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(54) **BI-DIRECTIONAL DAMPING SYSTEM**

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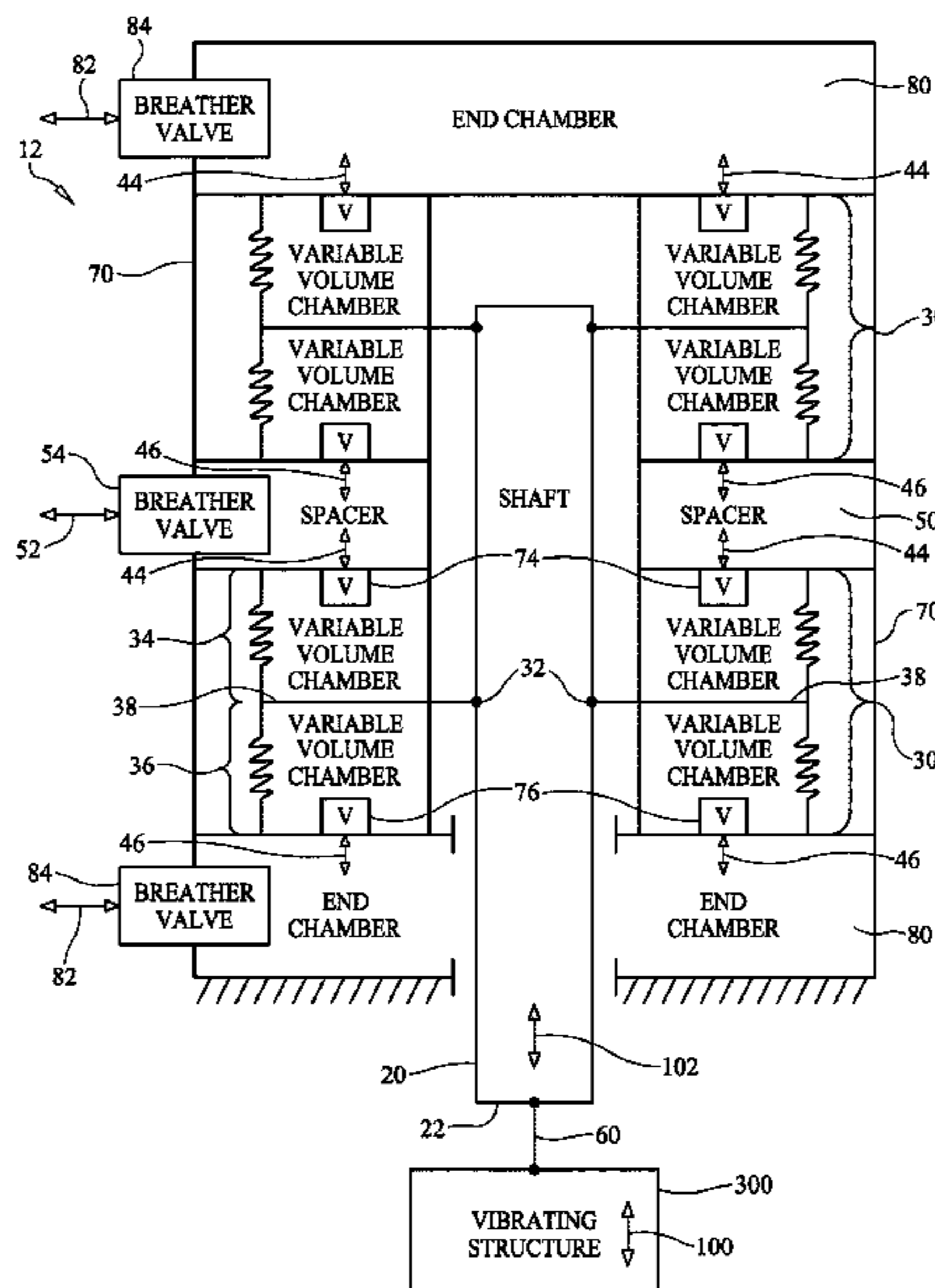
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See application file for complete search history.

(57) **ABSTRACT**

A bi-directional damping system generates damping forces in two opposing directions. A shaft has a plurality of bi-directional damping modules fixedly coupled thereto. Each module includes a fluid-filled variable-volume first chamber including at least one port through which fluid can flow based on changes in volume of the first chamber, and a fluid-filled variable-volume second chamber including at least one port through which fluid can flow based on changes in volume of the second chamber. The first chamber and second chamber are fluidically isolated from one another. A fluid-filled spacer chamber is coupled to adjacent ones of the modules. The spacer chamber includes at least one venting port through which fluid can flow based on pressure in the spacer chamber.

5 Claims, 2 Drawing Sheets



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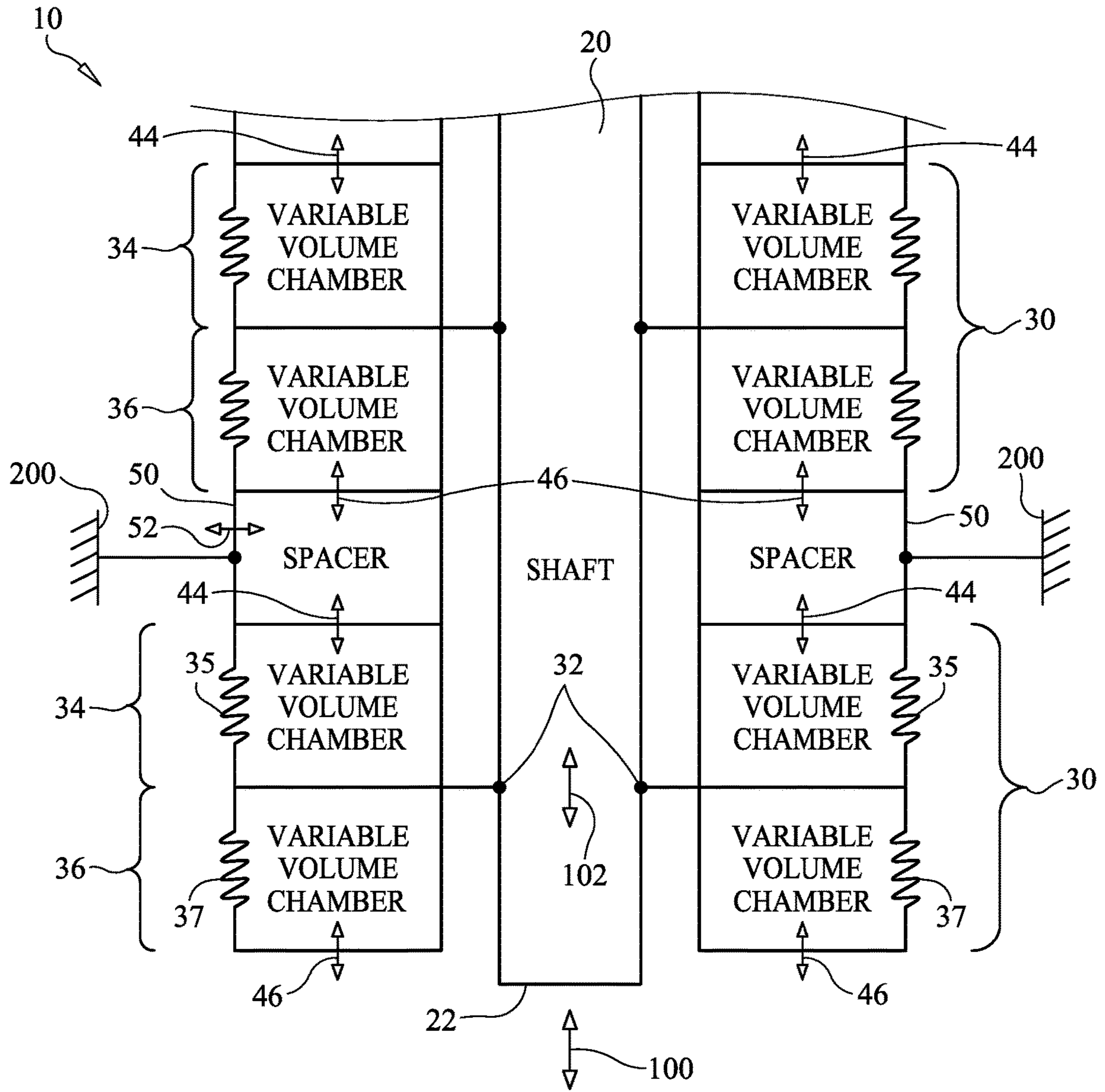
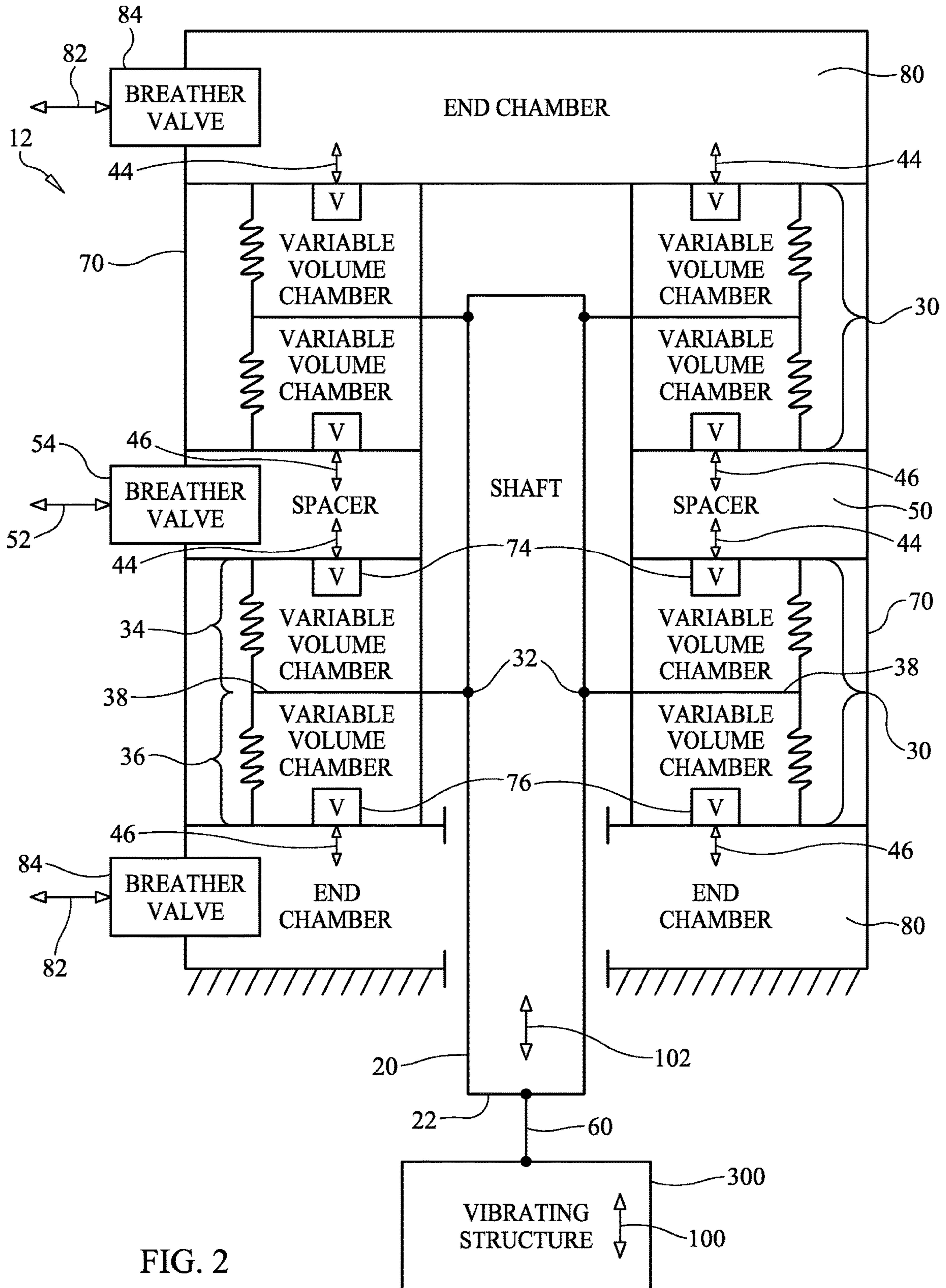


FIG. 1



1**BI-DIRECTIONAL DAMPING SYSTEM**

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.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to damping systems. More specifically, the invention is a damping system providing damping forces in each of two opposing linear directions.

2. Description of the Related Art

A variety of structures or mechanisms are susceptible to dynamic or cyclic deflection and/or vibratory behavior that can produce undesirable results. While conventional springs and dampers can be used to control vibrations in some applications, they generally do not have the ability to generate damping forces in two opposing linear directions and/or generally are not easily modified to adapt to changing vibration amplitude.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide a bi-directional damping system.

Another object of the present invention is to provide a damping system that can be configured to provide adjustable amounts of damping forces in each of two opposing directions.

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 bi-directional damping system for generating damping forces in two opposing directions includes a shaft and a plurality of bi-directional damping modules. Each module is fixedly coupled to the shaft at a unique longitudinal location thereof. Each module includes a fluid-filled variable-volume first chamber including at least one port through which fluid can flow based on changes in volume of the first chamber, and a fluid-filled variable-volume second chamber including at least one port through which fluid can flow based on changes in volume of the second chamber. The first chamber and second chamber are fluidically isolated from one another. A fluid-filled spacer chamber is coupled to adjacent ones of the modules and is uncoupled from the shaft. The spacer chamber includes at least one venting port through which fluid can flow based on pressure in the spacer chamber.

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:

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FIG. 1 is a schematic view of a bi-directional damping system in accordance with an embodiment of the present invention; and

FIG. 2 is a schematic view of a self-contained, bi-directional damping system 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 bi-directional damping system in accordance with the present invention is shown schematically and is referenced generally by numeral **10**. As will be explained further below, damping system **10** can generate damping forces in each of two opposing directions to counteract cyclic or vibrating motion of a structure or mechanism (not shown) where such vibratory motion is indicated in FIG. 1 by a two-headed arrow **100**. The type and/or size of the vibrating structure/mechanism are not limitations of the present invention.

Damping system **10** includes a shaft **20** that, in general, is coupled to the structure/mechanism that is subject vibratory motion **100**. For example, one end **22** of shaft **20** can be directly coupled to the vibrating structure/mechanism or indirectly coupled to the structure/mechanism through a linkage (not shown). Such coupling transfers vibratory motion **100** to shaft **20** to produce corresponding vibratory motion **102** of shaft **20** along the longitudinal length of shaft **20**. Shaft **20** is axially rigid and can be a one-piece or multiple-piece structure without departing from the scope of the present invention.

Shaft **20** extends substantially along the length of damping system **10** to deliver corresponding vibrating motion **102** to each of multiple damping modules **30** distributed along the length of shaft **20**. In the illustrated embodiment, two-damping modules **30** are shown. However, it is to be understood that additional modules **30** can be provided along the length of shaft **20** without departing from the scope of the present invention. The ability to add more damping modules **30**, as well as segments of shaft **20** as needed, allows damping system **10** to be configured and adapted to a variety of applications requiring different amounts of damping forces.

Each of damping modules **30** is fixedly and rigidly coupled to shaft **20** at a unique location along the length thereof as indicated at **32** such that vibrating motion **102** is transferred to each of damping modules **30**. In the illustrated embodiment, each of modules **30** is disposed annularly about shaft **20** such that shaft **20** is centrally disposed in each module **30**. Each of damping modules **30** has two variable-volume chambers **34** and **36** associated therewith. Both chambers **34** and **36** are filled with a fluid (e.g., a gas or, in some cases, a liquid). Chambers **34** and **36** are fluidically isolated from one another. The chambers' variable volume capability can be achieved in a variety of ways without departing from the scope of the present invention. By way of a non-limiting example, side walls **35** and **37** each of chambers **34** and **36**, respectively, can be constructed for flexibility using bellows, rolling diaphragms, etc.

During each phase of shaft **20**'s vibratory motion **102**, one of chambers **34** and **36** experiences compression (i.e., a reduction in volume), while the other experiences extension (i.e., an increase in volume). During a chamber's compression, fluid in the chamber is pushed therefrom. During a chamber's extension, additional fluid is pulled into the chamber. Such fluid movement into or out of chamber **34** is

indicated by two-headed arrow **44**, and such fluid movement into or out of chamber **36** is indicated by two-headed arrow **46**. Fluid movements **44** and **46** can be controlled using one or more valves (e.g., multiple one-way valves, a single two-way variable-aperture valve as disclosed in U.S. Pat. No. 8,939,178, etc.), the choice of which is not a limitation of the present invention. Regardless of the type(s) of valves used, fluid movements **44** and **46** experience resistance as they occur.

Adjacent damping modules **30** are separated and coupled to one another by a fixed-volume spacer chamber **50** that is coupled to a support structure **200**, but uncoupled from shaft **20** such that shaft **20** can experience vibratory motion **102** relative to spacer chamber **50**. Spacer chamber **50** is filled with the same fluid used to fill chambers **34** and **36**, and serves as a fluid reservoir for receiving and supplying the fluid to chambers **34** and **36** when experiencing compression and extension, respectively. To prevent fluid movements **44** and **46** from being dead-headed by pressure build-up or pressure drops in spacer chamber **50**, the chamber can be vented as indicated by two-headed arrow **52** where such venting can be regulated by, for example, breather valve(s) (not shown).

In operation, vibratory motion **102** of shaft **20** translates into the above-described compression/extension of chambers **34** and **36** and corresponding fluid movements **44** and **46**. The resistance encountered by fluid movements **44** and **46** lags (i.e., a phase lag) behind the vibratory motion **100** that is to be damped. Damping system **10** can be tuned to an optimum phase lag for a given application to reduce the gain of resonance. Such tuning can be readily achieved by the choice of and/or adjustment of the valves controlling fluid movements **44** and **46**.

Referring now to FIG. **2**, a self-contained bi-directional damping system in accordance with another embodiment of the present invention is shown and is referenced generally by numeral **12**. Damping system **12** is coupled to a vibrating structure **300** subject to the above-described vibratory motion **100**. More specifically, one end **22** of shaft **20** is coupled to structure **300** by a linkage **60** such that vibratory motion **100** is translated to shaft **20** as vibratory motion **102** as described above. Damping system **12** includes a rigid housing **70** that allows shaft **20** to extend therefrom and vibrate in motion **102**. Each damping module **30** includes a rigid plate **38** that is fixed to shaft **20** at **32** such that each plate **38** experiences vibratory motion **102** along with shaft **20**. Spacer chamber **50** can be attached to housing **70** or integrated therewith (as shown) without departing from the scope of the present invention. The above-described fluid movements **44** and **46** are controlled by one or more valves (“V”) **74** and **76**, respectively. The above-described venting **52** of spacer chamber **50** can be supported by a breather valve **54** that can communicate with an ambient environment when the fluid used in damping modules **30** and spacer chamber **50** is air.

Housing **70** can also be configured to provide end chambers **80** at opposing ends of damping system **12**. Each end chamber **80** functions similarly to spacer chamber **50** and, therefore, is equipped with a breather valve **84** to facilitate venting **82** based on pressure in chamber **80**.

The advantages of the present invention are numerous. Vibration motion in each of two opposing directions is damped by a system that is readily adapted and tuned by adding damping modules and/or adjusting the fluid movement resistance of the damping modules. Thus, the damping system has an adjustable dynamic range that enhances its functionality and value.

Although the invention has been described relative to a specific embodiment 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 bi-directional damping system for generating damping forces in two opposing directions, comprising:

a rigid housing;

a shaft disposed in said housing and extending on one end thereof from said housing, said one end adapted to be coupled to a structure subject to vibration;

a serial arrangement of bi-directional damping modules disposed in said housing, each of said modules fixedly coupled to said shaft at a unique longitudinal location thereof, each of said modules including

a rigid plate fixed to said shaft at said unique longitudinal location associated with one of said modules,

a fluid-filled variable-volume first chamber coupled to a first face of said plate, said first chamber including at least one first valve through which fluid flows based on changes in volume of said first chamber, and

a fluid-filled variable-volume second chamber coupled to a second face of said plate, said second chamber including at least one second valve through which fluid flows based on changes in volume of said second chamber, wherein said first chamber and said second chamber are fluidically isolated from one another by said plate;

said housing defining a fixed-volume reservoir between adjacent ones of said modules and at opposing ends of said serial arrangement wherein, for each of said modules, a first said reservoir is in fluid communication with said first chamber via said at least one first valve thereof and a second said reservoir is in fluid communication with said second chamber via said at least one second valve thereof; and

a breather valve disposed in said housing at each said reservoir, each said breather valve adapted to provide fluid communication with an ambient environment.

2. A system as in claim **1**, wherein said shaft is centrally disposed in each of said modules.

3. A system as in claim **1**, wherein each of said modules and each said spacing chamber is disposed annularly about said shaft.

4. A system as in claim **1**, wherein each said first chamber and each said second chamber include flexible side walls.

5. A system as in claim **1**, wherein a fluid filling said first chamber and said second chamber comprises a gas.