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(54) **MOTION DAMPER FOR FLOATING STRUCTURES**

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(52) **U.S. Cl.**
CPC ***B63B 39/02*** (2013.01)

(58) **Field of Classification Search**
CPC B63B 39/00; B63B 39/02
USPC 114/121, 122, 124, 125
See application file for complete search history.

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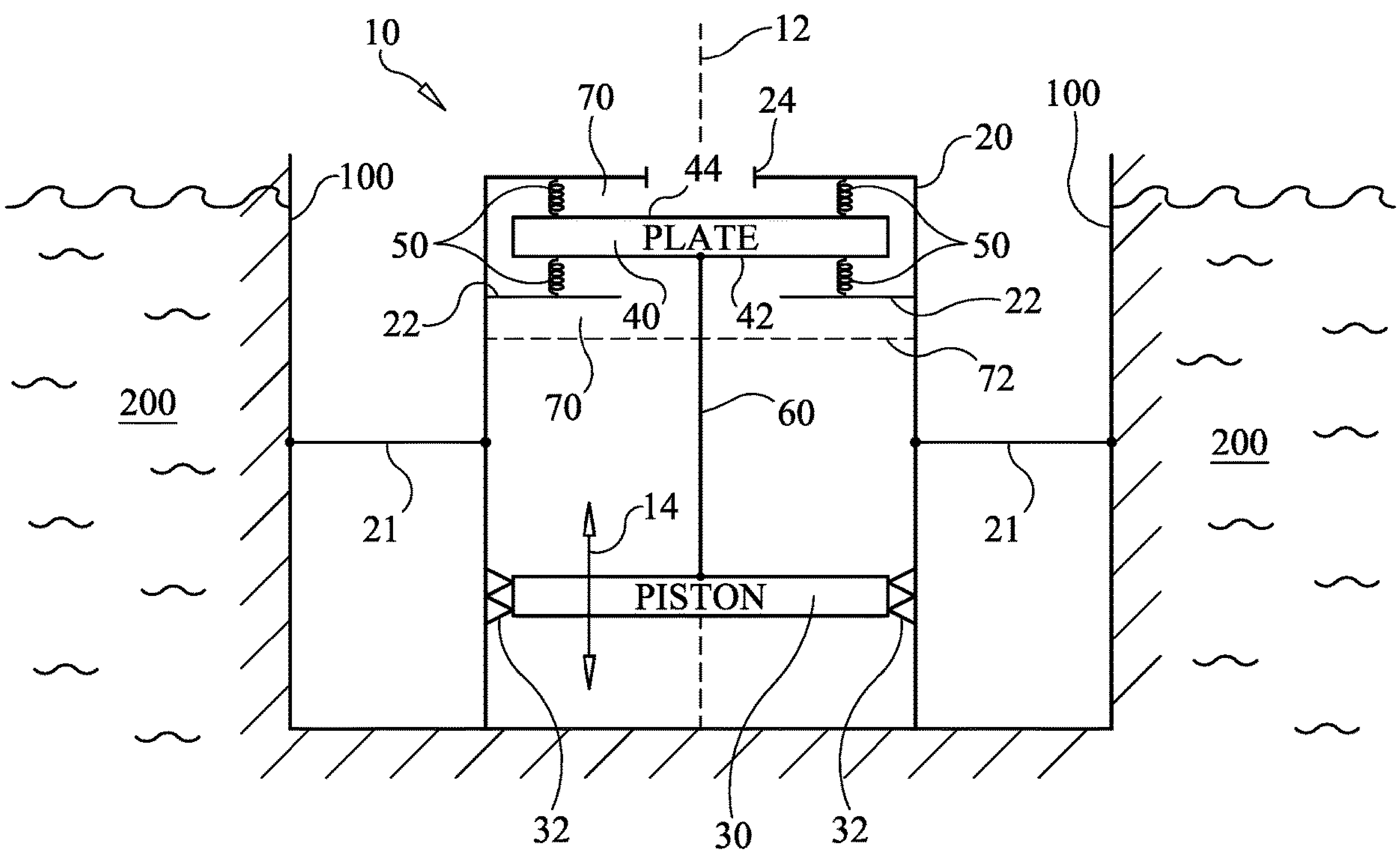
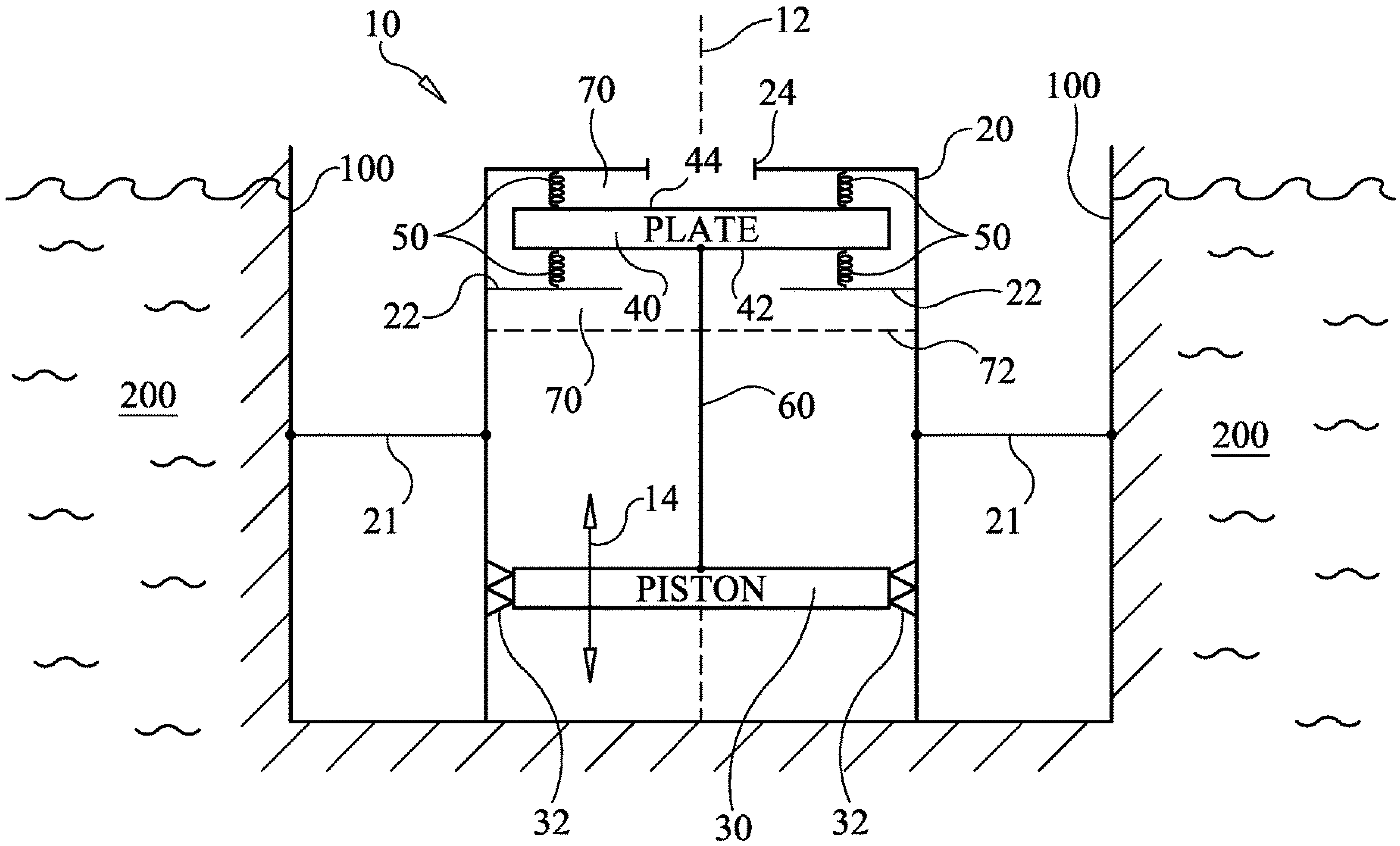
(57) **ABSTRACT**

A motion damper for structures includes a housing coupled to a structure such that the housing moves in correspondence with the structure. The housing includes a wall with a vent, and has an air chamber therein in fluid communication with the vent. A piston is sealed within the housing for one-dimensional motion therein. A rigid plate is disposed within the housing's air chamber. The plate is disposed between the piston and the vent, and is spaced apart from and fixedly coupled to the piston such that the plate moves in correspondence with the one-dimensional motion of the piston. At least one spring is mounted in the housing and is coupled to the plate for applying a force thereto that is in opposition to the one-dimensional motion of the piston.

23 Claims, 5 Drawing Sheets

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12
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44
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100
50
PLATE
50
22
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42
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70
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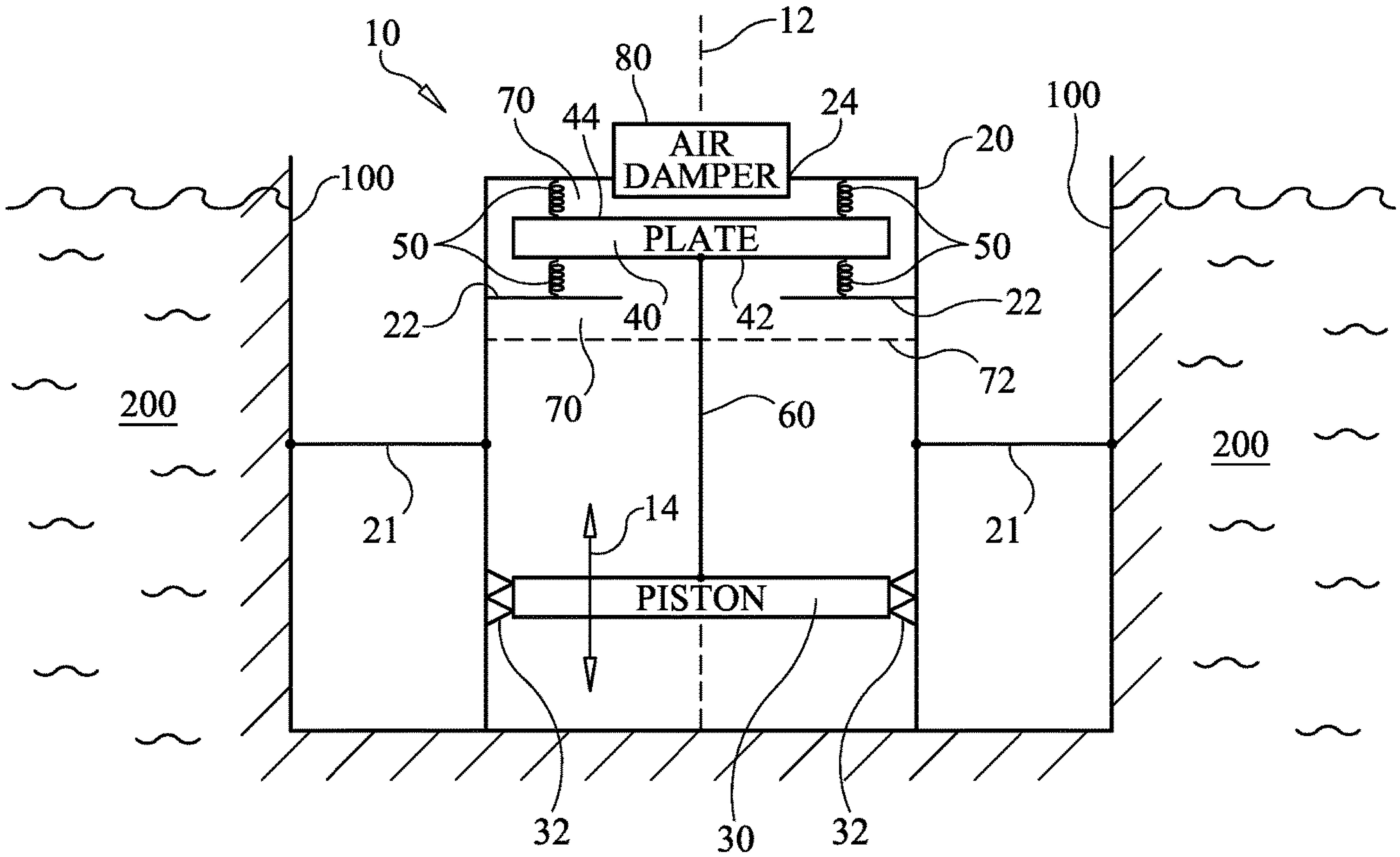
200
60
200
21
21
14
PISTON
32
30
32

FIG. 1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12
80
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44
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AIR
DAMPER
20
100
50
PLATE
50
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70
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200
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200
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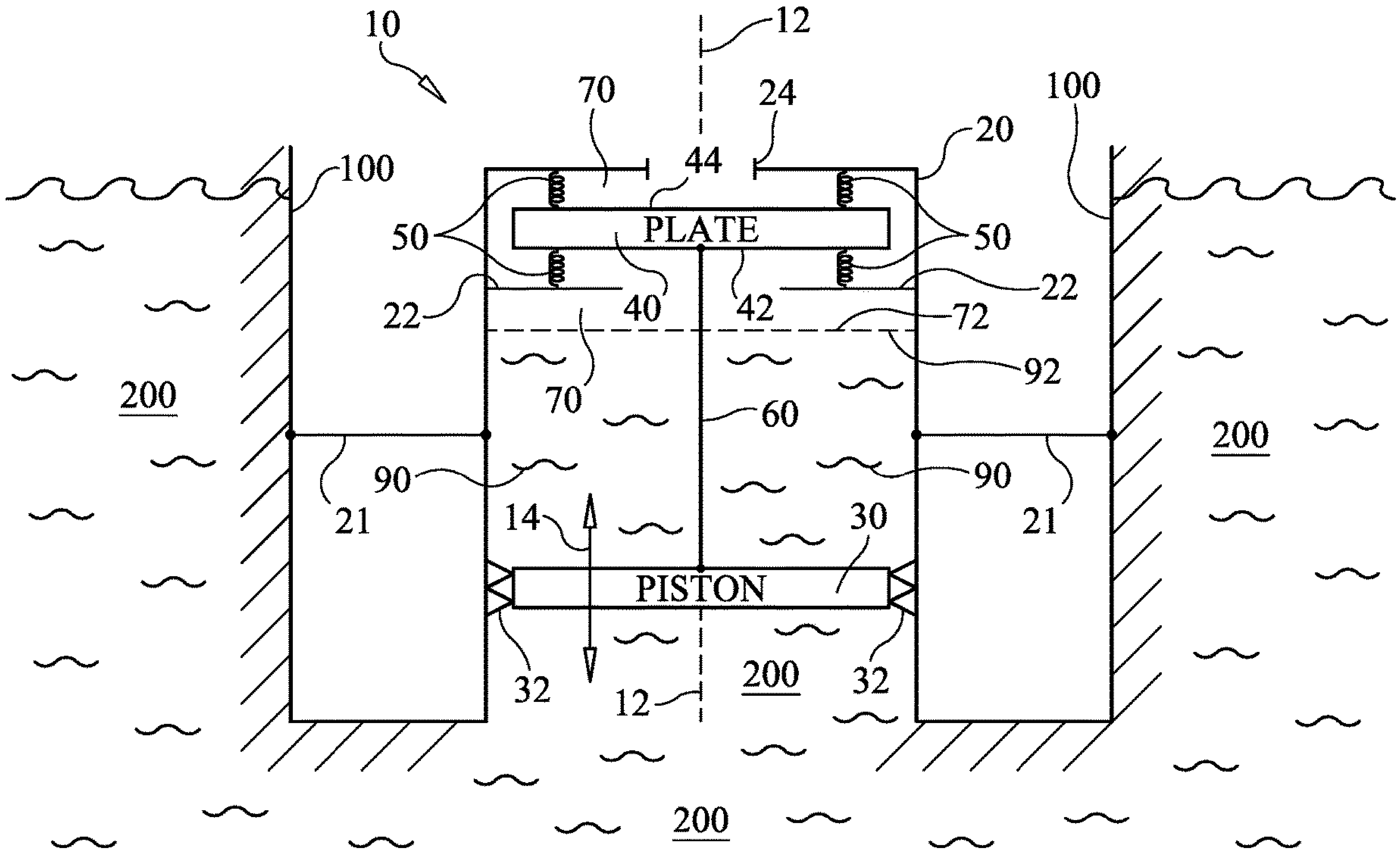
21
14
PISTON
32
30
32

FIG. 2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12
70
24
100
44
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50
PLATE
50
22
40
42
22
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92
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90
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21
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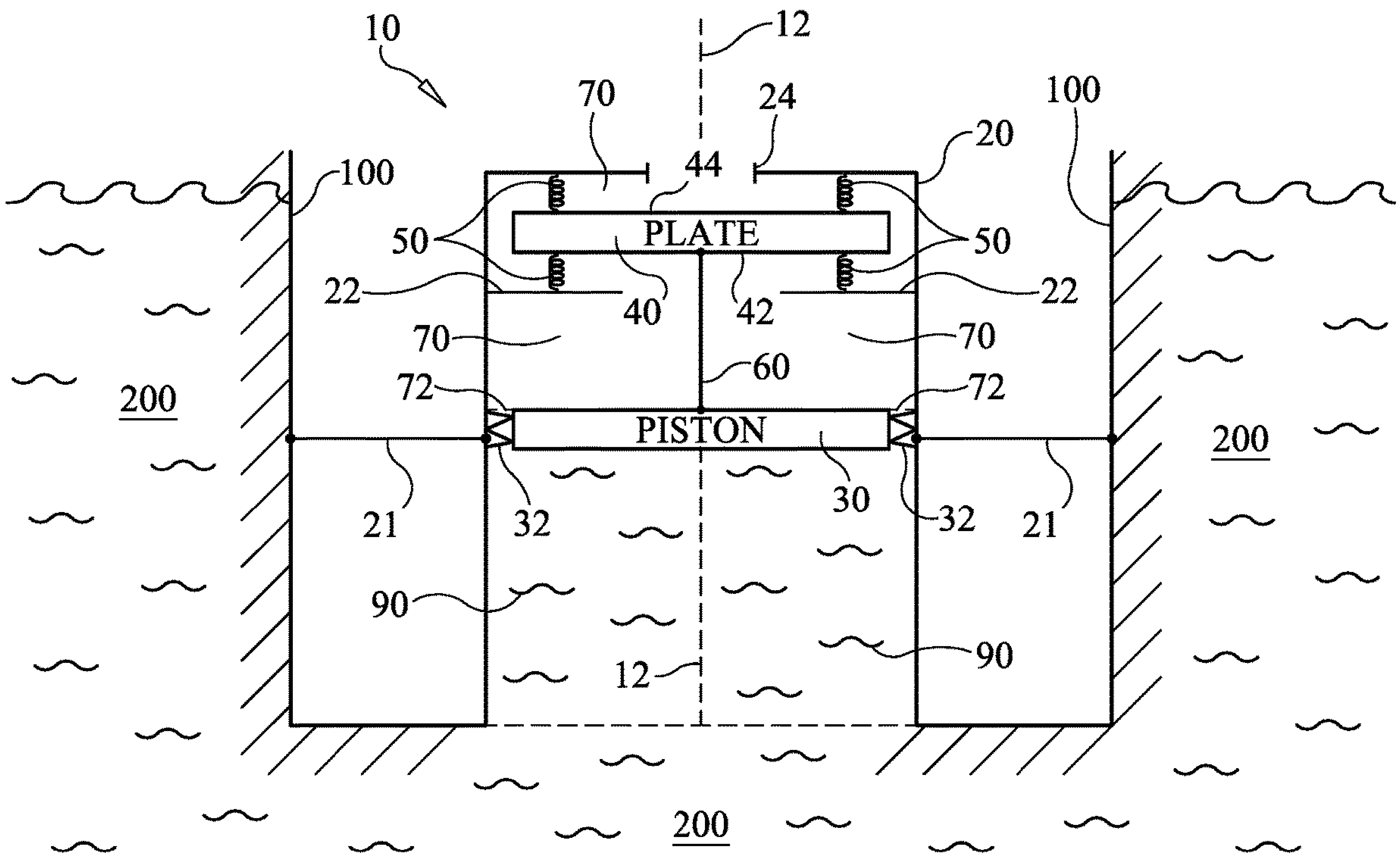
PISTON
32
12
200
32
200

FIG. 3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PISTON
200
21
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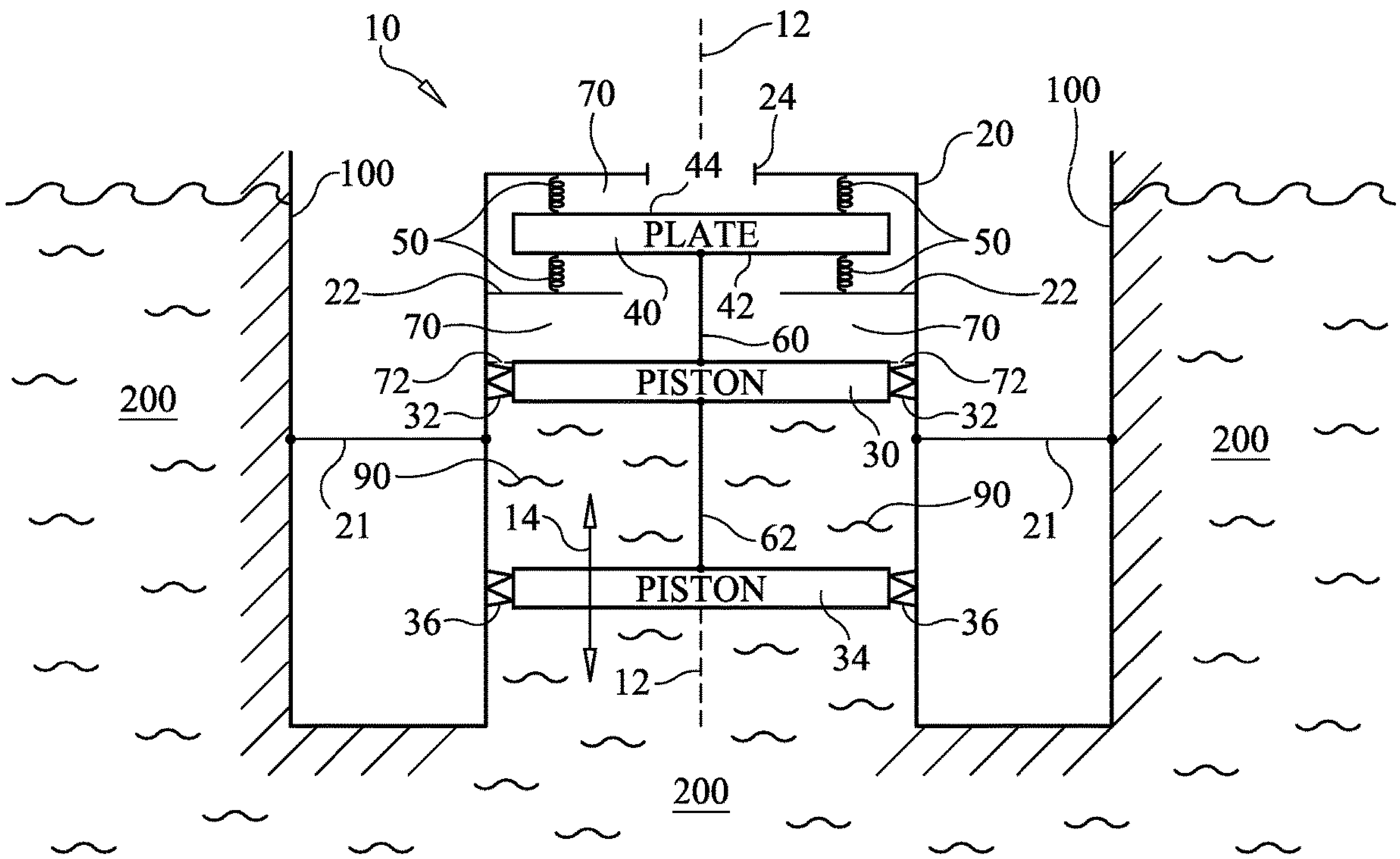
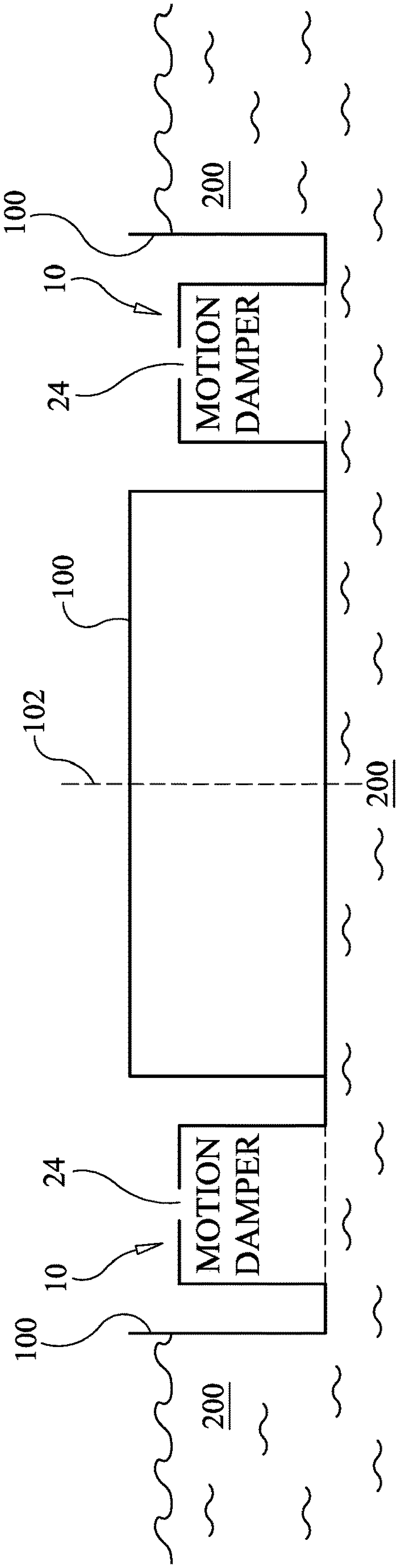
32
21
90
90
12
200

FIG. 4



10
12
70
24
44
100
20
100
50
PLATE
50
22
40
42
22
70
60
70
72
PISTON
72
200
32
32
30
200
90
21
90
21
14
62
PISTON
36
36
34
12
200

FIG. 5


100
200
10
MOTION
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24
100
102
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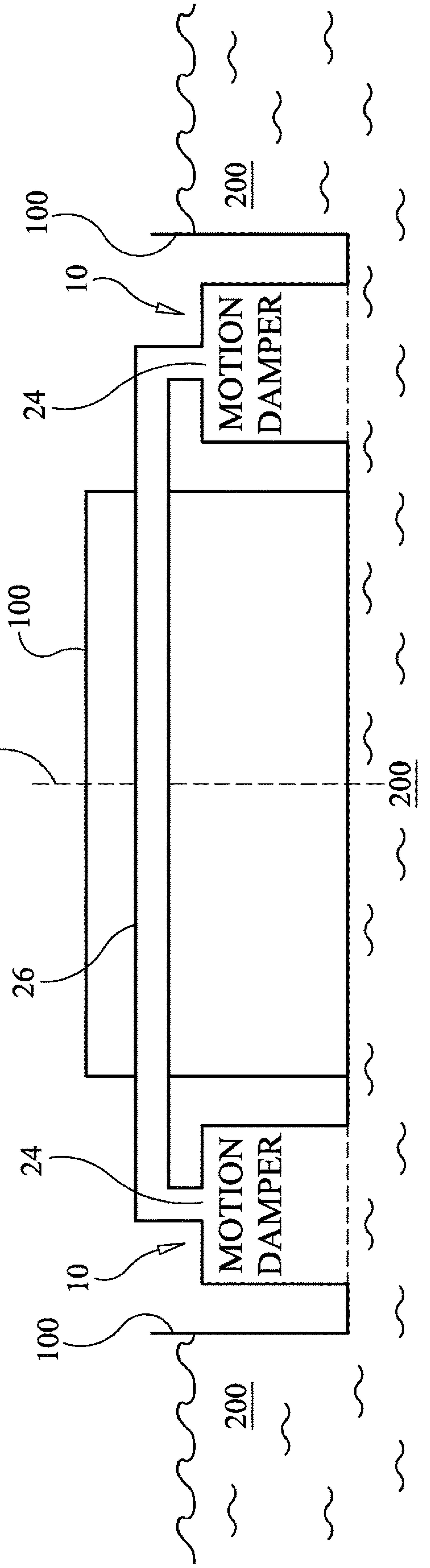
DAMPER
24
10
100
200

FIG. 6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10
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200

FIG. 7

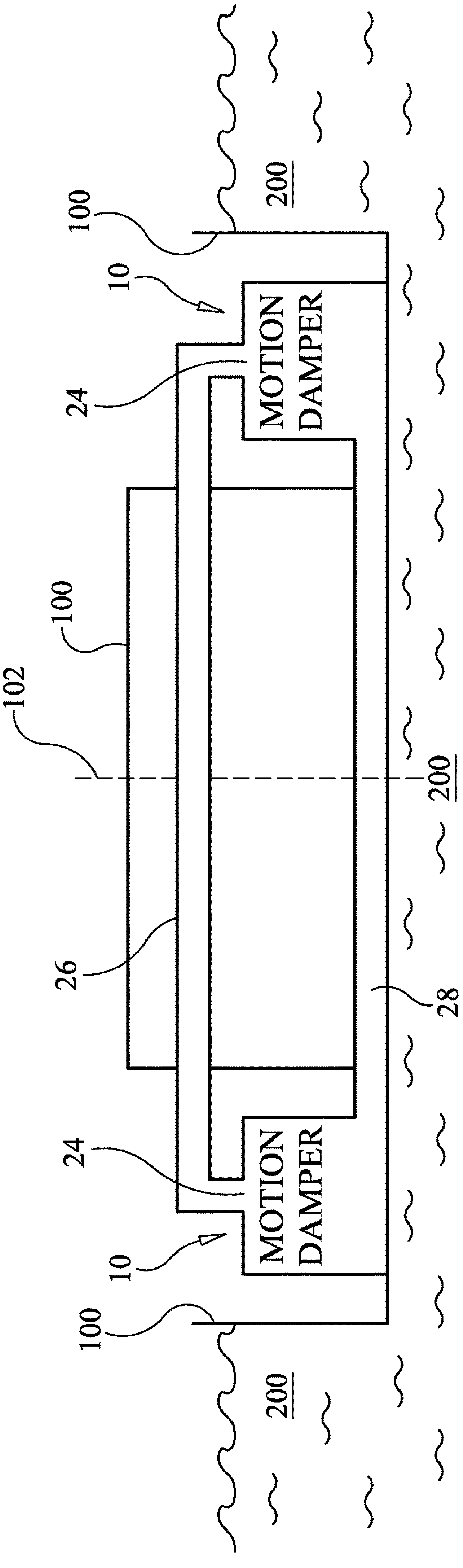
200
100
10
MOTION DAMPER
24
100
102
200
26
28
24
MOTION DAMPER
10
100
200

FIG. 8

MOTION DAMPER FOR FLOATING STRUCTURES

ORIGIN OF THE INVENTION

The invention described herein was made in the performance of work under a NASA contract and by an employee of the United States Government and is subject to the provisions of Public Law 96-517 (35 U.S.C. § 202) and may be manufactured and used by or for the Government for governmental purposes without the payment of any royalties thereon or therefore. In accordance with 35 U.S.C. § 202, the contractor elected to retain title.

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates to motion dampers. More specifically, the invention is a motion damper for use on structures such as those that float on a body of water.

Description of the Related Art

A variety of static and moving structures are subject to unwanted motion caused by environmental conditions. For example, maritime structures floating at the surface of a body of water (e.g., ships, barges, floating wind turbines, etc.), are subject to wave excitation that can cause a structure to experience pitch, roll, and/or heave motions that can limit the performance of the structure. In addition, wave-induced motion of maritime structures often reduces the lifespan thereof owing to structural degradation brought on by unmitigated wave-induced motion.

Performance and structural degradation of maritime structures are greatly exacerbated in the face of high-amplitude wave excitation. There are multiple families of existing tuned mass dampers and tuned vibration absorbers that are used for a variety of motion-damping applications across multiple industries. However, conventional motion dampers are not capable of damping the range of motion amplitudes and motion frequencies experienced by maritime structures in open water environments.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide a motion damper for structures.

Another object of the present invention to provide a motion damper for maritime structures.

Yet another object of the present invention is to provide a motion damper for installation on structures floating on the surface of a body of water.

Still another object of the present invention is to provide a motion damper configurable for the damping of motion of maritime structures subject to high-amplitude excitation forces.

Other objects and advantages of the present invention will become more obvious hereinafter in the specification and drawings.

In accordance with the present invention, a motion damper for structures includes a housing adapted to be coupled to a structure such that the housing moves in correspondence with the structure. The housing includes a wall with a vent. The housing has an air chamber therein in fluid communication with the vent. A piston is sealed within the housing for one-dimensional motion therein. A rigid plate is disposed within the housing's air chamber. The rigid plate is disposed between the piston and the vent. The rigid plate is spaced apart from and fixedly coupled to the piston such that the rigid plate moves in correspondence with the one-dimensional motion of the piston. At least one spring is mounted in the housing and is coupled to the rigid plate for applying a force to the rigid plate that is in opposition to the one-dimensional motion of the piston.

BRIEF DESCRIPTION OF THE DRAWING(S)

Other objects, features and advantages of the present invention will become apparent upon reference to the following description of the preferred embodiments and to the drawings, wherein corresponding reference characters indicate corresponding parts throughout the several views of the drawings and wherein:

FIG. **1** is a schematic view of a motion damper for a floating structure in accordance with an embodiment of the present invention;

FIG. **2** is a schematic view of a motion damper for a floating structure incorporating an air damping device in accordance with another embodiment of the present invention;

FIG. **3** is a schematic view of a motion damper partially filled with a liquid between the motion damper's piston and air chamber plate in accordance with an embodiment of the present invention;

FIG. **4** is a schematic view of a motion damper partially filled with a liquid beneath the motion damper's piston in accordance with another embodiment of the present invention;

FIG. **5** is a schematic view of a motion damper having two spaced-apart pistons and a liquid filling the volume between the two pistons in accordance with another embodiment of the present invention;

FIG. **6** is a schematic view of a floating structure having two independently-operating motion dampers of the present invention installed thereon in accordance with an embodiment of the present invention;

FIG. **7** is a schematic view of a floating structure having two motion dampers of the present invention installed thereon with their vents in fluid communication in accordance with another embodiment of the present invention; and

FIG. **8** is a schematic view of a floating structure having two motion dampers of the present invention installed thereon with their respective vents and pistons in fluid communication in accordance with another embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

Referring now to the drawings and more particularly to FIG. **1**, a schematic view of a motion damper for a structure **100** in accordance with an embodiment of the present invention is shown and is referenced generally by numeral **10**. While the present invention can be adapted for use with land-based and water-based structures, the description to follow will assume that structure **100** is a floating structure. Floating structure **100** can be any fixed or movable "platform" configured for floating at the surface of a body of water **200**, e.g., a river, lake, bay, ocean, etc. Examples of floating structure **100** include, but are not limited to, ships, barges, and wind turbine platforms. In general, most such floating structures include ballast tanks (not shown) to control the structure's buoyancy as is well understood in the art.

As is well-known in the art, wave and wind action occurring at the surface of water **200** causes floating structure **100** to experience one or more of roll, pitch, and heave motions. The amplitude and/or frequency of the structure's motions can negatively impact the performance and integrity of the structure. As will be explained further below, motion damper **10** presents a novel approach to damping out a wide range of the wave and wind induced motions of floating structure **100**. While the essential features of a single motion damper **10** will be described herein, it is to be understood that many applications could benefit from the installation of a plurality of motion damper **10** on a floating structure. Accordingly, some representative examples of multiple motion damper installations will also be described herein.

Motion damper **10** includes a rigid housing **20** that is fixedly coupled to some designated portion of floating structure **100** by coupling elements **21** such that housing **20** experiences the motion of floating structure **100** at the designated portion of the floating structure. The placement, orientation, and method of fixing housing **20** to floating structure **100** (using coupling elements **21**) are chosen to address the specific motion damping needs of a particular application and are, therefore, not limitations of the present invention. Coupling elements **21** can be realized by, for example, rigid brackets, beams, and/or other conventional coupling elements for fixedly coupling housing **20** to floating structure **100** in ways well-understood by one of ordinary. skill in the art such that housing **20** moves in correspondence with floating structure **100**. However, in general, motion damper **10** has an axis of damping sensitivity (indicated by dashed line **12**) aligned with the longitudinal axis of housing **20**. In the illustrated example, motion damper **10** is coupled to floating structure **100** via coupling elements **21** such that its axis of damping sensitivity **12** is approximately perpendicular to the surface of water **200** thereby making motion damper **10** sensitive to heave motion of floating structure **100**.

Disposed within housing **20** are a piston **30**, a rigid plate **40** coupled to piston **30**, and one or more springs **50** coupled to plate **40** and housing **20**. Piston **30** is sealed within housing **20** in a way that allows piston **30** to experience one-dimensional motion along axis of damping sensitivity **12**. For example, an annular rolling diaphragm **32** can be positioned between the periphery of piston **30** and the inside surface of housing **20** to support the one-dimensional movement (e.g., up or down in the illustration) of piston **30** within housing **20** as well as provide a fluid seal between housing **20** and piston **30**. Since the functions of piston **30** and rolling diaphragm **32** could also be achieved with other structures (e.g., bellows or diaphragm sealed within housing **20**), the term "piston" as used herein can be extended to include such alternative structures without departing from the scope of the present invention.

Plate **40** is rigidly coupled to and spaced apart from piston **30** along axis of damping sensitivity **12** such that plate **40** moves in unison with piston **30** along axis of damping sensitivity **12**. Coupling of piston **30** to plate **40** can be achieved by a rigid support (or supports) **60**, the design of which is (are) not a limitation of the present invention. In all embodiments of the present invention, plate **40** resides and moves within a gaseous/air space or chamber **70** within housing **20**. In the illustration, the delineation between air chamber **70** and the rest of housing **20** is indicated by a dashed line **72**. The line of delineation **72** can be created in a variety of ways without departing from the scope of the present invention. Several non-limiting embodiments of the present invention will be presented later below to illustrate exemplary ways to create air chamber **70**.

One or more springs **50** are disposed in housing **20** and are coupled to plate **40** such that springs **50** apply forces to plate **40** that are in opposition to both directions of the one-dimensional movement of plate **40** along axis of damping sensitivity **12**. For example and as illustrated, springs **50** are coupled to the opposing faces **42/44** of plate **40**, and to rigid portions of housing **20** (e.g., a wall of housing **20**, rigid supports **22** within housing **20**, etc.). Springs **50** can be realized by a variety of constructions without departing from the scope of the present invention.

Housing **20** is also provided with at least one vent **24** that provides fluid communication between air chamber **70** and a gaseous or air environment external to housing **20**. As will be explained further below, the external gaseous environment can be ambient air or an enclosed air space in a manifold coupled to vent **24** depending on the installation configuration. In some embodiments of the present invention, the size of vent **24** controls the amount of air/gas flow there through. In other embodiments of the present invention and as illustrated in FIG. **2**, an air damping device **80** can be provided in vent **24**. Such air damping devices can include, for example, a simple orifice plate, a tuned port, an adjustable valve, a reed valve, a variable-aperture reed (VARR) valve, or any other air/gas flow control element(s). Air damping device **80** can be placed directly in vent **24** (as shown) or can be placed in a conduit (not shown) coupled and sealed to vent **24** without departing from the scope of the present invention.

In each embodiment of the present invention, motion damper **10** damps motion of floating structure **100** by capturing a mass of a liquid contained inside of housing **20**. The mass of the captured liquid acts on piston **30** in accordance with the motion of floating structure **100** at the installation location of motion damper **10**. Any component of the floating structure's motion that is aligned with axis of damping sensitivity **12** is then damped. More specifically, as piston **30** is moved along axis of damping sensitivity **12** along either direction as indicated by two-headed arrow **14** when the forces of springs **50** are exceeded, air flows through the restriction defined by vent **24** (or air damping device **80** in fluid communication with vent **24**). The force provided by springs **50** and the air flow restriction provided at vent **24** can be tailored to tune motion damper **10** in terms of its amplitude, frequency, and phase response. In general, movement of piston **30** is effected by a fluid acting thereon as will be explained further below in descriptions of various embodiments of the present invention.

Motion damper **10** can be constructed in an on-shore environment and then transported to its in-the-water installation. Accordingly, motion damper **10** is ideally-suited as a retro-fit motion damper for existing floating structures. For new floating structures, motion damper **10** can be incorporated into an initial design and build. Regardless of its ultimate installation, motion damper **10** can leverage readily-available liquid (i.e., the surrounding body of water) in its motion damping operation. By way of illustrative examples, three designs of the present invention utilizing available water from the surrounding body of water will be described with reference to FIGS. **3-5**.

The motion damper embodiment illustrated in FIG. **3** captures a mass of a liquid **90** in housing **20** with liquid **90** being in contact with the face of piston **30** that faces plate **40**. The amount of liquid **90** is selected such that a free surface

92 of liquid 90 abuts air chamber 70 such that plate 40 remains in air chamber 70 for all expected movements of piston 30. That is, free surface 92 is commensurate with the above-described line of delineation 72 which will move in correspondence with the movement of piston 30. The face of piston 30 facing away from plate 40 is exposed to the external body of water 200. When water 200 moves to apply pressure to piston 30 or moves to pull away from piston 30, piston 30 moves to act on fluid mass 90 which opposes motion of structure 100. As the structure 100 moves (i.e., heaves, rolls, pitches) in water 200, the pressure exerted by water 200 on piston 30 changes, causing the piston to move in response to the structure's motion. This movement of the piston is damped via plate 40, springs 50, and vent 24 (or air damping device 80) which set the appropriate phase lag between piston 30 and structure 100, thus damping out the motion of structure 100.

The motion damper embodiment illustrated in FIG. 4 also captures a mass of liquid 90 in housing 20 in a way that liquid 90 is separated from air chamber 70 by piston 30. That is, liquid 90 is in contact with the face of piston 30 that faces away from plate 40 whereas the face of piston 30 facing plate 40 is commensurate with the above-described line of delineation 72 of air chamber 70. As in the previous embodiment, the face of piston 30 facing away from plate 40 is exposed to the external body of water 200. When water 200 moves to apply pressure to piston 30 or moves to pull away from piston 30, motion of structure 100 is damped in the same way as described above for FIG. 3

The motion damper embodiment illustrated in FIG. 5 includes a second piston 34 sealed within housing 20 and fixedly coupled to piston 30 in a spaced-apart relationship. Pistons 30 and 34 are coupled to one another for movement in correspondence with one another along axis of damping sensitivity 12. For example, one or more supports 62 can be used to fixedly couple piston 30 to piston 34. Similar to piston 30, piston 34 is sealed within housing 20 by, for example, an annular rolling diaphragm 36 that permits one-dimensional movement of piston 34 along axis of damping sensitivity. Piston 30 is disposed between piston 34 and plate 40. In this embodiment, liquid 90 fills the sealed volume between pistons 30 and 34. That is, the mass of liquid 90 is a fixed mass captured in the sealed volume between pistons 30 and 34 in housing 20. The face of piston 30 facing towards plate 40 is commensurate with the above-described line of delineation 72 of air chamber 70. The face of piston 34 facing away from piston 30 is exposed, for example, to the external body of water 200. When water 200 moves to apply pressure to piston 34 or moves to pull away from piston 34, motion of structure 100 is damped in the same way as described above for FIG. 3. In some embodiments of the present invention, this two-piston arrangement can be configured such that piston 34 is not in contact with body of water 200 as is shown above in FIGS. 1 and 2.

As mentioned above, the motion damper of the present invention can be used in isolation or in multiples thereof. In some embodiments of the present invention, multiple independently-operating motion dampers can be distributed about a floating structure. In some embodiments of the present invention, multiple motion dampers can be coupled together to work cooperatively to damp motion caused by wave action as the wave propagates along or across a floating structure. Three floating structures configured with multiple motion dampers will now be described with reference to FIGS. 6-8. In each embodiment, a floating structure 100 has a centerline (e.g., bow-to-stem centerline, port-to-starboard centerline, etc.) indicated by a dashed line 102. Each embodiment shown in FIGS. 6-8 has a motion damper 10 coupled to floating structure 100 on each of opposing sides of centerline 102.

In the FIG. 6 embodiment, each motion damper 10 has its piston (e.g., the above-described piston 30 or 34 but not shown for clarity of illustration) exposed to water 200 and has its vent 24 open to the ambient atmosphere. As described above, vent 24 can be configured for controlling/damping the movement of air there through. In the FIG. 7 embodiment, each motion damper 10 has its piston (e.g., the above-described piston 30 or 34 but not shown for clarity of illustration) exposed to water 200. However, the vents 24 of the two motion dampers 10 are placed in fluid communication with one another by a manifold 26 that can incorporate one or more air damper devices (not shown) therein to control the flow of air between the air chambers of motion dampers 10. By coupling the air chambers of the two motion dampers 10, the captured fluid masses in motion dampers 10 are cross-coupled such that motion dampers 10 cooperate to act as a sway bar to damp out wave propagation-induced motion of floating structure 100. In the FIG. 8 embodiment, motion dampers 10 are also coupled to one another by a manifold 28 such that the faces of the dampers' liquid-mass-capturing pistons (e.g., piston 30 or piston 34) are in fluid communication with one another as opposed to being exposed to water 200. Manifold 28 can be pressurized with the pressurization thereof being used as an additional and controllable spring force for the captured liquid mass within each motion damper 10. In some embodiments of the present invention, manifold 28 can be vented to the atmosphere.

The advantages of the present invention are numerous. The motion damper is passive and self-contained thereby eliminating the need for control systems for many applications while also simplifying maintenance. The present invention lends itself to a modular design such that the whole unit can be removed and replaced if needed. The response frequency of the motion damper is not dependent upon the geometry of the liquid-mass-containment housing. Because the response frequency is independent of the motion damper's geometry, a single design could be used for a multitude of structures and would not have to be completely redesigned for each one. The compressible portion of the motion damper is separate from its piston to provide for control over the motion damper's response frequency. The vent/damping element is also separate from the piston to provide for control over the damping properties. Multiple motion dampers can be cross-coupled to potentially increase the effectiveness of motion damping. For multiple motion damper embodiments utilizing coupling manifolds that may be pressurized, an air pressurization system can be included to provide for tuning of the response of the cooperatively-coupled motion dampers. The present invention is particularly valuable for maritime applications where mitigations of heave, pitch, and roll is needed. However, it is to be understood that the present invention can be adapted for use in any structure to mitigate unwanted dynamics.

Although the invention has been described relative to specific embodiments thereof, there are numerous variations and modifications that will be readily apparent to those skilled in the art in light of the above teachings. It is therefore to be understood that, within the scope of the appended claims, the invention may be practiced other than as specifically described.

What is claimed as new and desired to be secured by Letters Patent of the United States is:

1. A motion damper for floating structures, comprising:

a housing adapted to be coupled to a floating structure wherein said housing moves in correspondence with the floating structure, said housing including a wall with a vent, said housing having an air chamber therein in fluid communication with said vent;

a piston sealed within said housing for one-dimensional motion therein;

a rigid plate disposed within said housing in said air chamber, said rigid plate disposed between said piston and said vent;

said rigid plate being spaced apart from and fixedly coupled to said piston, wherein said rigid plate moves in correspondence with said one-dimensional motion of said piston; and

at least one spring mounted in said housing and coupled to said rigid plate for applying a force to said rigid plate in opposition to said one-dimensional motion of said piston.

2. A motion damper as in claim **1**, further comprising a liquid disposed within said housing and in contact with said piston.

3. A motion damper as in claim **2**, wherein said liquid comprises water.

4. A motion damper as in claim **2**, wherein said liquid is separated from said air chamber by said piston.

5. A motion damper as in claim **2**, wherein said liquid is disposed between said piston and said rigid plate, said liquid having a free surface in said housing, said free surface abutting said air chamber.

6. A motion damper as in claim **2**, further comprising a second piston wherein said piston is disposed between said rigid plate and said second piston, said second piston sealed within said housing, said second piston fixedly coupled to said piston wherein said second piston moves in correspondence with said one-dimensional movement of said piston, said liquid being disposed between said piston and said second piston.

7. A motion damper as in claim **1**, wherein said at least one spring comprises a plurality of springs disposed about and coupled to opposing faces of said rigid plate.

8. A motion damper as in claim **1**, further comprising an air damper device coupled to said vent.

9. A motion damper for floating structures, comprising:

a housing adapted to be coupled to a structure floating on water wherein said housing moves in correspondence with the structure, said housing including a wall with a vent, said housing having an air chamber therein in fluid communication with said vent;

a piston sealed within said housing for one-dimensional motion therein;

a rigid plate disposed within said housing in said air chamber, said rigid plate disposed between said piston and said vent;

at least one support for coupling said rigid plate to said piston in a spaced-apart fashion, wherein said rigid plate moves in correspondence with said one-dimensional motion of said piston; and

springs mounted in said housing and coupled to opposing faces of said rigid plate for applying forces to said rigid plate in opposition to said one-dimensional motion of said piston.

10. A motion damper as in claim **9**, further comprising a liquid disposed within said housing and in contact with said piston.

11. A motion damper as in claim **10**, wherein said liquid comprises water.

12. A motion damper as in claim **10**, wherein said liquid is separated from said air chamber by said piston.

13. A motion damper as in claim **10**, wherein said liquid is disposed between said piston and said rigid plate, said liquid having a free surface in said housing, said free surface abutting said air chamber.

14. A motion damper as in claim **10**, further comprising a second piston wherein said piston is disposed between said rigid plate and said second piston, said second piston sealed within said housing, said second piston fixedly coupled to said piston wherein said second piston moves in correspondence with said one-dimensional movement of said piston, said liquid being disposed between said piston and said second piston.

15. A motion damper as in claim **8**, further comprising an air damper device coupled to said vent.

16. A motion damper for floating structures, comprising:

at least one housing;

each said housing adapted to be coupled to a portion of a structure floating on a body of water wherein said housing moves in correspondence with the portion of the structure as the body of water acts on the structure;

each said housing including

a wall with a vent,

an air chamber in said housing and in fluid communication with said vent,

a piston sealed within said housing for one-dimensional motion therein,

a rigid plate disposed within said housing in said air chamber, said rigid plate disposed between said piston and said vent, said rigid plate being spaced apart from and fixedly coupled to said piston, wherein said rigid plate moves in correspondence with said one-dimensional motion of said piston,

at least one spring mounted in said housing and coupled to said rigid plate for applying a force to said rigid plate in opposition to said one-dimensional motion of said piston, and

a liquid disposed within said housing and in contact with said piston.

17. A motion damper as in claim **16**, wherein said liquid comprises water.

18. A motion damper as in claim **16**, wherein said liquid comprises water from the body of water.

19. A motion damper as in claim **16**, wherein said liquid is separated from said air chamber by said piston.

20. A motion damper as in claim **16**, wherein said liquid is disposed between said piston and said rigid plate, said liquid having a free surface in said housing, said free surface abutting said air chamber.

21. A motion damper as in claim **16**, further comprising a second piston wherein said piston is disposed between said rigid plate and said second piston, said second piston sealed within said housing, said second piston fixedly coupled to said piston wherein said second piston moves in correspondence with said one-dimensional movement of said piston, said liquid being disposed between said piston and said second piston.

22. A motion damper as in claim **16**, wherein said at least one spring comprises a plurality of springs disposed about and coupled to opposing faces of said rigid plate.

23. A motion damper as in claim **16**, further comprising an air damper device coupled to said vent.

* * * * *