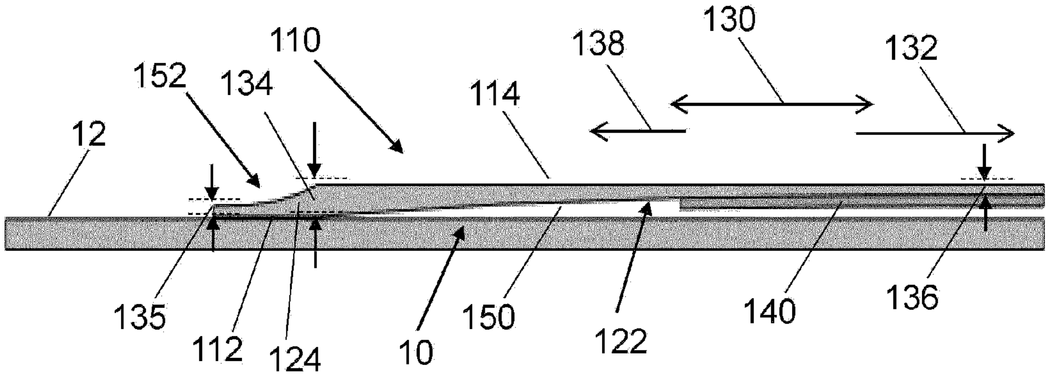

Fig. 4

EP 4 303 866 A1

Description

FIELD

[0001] The present invention relates to a damper device, a structurally damped structure, and method of damping a primary structure.

BACKGROUND

[0002] In product design, it is often necessary to design a product that is both lightweight and a low noise structure. However, this results in a conflict between reducing the weight and increasing the sound radiation from the structure. It is known to use a structure referred to as an acoustic black hole (ABH) to provide structural damping.

[0003] An acoustic black hole was originally described by Mironov in 1988 (M.A. Mironov. Propagation of a flexural wave in a plate whose thickness decreases smoothly to zero in a finite interval. Soviet Physics: Acoustics, 34(3):318-319, 1988). The acoustic black hole effect is typically achieved by introducing a power law taper into a beam or plate that changes the thickness over a set distance. This change in thickness profile causes the flexural waves propagating along the direction of the ABH to decrease in wave speed. In the theoretical limit, there is no reflection of the waves from the ABH. The ABH effect can also be achieved using other gradient functions, including a power-cosine curve, for example.

[0004] Figure 1 shows an example of an ABH 1 on a beam 2. The ABH 1 is provided with a layer of damping material 3. The flexural wave speed c_f (x), decreases as the taper height decreases as:

$$c_f(x) = \left(\frac{Eh^2(x)}{12\rho_s}\right)^{\frac{1}{4}} \omega^{\frac{1}{2}} \qquad (1)$$

where E is the Young's modulus of the ABH material, h(x) is the height of the taper, ρ_s is the density of the ABH material and w is the angular frequency.

[0005] From Equation 1 it can be seen that if the tip of the ABH reduces to zero thickness, i.e. h(x)=0, then the flexural wave speed at the tip will be c_f (x)=0. In this ideal, theoretical case, the incident wave will not be reflected from the end of the tapered beam and will therefore, be effectively attenuated.

[0006] In this respect, acoustic black holes are known in the art. For example, 'Higher-order WKB analysis of reflection from tapered elastic wedges' Journal of Sound and Vibration 449 (2019) 368-388 (Angelis Karlos, Stephen J. Elliot, Jordan Cheer), the contents of which are incorporated herein, provides examples of different types of 'one-dimensional' acoustic black holes. The thickness variations, of these acoustic black holes, are according to the expressions provided in Table 1 below:

Table 1

Thickness profile type	Thickness variation	Length of ideal wedge	Decay parameter
Power-law	$h = h_0\left(1 - \frac{x}{x_0}\right)^n$	$x_0 = \frac{x_1}{1-\left(\frac{h_1}{h_0}\right)^{1/n}}$	-
Exponential	$h = h_0 e^{-\beta x}$	∞	$\beta = \frac{1}{x_1 \ln\left(\frac{h_0}{h_1}\right)}$
Power-cosine	$h = h_0 \cos^n\left(\frac{\pi x}{2x_0}\right)$	$x_0 = \frac{\pi x_1}{2\arccos\left(\left(\frac{h_1}{h_0}\right)^{1/n}\right)}$	-
Gaussian	$h = h_0 e^{-\gamma x^2}$	∞	$\gamma = \frac{1}{x_1^2 \ln\left(\frac{h_0}{h_1}\right)}$
Compound power-law	$h = \begin{cases} \frac{h_0}{2}\left(2 - \left(\frac{2x}{x_0}\right)^n\right), 0 \le x \le \frac{x_0}{2} \\ \frac{h_0}{2}\left(2 - \frac{2x}{x_0}\right)^n, \frac{x_0}{2} \le x \le x_0 \end{cases}$	$x_0 = \frac{2x_1}{2-\left(\frac{h_1}{h_0}\right)^{1/n}}$	-

where:

'x' is the distance, in the length direction, from the upstream end of the acoustic black hole (i.e. at the start of the taper);

'x1' is the length of the acoustic black hole;

'h' is the thickness of the acoustic black hole (at position (x));

'h0' is the thickness of the acoustic black hole at the upstream end of the acoustic black hole (i.e. at position (x = 0));

'h1' is the thickness of the acoustic black hole at the downstream end of the acoustic black hole (i.e. at position (x = x1));

'n' is power coefficient of the shape function (which must be greater or equal to 2).

[0007] These parameters are illustrated in Figure 1.

[0008] It is known in the art to provide damper devices comprising ABHs as an add-on for a beam. These add-ons are attached to the beam at an edge of the beam. Whilst advantageous in providing damping, the ABH is susceptible to damage. As examples, damage may be caused by contact with surrounding components, or by stress-related weaking over time and operation. Additionally, the ABH may degrade due to exposure to air or contaminants. Furthermore, damping material is typically provided, which, whilst improving damping performance of the ABH, it would be desirable to further improve damping performance where possible. To broaden the potential applications of ABHs, it is desirable to overcome these limitations.

[0009] It is one aim of the present invention, amongst others, to provide an improved damper device and/or address one or more of the problems discussed above, or discussed elsewhere, or to at least provide an alternative damper device.

SUMMARY

[0010] According to a first aspect of the present invention, there is provided a damper device for providing damping of primary structure, the damper device comprising: a body comprising a first surface and a second surface; a first acoustic black hole, ABH, provided at the first surface of the body, wherein the first surface of the body is adapted to contact, in a facing manner, a surface of the primary structure.

[0011] In one example, the body is a plate, and the first surface is a first surface of the plate, and the second surface is a second surface of the plate.

[0012] In one example, the body is adapted to contact the surface of the primary structure such that a cavity is formed between the first ABH and the surface of the primary structure.

[0013] In one example, the cavity is enclosed.

[0014] In one example, the first ABH is in the form of a concave circular recess in the first surface.

[0015] In one example, the body has a circular form.

[0016] In one example, the first ABH comprises in a first axis, in a first direction, a tapering from a first characteristic to a second characteristic.

[0017] In one example, the damper device further comprises a second ABH provided at the second surface of the body.

[0018] In one example, the second ABH is provided proximal to an edge of the body.

[0019] In one example, the second ABH has an annular form.

[0020] In one example, the second ABH comprises in a first axis, in a second direction opposite to the first direction, a tapering from a first characteristic to a second characteristic.

[0021] In one example, the characteristic is one or more of: a spatial property, optionally a thickness and/or shape; a material and/or a material property, optionally a rigidity and/or density.

[0022] In one example, a damping material is provided on the first ABH.

[0023] According to a second aspect of the present invention, there is provided a structurally damped structure comprising: a primary structure; and the damper device according to the first aspect, to provide damping of the primary structure.

[0024] According to a third aspect of the present invention, there is provided a method of damping a primary structure comprising: providing a damper device comprising: a body comprising a first surface and a second surface; a first acoustic black hole, ABH, provided at the first surface of the body, wherein the first surface of the body is adapted to contact, in a facing manner, a surface of the primary structure; and contacting the surface of the primary structure with the first surface of the body.

[0025] Features of any one aspect may be combined with features of any other aspect, as desired or as appropriate. In particular, features of the damper device according to the first aspect and/or structurally damped structure according to the second aspect may be combined with features of the method according to the third aspect.

BRIEF DESCRIPTION OF THE FIGURES

[0026] Embodiments of the invention will now be described by way of example only with reference to the figures, in which:

Figure 1 shows an acoustic black hole on a beam according to the prior art;
Figure 2 shows a damper device provided on a primary structure;
Figure 3 shows a perspective cross sectional view through the damper device and primary structure;
Figure 4 shows a side cross sectional view through the damper device and primary structure;
Figure 5 shows a schematic of a structurally damped structure comprising a damper device and primary structure;
Figure 6 shows a vehicle;
Figure 7 shows a structure; and
Figure 8 shows general methodology principles.

DETAILED DESCRIPTION

[0027] In the description which follows, acoustic black holes, damper devices, structurally damped structures, and methods, are described.
[0028] The term "acoustic black hole", or "ABH", is used to refer to an element, member, or structure, which, in use, exhibits the acoustic black hole effect.
[0029] In the description herein, acoustic black holes comprise regions of taper. In the examples shown and described, the taper is a thickness taper. That is, the thickness of the acoustic black hole tapers (i.e., reduces or diminishes in thickness in a direction and along a line toward a point, line or region). Additionally, or alternatively, tapering may be in shape. A thickness or shape may be referred to generally as a "spatial property". Conventional ABHs incorporate tapers in thickness, from a first thickness to a second thickness. The first thickness is typically a non-zero thickness. The second thickness is, in the ideal case, a zero thickness. A thickness or shape taper may be advantageous in that it may be simpler to manufacture than, for example, a taper in material and/or material property.
[0030] However, in contrast to a thickness taper, the taper could also be a "functional taper" or a "functional grading". That is, the tapering could be a tapering function of the acoustic black hole, rather than a tapering thickness. For example, the tapering may be a tapering of material and/or material property. The material property may be, for example, density and/or rigidity. This may be achieved by use of additive layer manufacturing (e.g. 3D printing) to form an acoustic black hole having a tapering, graded, or varying, material property. A tapering in material and/or material property may be advantageous in that thin ABH regions need not be provided, which may improve the structural strength, and operational lifetime, of the ABH.
[0031] In this way, it is appropriate to refer to ABH tapers as tapering of a "characteristic". Tapering may be from a "first characteristic" to a "second characteristic". A similar or identical effect to a thickness tapering may be achieved by a tapering in material and/or material property. For example, a tapering from a region of high rigidity to a region of low rigidity may provide a reduction of the flexural wave speed to $c_f(x)=0$, as described above, thereby to provide the ABH effect.
[0032] The term "damper device" is used to refer to an arrangement, assembly or kit comprising a body and an acoustic black hole. The damper device is adapted to provide structural damping to a structure to which the damper device is connected, coupled, or otherwise provided on or at.
[0033] The term "structurally damped structure" is used to refer to a structure, arrangement, assembly or kit comprising a damper device and a primary structure.
[0034] The term "primary structure" is used to refer to a structure that the damper device is arranged to provide structural damping to. The primary structure is a structure that, in use, has a vibration applied to it. The primary structure may be a structure that is vibrated, directly or indirectly, by a source of vibration (e.g., an engine, fluid flow, etc.).
[0035] The damper device may be formed in or on the primary structure. For example, the damper device may be integral to the primary structure. Alternatively, or additionally, the damper device may be coupled to the primary structure. That is, the damper device may be manufactured separately and coupled, or connected, to the primary structure.
[0036] Referring to Figure 2, a perspective view of a primary structure 10 and damper device 100 are shown. In the illustrated arrangement, three damper devices 100 are shown provided at an upper surface 12 of the primary structure 10.
[0037] In this exemplary embodiment, the primary structure 10 is a component in the form of a duct 10. For example, the duct 10 may be a duct for gas or liquid. Nevertheless, it will be appreciated that the primary structure 10 may be any structure to which it is desired to damp, for example any structure or component which exhibits or undergoes vibration.
[0038] Referring to Figure 3, a perspective cross sectional view through the duct 10 and damper device 100 is shown.

The cross section is taken along line A - A in the direction of arrows B, as shown in Figure 2. The damper device 100 comprises a body 110. The body 110 has a circular form. The circular form of the body 110 is advantageous in simplifying construction of the damper device 100. Furthermore, the circular form of the body 110 is particularly advantageous in facilitating the incorporation of the advantageous forms of ABHs described herein, particularly the circular first ABH and annular second ABH (described in greater detail below).

[0039] Referring to Figure 4, a side cross sectional view through the duct 10 and damper device 100 is shown. The cross section is also along line A - A in the direction of arrows B, as shown in Figure 2. However, it will be appreciated from Figure 4 that only a quadrant, or quarter, of the body 110 is shown in cross section.

[0040] The body 110 comprises a first surface 112 and a second surface 114. In this exemplary embodiment, the first surface 112 is a lower surface and the second surface 114 is an upper surface. The first surface 112 of the body 110 is adapted to contact the upper surface 12 of the component 10. The first surface 112 of the body 110 is adapted to contact the upper surface 12 of the component 10 in a facing manner. That is, the first surface 112 does not extend laterally from the component 10, as in conventional add-on damper devices for beams or the like. Instead, the first surface 112 of the body 110 and upper surface 12 component 10 are arranged, or provided, such that they face one another. The facing manner may alternatively be described as a "layered" construction, or one where the first surface 112 is provided to extend across a surface (e.g., the upper surface 12) of a primary structure 10, or the first surface 112 "opposing" the primary structure 10.

[0041] An acoustic black hole (ABH) 122 is provided at the first surface 112. The ABH 122 may be referred to as a "first ABH 122". The first ABH 122 being provided at the first surface 112 may be described as the first ABH 122 being "embedded" in the first surface 112. In this exemplary embodiment, the first ABH 122 is in the form of a concave, circular, recess provided in the first surface 112. By providing a concave recess, a low-profile damper device 100 is obtained. Furthermore, a circular recess simplifies manufacturing, and is particularly advantageous where the body 110 has a corresponding circular form.

[0042] By the first ABH 122 being provided at the first surface 112, and the first surface 112 of the body 110 being adapted to contact the upper surface 12 of the primary structure 10 in a facing manner, numerous advantages are realised. Vibrational damping of the component 10 is provided by the body 110 comprising the first ABH 122 being in contact with the primary structure 10. Furthermore, the thinnest region of the first ABH 122 is provided displaced over (e.g., above, as in this exemplary embodiment) the upper surface 12 of the primary structure 10. The risk of damage to the first ABH 122 is thereby reduced, as the thin region of the ABH does not extend laterally/project freely from the edge of the primary structure 10, as in conventional add-on damper devices. Additionally, the first ABH 122 is not required to extend laterally from the primary structure 10, which has advantages in space-saving, in that the total footprint of the primary structure 10 and damper device 100 is not increased beyond that of the primary structure 10 itself.

[0043] As mentioned above, the body 110 is in contact with the primary structure 10 at the first surface 112. Flexural waves propagate from the primary structure 10 to the damper device 100 at the point of contact therebetween. The damper device 100 may be described as being coupled, attached or connected to the primary structure 10. Coupling may be by application of adhesive or other coupling/attachment means. Alternatively, the damper device 100 may be integrally formed with the primary structure, e.g., one-piece formed. Additive layer manufacturing may be used as a suitable construction technique.

[0044] A first axis 130 is shown in Figure 4. In this exemplary embodiment, the first axis 130 is a radial axis of the circular body 110. The first ABH 122 comprises, in the first axis 130, and in a first direction 132 a tapering from a first characteristic to a second characteristic. In this way, the first ABH 122 is configured to exhibit the ABH effect. In the exemplary embodiment illustrated in the figures, the taper is a thickness taper, and as such the characteristic is a thickness. In Figure 4, the first characteristic is indicated as first thickness 134, and the second characteristic is indicated as second thickness 136.

[0045] The first ABH 122 is adapted to contact the upper surface 12 of the duct 10. In this exemplary embodiment, an outermost region (indicated at 124) of the first ABH 122 is adapted to contact the upper surface 12 of the duct 10. The outermost region 124 is in proximity of the region of first characteristic of the ABH 122. In this way, the ABH 122 contacts the primary structure 10 at a point or region having relatively greater strength compared with other points or regions of the first ABH 122, for example regions of the first ABH 122 having the second characteristic. Furthermore, the primary structure 10 can provide cooperative structural support to the first ABH 122.

[0046] The body 110 is in the form of a plate. The first surface 112 is a first planar surface and the second surface is a second planar surface 114.

[0047] In this way, the damper device 100 has a low profile. The damper device 100 is thus highly advantageous in that it can be employed in situations where space is limited, such as in a duct or vent system. Furthermore, the risk of damage to the damper device 100 is reduced due to the low-profile of the plate form of the body 110.

[0048] At least a part of the first surface 112 and/or ABH 122 formed in the upper surface 112 does not contact the duct 10. That is, the first surface 112 may be arranged to contact the upper surface 12 of the duct 10 such that a gap is formed between the ABH 122 and the upper surface 12 of the duct 10. Advantageously, this may improve performance of the ABH 122, as the ABH effect can be exhibited in an unimpaired manner. Furthermore, this may advantageously facilitate inclusion of damping material (or the existence of air, which may act to provide damping) in the gap.

[0049] The first surface 112 is arranged to contact the upper surface 12 of the duct 10 such that a cavity 150 is formed between the ABH 122 and the upper surface 12 of the duct 10. Advantageously, a cavity 150 can improve performance of the damper device 100, as air within the cavity 150, or between the ABH 122 and the upper surface 12 of the duct 10, provides a level of damping. Furthermore, deterioration of the ABH 122 is inhibited/prevented due to protection offered by the cavity 150.

[0050] In an exemplary embodiment, the cavity 150 may be partially, or substantially, enclosed. In this way, structural strength of the ABH 122 is improved. A partially, or substantially, enclosed cavity 150 may mean that the cavity 150 is only open at side regions.

[0051] In a particularly advantageous embodiment, and as illustrated in the figures, the cavity 150 is completely enclosed, or sealed. Advantageously, the structural strength of the ABH 122 is improved. Furthermore, in this way, a volume of air is retained within the cavity 150. This is advantageous in improving damping performance of the damper device 100, as the air retained within the cavity 150 provides a level of damping. Additionally, ingress of external air or contaminants are prevented from entering the cavity 150, thus preventing degradation of the damper device 100 and the materials thereof over time. The lifetime of the damper device 100 is thus increased.

[0052] A damping material 140 is provided on the first ABH 122. The damping material 140 is provided on at least a region of the first ABH 122. The damping material 140 is provided on the surface of the first ABH 122. Where the first ABH 122 comprises tapering, the damping material 140 may be provided on the tapering surface of the first ABH 122. The damping material 140 may be provided on the whole of the first ABH 122. The damping material 140 may be a viscoelastic layer. The damping material 140 may be a thin layer. Advantageously, the damping material 140 provides an additional damping effect in the first ABH 122, which may reduce reflection of an incident wave.

[0053] The damper device 100 further comprises a second ABH 152. The second ABH 152 is provided at the second surface 114 of the body 110. That is, the second ABH 152 is provided at the upper surface 114 of the body 110.

[0054] Providing a second ABH 152 at the second surface 114 is highly advantageous. The second ABH 152 provides further damping, in addition to that of the first ABH 122, such that performance of the damper device 100 is improved. That is, a combined damping effect is realised. Furthermore, the weight of the body 110 is reduced by provision of the second ABH 152.

[0055] The second ABH 152 comprises, in the first axis 130, in a second direction 138 opposite to the first direction 132, a tapering from a first characteristic to a second characteristic. In this way, the second ABH 152 is configured to exhibit the ABH effect. In the exemplary embodiment illustrated in the figures, the taper is a thickness taper, and as such the characteristic is a thickness. In Figure 4, the first characteristic is indicated as first thickness 134, and the second characteristic is indicated as second thickness 135.

[0056] It is possible to use alternative ordinal numbers (e.g., "third", "fourth") to refer to the characteristics of the second ABH 152. For example, the first characteristic and second characteristic of the second ABH 152 may be referred to as "third characteristic" and "fourth characteristic", which may clarify and distinguish said characteristics from those of the first ABH 122. Nevertheless, the characteristic of the second ABH 152 may similarly be a thickness, shape, material and/or material property, for example rigidity and/or density.

[0057] The second ABH 152 is provided proximal to an edge of the body 110. This may lead to a simplified construction of the damper device 100, as it is not necessary to fully embed the second ABH 152 in the body 110. The second ABH 152 tapers in the second direction 138 to the edge of the body 110. As will be understood from considering the damper device 100 in plan and/or side view, the edge of the body 110 is the outermost edge (the circumference) of the circular body 110.

[0058] The second ABH 152 has an annular form. That is, the second ABH 152 extends fully around the circumference of the circular body 110. In this way, the second ABH 152 may be adapted to damp waves propagating in all directions through the body 110. The second ABH 152 is vertically disposed above the region, or point, of contact of the first surface 112 with the primary structure 10. As such, the second ABH 152 is proximal to the point or region at which flexural waves propagate from the primary structure 10 to the damper device 100.

[0059] The rate of taper of the second ABH 152 is greater than the rate of taper of the first ABH 122. Advantageously, in this way, each ABH may be suited to damping of different types/properties of vibrations.

[0060] Referring to Figure 5, a structurally damped structure 1000 is schematically shown. The structurally damped structure 1000 comprises a primary structure 10. The structurally damped structure 1000 further comprises a damper device 100 to provide damping of the primary structure 10. The damper device 100 may incorporate any of the features herein described.

[0061] In this way, a structurally damped structure 1000 is provided in which vibrations of the primary structure 10 are damped (e.g., controlled) by the damper device 100.

[0062] Referring to Figure 6, a vehicle 600 is schematically shown. The vehicle 600 comprises a damper device 100 and/or a structurally damped structure 1000, according to any of the embodiments described herein. The vehicle 600 may be a land-based vehicle, watercraft, or aircraft. The vehicle, or a component thereof, may comprise, or be, the primary structure.

[0063] Referring to Figure 7, a structure 700 is schematically shown. The structure 700 comprises a damper device 100 and/or a structurally damped structure 1000, according to any of the embodiments described herein. The structure 700 may be a building, infrastructure, construction, or the like. The structure, or a component thereof, may comprise, or be, the primary structure.

[0064] Referring to Figure 8, a method of damping a primary structure is schematically shown. Step 8010 comprises providing a damper device comprising: a body comprising a first surface and a second surface; a first acoustic black hole, ABH, provided at the first surface of the body, wherein the first surface of the body is adapted to contact, in a facing manner, a surface of the primary structure. Step 8020 comprises contacting the surface of the primary structure with the first surface of the body.

[0065] In this way, a method of damping is provided using an advantageous damper device 100, due to its high performance, low-profile form, simplicity, and lightweight construction.

Claims

1. A damper device for providing damping of primary structure, the damper device comprising:

a body comprising a first surface and a second surface;
a first acoustic black hole, ABH, provided at the first surface of the body,
wherein the first surface of the body is adapted to contact, in a facing manner, a surface of the primary structure.

2. The damper device as claimed in claim 1, wherein the body is a plate, and the first surface is a first surface of the plate, and the second surface is a second surface of the plate.

3. The damper device as claimed in claim 1 or claim 2, wherein the body is adapted to contact the surface of the primary structure such that a cavity is formed between the first ABH and the surface of the primary structure.

4. The damper device as claimed in claim 3, wherein the cavity is enclosed.

5. The damper device as claimed in any one of the preceding claims, wherein the first ABH is in the form of a concave circular recess in the first surface.

6. The damper device as claimed in any one of the preceding claims, wherein the body has a circular form.

7. The damper device as claimed in any one of the preceding claims, wherein the first ABH comprises in a first axis, in a first direction, a tapering from a first characteristic to a second characteristic.

8. The damper device as claimed in any one of the preceding claims, further comprising a second ABH provided at the second surface of the body.

9. The damper device as claimed in claim 8, wherein the second ABH is provided proximal to an edge of the body.

10. The damper device as claimed in either of claim 8 or claim 9, wherein the second ABH has an annular form.

11. The damper device as claimed in any one of claims 8 to 10, wherein the second ABH comprises in a first axis, in a second direction opposite to the first direction, a tapering from a first characteristic to a second characteristic.

12. The damper device as claimed in either of claim 7 or claim 11, wherein the characteristic is one or more of:

a spatial property, optionally a thickness and/or shape;
a material and/or a material property, optionally a rigidity and/or density.

13. The damper device as claimed in any one of the previous claims, wherein a damping material is provided on the first ABH.

14. A structurally damped structure comprising:

a primary structure; and
the damper device according to any one of the previous claims to provide damping of the primary structure.

15. A method of damping a primary structure comprising:

providing a damper device comprising:

a body comprising a first surface and a second surface;
a first acoustic black hole, ABH, provided at the first surface of the body,
wherein the first surface of the body is adapted to contact, in a facing manner, a surface of the primary structure; and

contacting the surface of the primary structure with the first surface of the body.

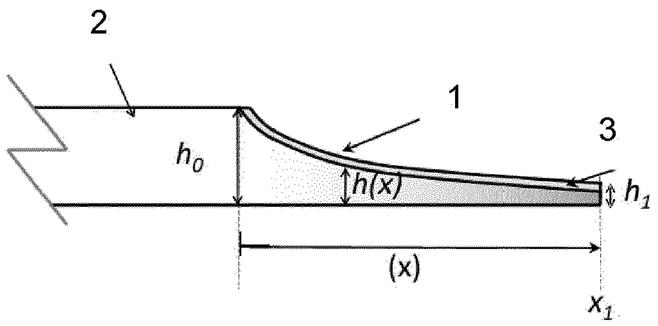

Fig. 1

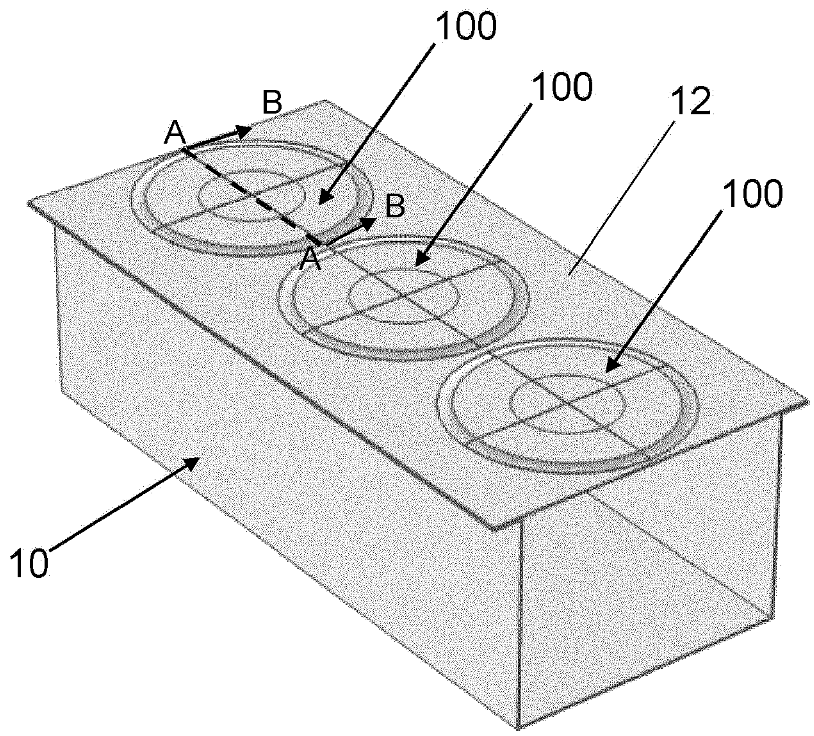

Fig. 2

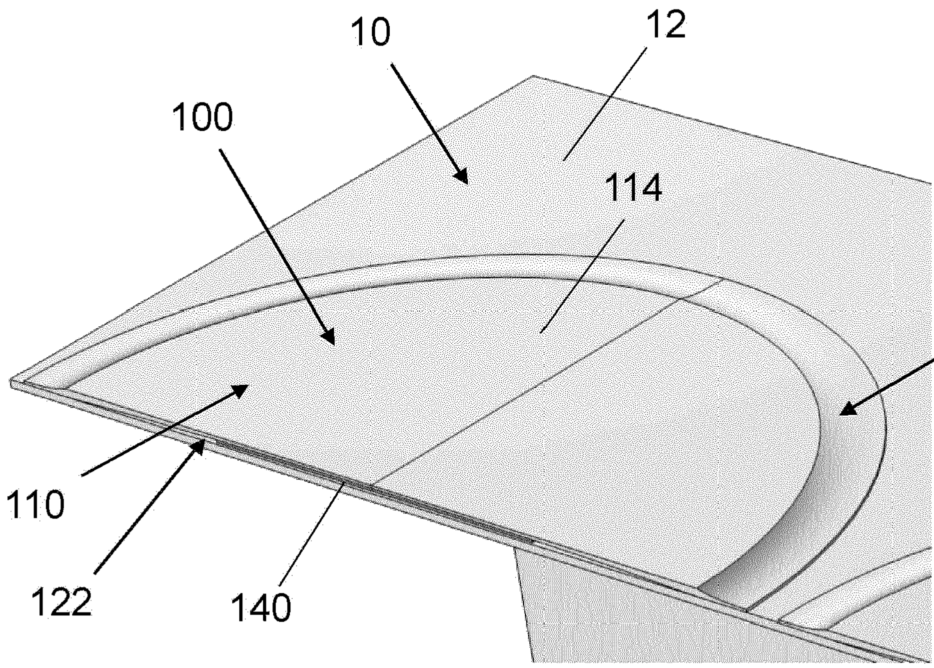
10
12
100
114
152
110
122
140

Fig. 3

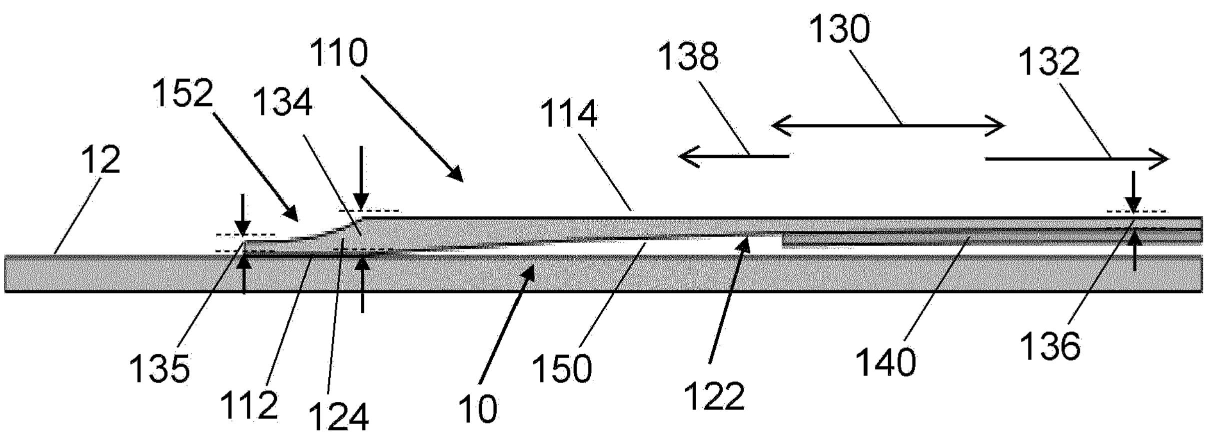
110
130
152
134
138
132
12
114
135
112
124
10
150
122
140
136

Fig. 4

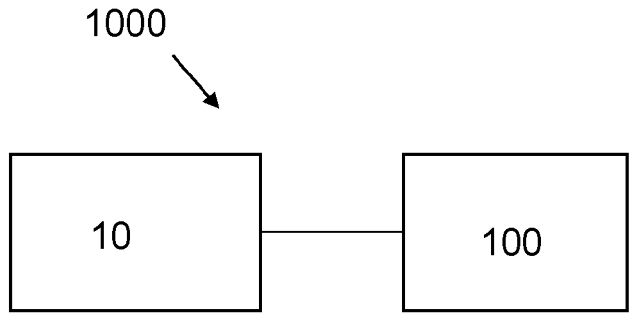

Fig. 5

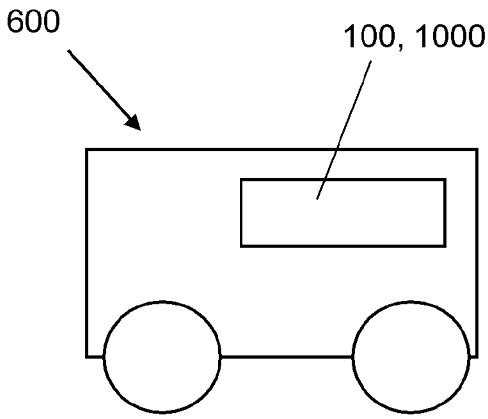

Fig. 6

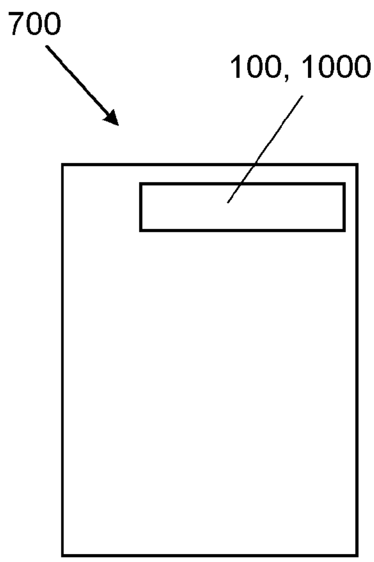

Fig. 7

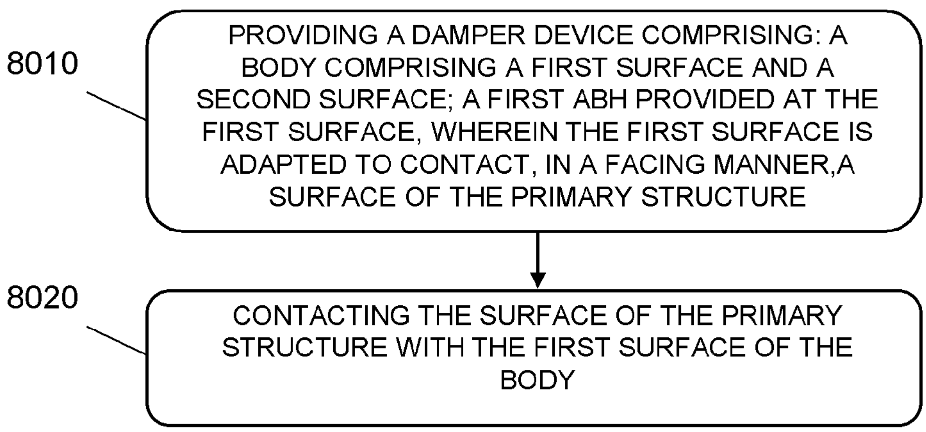

Fig. 8

Europäisches Patentamt
European Patent Office
Office européen des brevets

EUROPEAN SEARCH REPORT

Application Number
EP 22 27 5087

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	CN 110 379 403 A (UNIV TIANJIN) 25 October 2019 (2019-10-25) * abstract * * figures 1-4 * * pages 1-5 *	1-7,12, 14,15	INV. G10K11/16 G10K11/162
X	FR 3 028 906 A1 (INST DE RECH TECH JULES VERNE [FR]; UNIV MAINE [FR]) 27 May 2016 (2016-05-27) * abstract * * figures 1B, 2,4A,6A-6C * * pages 1-9 *	1-15	
X	CN 111 862 921 A (UNIV NANJING AERONAUTICS & ASTRONAUTICS) 30 October 2020 (2020-10-30) * abstract * * figures 1-4 * * pages 1-4 *	1-3,6-15	
X	CN 109 555 805 B (UNIV NANJING AERONAUTICS & ASTRONAUTICS) 24 January 2020 (2020-01-24) * abstract * * figures 1,7,8,9 * * pages 1-6 *	1-5,7-9, 11-15	TECHNICAL FIELDS SEARCHED (IPC) G10K B23Q F01D F02K F42D B64C F16F
X	CN 113 182 922 A (UNIV SICHUAN) 30 July 2021 (2021-07-30) * abstract * * figures 1-5 * * pages 1-4 *	1-3, 6-10, 12-15	

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	28 November 2022	Meyer, Matthias

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 22 27 5087

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

28-11-2022

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
CN 110379403	A	25-10-2019	NONE	
FR 3028906	A1	27-05-2016	NONE	
CN 111862921	A	30-10-2020	NONE	
CN 109555805	B	24-01-2020	NONE	
CN 113182922	A	30-07-2021	NONE	

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

REFERENCES CITED IN THE DESCRIPTION

Non-patent literature cited in the description

- **M.A. MIRONOV.** Propagation of a flexural wave in a plate whose thickness decreases smoothly to zero in a finite interval. *Soviet Physics: Acoustics,* 1988, vol. 34 (3), 318-319 **[0003]**
- **ANGELIS KARLOS ; STEPHEN J. ELLIOT ; JORDAN CHEER.** Higher-order WKB analysis of reflection from tapered elastic wedges. *Journal of Sound and Vibration,* 2019, vol. 449, 368-388 **[0006]**