DAMPING SYSTEM

The present invention relates to a damping system. More particularly, the present invention relates to a damping system adapted for the damping of vibrations in building structures.

BACKGROUND OF THE INVENTION

It is a well-known fact that large civil structures are frequently exposed to severe dynamic loading from several sources including seismic events like earthquakes and high winds. During aforementioned high winds and seismic events, the sway motion of tall civil structures that include tall building structures and the long vertical deflections on civil structures such as suspension bridges, necessitate the need for damping said sway motion and said vertical deflections on particularly large civil structures to prevent the occurrence of said swing motions or said vertical deflection from effectively oscillating at resonance and causing damage to the building structures afflicted.

Until recently, throughout the history of mankind, large building structures were built as passive structures, in which the passive external dynamic load were resisted solely by the mass and stiffness of the structure. However, due to the fact that in recent times, building structures have evolved to be very tall structures that span several hundred meters into the air. The behaviour of such structures when subjected to strong cross winds especially at high altitudes and seismic events such as earthquakes, led to the development of damping systems which served the purpose of damping vibrations of said building structures.

A damper is an active or a passive control device that helps to suppress the vibration of a structure excited by dynamic forces by dissipating energy from it. The role of such devices has gained considerable importance due to rapid infrastructure development globally. Active dampers are usually installed on the top floor of a tall building structure and are characterized by active intervention of a control system to actuate changes to tune the natural frequency of oscillation of the damper to hence enable damping of oscillations that vary from time to time in terms of fundamental frequency of oscillation. Passive control devices (i.e. passive dampers in this context) on the other hand are tuned to particular frequencies, as such a passive control device is thus only effective if the forcing frequencies afflicting a particular building structure are close to the device's tuned frequency. Excitations that affect large civil structures are often multi-frequency forces. For example, seismic excitations have energies spread over a band of frequencies. When the excitation is a multi-frequency force, passive control devices are much less effective. Active control devices are needed to improve damping effectiveness against multi-frequency excitation forces. The state of the art in relation to damping devices for structures such as building structures comprise of damping devices/or systems such as active tendon systems and active mass dampers. The inherent disadvantage of active dampers is the need for additional power to power the control system to enable adaptive tuning of the natural frequency of oscillation of the damping element to enable effective damping of oscillations despite changes in the fundamental mode of vibration of the building structure. Active damping systems further present the disadvantage of adding cost and complexity to a given building structure damping system. Examples of damping devices of the state of the art include the Tuned Mass Dampers (TMD), the Tuned Liquid Damper (TLD) and the Tuned Liquid Column Damper (TLCD).

The following passages are excerpts taken from the background section of US 6,857,231 that attempt to detail configurations of conventional dampers of the state of the art.

Tuned Mass Damper (TMD)

Figure 1 illustrates typical prior art Tuned Mass Damper (TMD) system. More particularly with reference to figure 1, the Tuned Mass Damper (TMD) of the prior art depicted in figure 1, is disposed on a plane frame structure comprising of a beam **1** and two supporting beams **2**. The "Tuned Mass Damper" (TMD) comprises of a mass **3**, a spring **4**, a dashpot **5**, and several rollers **6**. The weight of the mass **3** of the TMD is usually about 0.5 – 2.0% of the total weight of the plane frame. The damper works by producing lateral oscillatory motion of the mass in counter phase with the vibration of the plane frame structure effected by an oscillatory disturbance. The tuned mass damper which is a type of passive damper suffers from the limitation of being only capable of damping oscillations of a building structure at a single primary frequency of oscillation.

Tuned Liquid Damper (or TLD)

Figure 2 illustrates a typical prior art Tuned Liquid Damper (TLD). More particularly with reference to figure 2, similar to the Tuned Mass Damper depicted in figure 1, the Tuned Liquid Damper (TLD) of the prior art depicted in figure 2, is disposed on a plane frame structure comprising of a beam **1** and two supporting beams **2**. The “Tuned Liquid Damper” (TLD) comprises of a liquid tank **7** partially filled with liquid (or water) **8**. An appropriately designed water-storing tank on the roof of a high rise building can serve as a TLD. The liquid weight of TLD is about 0.5 ~2.0% of the total weight of a structure which is under vibrational control. The fluid sloshing and oscillation inside the fluid tank **7** due to resonance can provide the force opposite to the direction of the vibration of the structure and can reduce vibration efficiently. The fundamental period of a TLD can be adjusted by changing the shape and dimensions (including the water depth) of the fluid tank **7**. Although the structure of the TLD is simple, i.e. a fluid tank **7** and its inside fluid **8**, the practical application of TLD’s are still very limited, particularly in applications for high rise buildings due to difficulty in achieving accurate and precise tuning of the period and hence frequency of oscillation (i.e. frequency of sloshing of the fluid contained within the liquid tank **7**). TLD’s thus far, due to technical difficulties in tuning, have been limited to application as passive control devices.

Tuned Liquid – Column Damper (TLCD)

Figure. 3 illustrates a typical prior art Tuned Liquid – Column Damper (TLCD). More particularly, with reference to figure 3, the structure of “Tuned Liquid-Column Damper” is disposed on a plane frame structure comprising of a beam **1** and two supporting beams **2**. A typical “Tuned Liquid-Column Damper (TLCD)” takes the form of a U-shaped vessel **9** partially filled with fluid **8** (e.g. water). Aforementioned U-shaped shaped vessel **9** can take the form of a long circular or rectangular tube. The length of said tube, as a rule of thumb, should be at least 10 times greater than the diameter or the in-plane dimension of the cross section. The cross-section of a TLCD can either be uniform or non-uniform, but it is usually symmetrical about a vertical centre line that divides said U-shaped vessel **9** into two equal portions. The end of the vertical columns of the TLCD are usually open. The fluid weight of a TLCD, similar to the case of TMDs and TLDs is usually about 0.5 ~ 2.0% of the total weight of the structure under vibrational control.

The fluid flow and sloshing frequency inside the U-shaped vessel **9** due to resonance can provide a force opposite to the direction of vibration of the structure and effectively dampen the forced vibrations of a structure. The natural period of a TLCD can be adjusted by changing the wetted length of the U-shape vessel **9** (i.e. the sum of the length of the horizontal section and the water heads of the vertical columns). The TLCD has optimal performance in vibrational control, if the natural period and the damping ratio are equal to the tuned period and the optimal damping ratio. Usually the tuned period is very close to the fundamental period of the structure under vibration control.

In general the damping ratio of a "Tuned Liquid Column Damper (TLCD)" is smaller than an optimal damping ratio and as a consequence in some embodiments, the horizontal section of the U-shaped TLCD damping device includes one or more orifices **10** to enable a given TLCD to achieve optimal damping ratio. The shape, size and number of orifices **10** of a TLCD damper can be ascertained through test and engineering experience.

Thus far, many attempts have been made toward actively controlling the tuning of the natural frequency of oscillation of tuned damping systems. However, there appears to be no attempt directed at providing variable damping to a given tuned damping system. In addition, by making a comparison of the various types of damping devices/systems, due to ease of tuning, it would be advantageous to conceive a tuned mass damping system with adjustable damping. Moreover it may be advantageous to conceive of a hybrid damping system with adjustable damping that incorporates primarily the damping effect of a tuned mass damper and secondarily an auxiliary damping effect of a tuned liquid damper.

SUMMARY OF THE INVENTION

The following presents a simplified summary of the invention in order to provide a basic understanding of some aspects of the invention. This summary is not an extensive overview of the invention. This summary is not intended to identify key/critical elements or essential features of the claimed subject matter. Its sole purpose is to present some concepts of the invention in a simplified form as a prelude to the more detailed description that is presented later.

In one aspect, the present invention provides a damping system for damping vibrations of a large civil structure due to cross-winds and seismic events comprising a translational tuned mass damper including:

a moveable mass that is laterally restrained by a spring member and that is tuned at a fundamental mode of vibration of a building structure; and

a dashpot that serves to dampen vibrations of the moveable mass of the translational tuned mass damper, said dashpot configured to provide adjustable damping to hence provide a measure of control to the damping of the vibrations of the building structure that include vibrations at a fundamental mode of vibration.

In accordance to a preferable embodiment of the damping system of the present invention, the translational tuned mass damper is laterally restrained by a pair of spring members.

In accordance to another preferable embodiment of the damping system of the present invention, the translational tuned mass damper includes a pair of dashpots.

In accordance to yet another preferable embodiment of the damping system of the present invention, the dashpot of the tuned mass damper comprises:

a piston member extending from said moveable mass of the translational tuned mass damper with the piston member comprising of a piston rod and piston head; and

a liquid storage tank that includes a main body and a passageway extending from the main body, the passageway being configured to snugly receive a piston head of a respective piston member extending from said moveable mass; the passageway including an orifice member that can be actuated to control a degree of opening of an orifice defined by a cross sectional area of the passageway and obstructed by the orifice member.

In accordance to said preferable embodiment of the damping system of the present invention, the pair of liquid storage tanks are tuned to dampen vibrations of a building structure.

In accordance to said preferable embodiment, the orifice member is an electro-mechanically actuated member chosen from a list that includes a control valve.

In accordance to another preferable embodiment, the orifice member is a manually actuated member such as a manually actuated butterfly valve.

In accordance to the preferable embodiment of the damping system, in which the orifice member is an electro-mechanically actuated member such as a control valve, said preferable embodiment further includes a remote monitoring and actuating system for actuating the electro-mechanically actuated orifice member to control a degree of opening of the orifice obstructed by the orifice member in the passageway extending from the main body of the liquid storage tank, to hence enable tuning of a damping characteristic of said damping system during or after installation on a building structure.

It is an advantage of the present invention to provide a hybrid damping system.

It is an advantage of the present invention to provide a damping system that combines the damping effect of a tuned liquid damping device and a tuned mass damping device.

It is an advantage of the present invention to provide a damping system in which the amount of damping is adjustable.

It is an advantage of the present invention to provide a damping system, in which an amount of damping is tuneable/adjustable to a critically required amount of damping that may be easily adjusted or easily altered during or after installation.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other objects, features and other advantages of the present invention will be more clearly understood from the detailed description taken in conjunction with the accompanying drawings, in which:

Figure 1 is a diagram illustrating a plane-frame structure under vibration control of a tuned-mass damper;

Figure 2 is a diagram illustrating a plane –frame structure under vibration control of a tuned liquid damper;

Figure 3 is a diagram illustrating a plane-frame structure under vibration control effected by a tuned liquid column damper;

Figure 4 is a schematic of a damping system in accordance to a preferable embodiment of the present invention; and

Figure 5 is a schematic of a damping system in accordance to another preferable embodiment of the present invention in which the pair of orifice members are electro-mechanically actuated members that are actuated by a remote monitoring and actuating system to effect adjustability to a degree of opening of an orifice to enable adjustable damping of the translational tuned mass damper of the damping system of the present invention during or after installation.

DETAILED DESCRIPTION OF THE INVENTION

The detailed description set forth below in connection with the appended drawings is intended as a description of one or more exemplary embodiments and is not intended to represent the only forms in which the embodiments may be constructed and/or utilized. The description sets forth the functions and the sequence for constructing one or more exemplary embodiments. However, it is to be understood that the same or equivalent functions and sequences may be accomplished by different embodiments that are also intended to be encompassed within the scope of this disclosure.

The damping system of the present invention, will now be described with reference to figure 4 and 5 appended herein.

With reference to aforementioned figures 4 and 5, in accordance to a preferable embodiment, the present invention provides a damping system for damping vibrations of a large civil structure due to cross-winds and seismic events comprising a translational tuned mass damper **100** including a moveable mass **10** that is laterally restrained by a pair of spring members **20a**, **20b** and that is tuned at a fundamental mode of vibration of a building structure, and a pair of dashpots **70a**, **70b** that serve to dampen vibrations of the moveable mass of the translational tuned mass damper **100**, said pair of dashpots **70a**, **70b** configured to provide adjustable damping to hence provide a measure of control to the damping of the vibrations of the building structure that include vibrations at a fundamental mode of vibration of said building structure.

Aforementioned translational tuned mass damper **100** being configured to have a given mass such that the natural frequency of oscillation of said translational tuned mass damper **100** is at or near the fundamental frequency of oscillation (i.e. fundamental mode of vibration) of the building structure when subjected to a vibrational excitation.

In accordance to the damping system of the present invention, it is the damping of the oscillations of the translational tuned mass damper **100** that is tuned in order, to provide a measure of control to the overall damping due to a vibrational excitation experienced by a building structure installed with said damping system of the present invention.

In accordance to a preferred embodiment of the damping system of the present invention described herein with reference to the appended figures 4 and 5, the pair of dashpots **70a**, **70b** of the tuned mass damper **100** comprises:

a pair of piston members **11a**, **11b** extending from said moveable mass **10** of the translational tuned mass damper **100** with each piston member **11a**, **11b** comprising of a piston head **11aa**, **11ba** and piston rod **11ab**, **11bb**; and

a pair of liquid storage tanks **50a**, **50b** that each include a main body **51a**, **51b** and a passageway **52a**, **52b** extending from the main body **51a**, **51b**, with each passageway **52a**, **52b** being configured to snugly receive a piston head **11ab**, **11bb** of a respective piston member **11a**, **11b** extending from said moveable mass **10**; said each passageway **52a**, **52b** respectively including an orifice member **54a**, **54b** that can be actuated to control a degree of opening of an orifice defined by a cross sectional area of said each passageway and that is obstructed by said orifice member **54a**, **54b**.

In accordance to a preferable embodiment of the damping system of the present invention, the pair of orifice members **54a**, **54b** are manually actuated orifice members **54a**, **54b** that are chosen from a list that include manually actuated butterfly valves.

In accordance to the preferred embodiment of the damping system of the present invention described herein, the pair of orifice members **54a**, **54b** are electro-mechanically actuated orifice members **54a**, **54b**. Each orifice member **54a**, **54b,** in accordance to said preferred embodiment, are each disposed substantially midway of each passageway **52a**, **52b** extending from the main body **51a**, **51b** of each liquid storage tank **50a**, **50b** respectively. Said each orifice member **54a**, **54b**, obstructing an orifice defined by a cross-sectional area of each passageway **52a**, **52b** and is disposed substantially midway of each passageway **52a**, **52b** of each liquid storage tank **50a**, **50b**. In accordance to said preferred embodiment of the damping system in which the pair of orifice members **54a**, **54b**, are electro-mechanically actuated orifice members **54a**, **54b** such as control-valves which have the capability of providing feedback, said damping system further includes a remote monitoring and actuating system **60** for actuating the electro-mechanically actuated orifice members **54a**, **54b** to control a degree of opening of the orifice obstructed by an orifice member **54a**, **54b** in each passageway **52a**, **52b** extending from the main body **51a**, **51b** of each liquid storage tank **50a**, **50b**, to hence enable tuning of a damping characteristic of said damping system during or after installation on a building structure.

The damping system of the present invention differs from conventional damping systems of the prior art, in view of the fact, that in the damping system of the present invention, the damping that the translational tuned mass damper **100** experiences, is adjusted by passively actuating the pair of electro-mechanically actuated orifice members **54a**, **54b** to control a degree of opening of an orifice obstructed by said pair of orifice members **54a**, **54b** respectively, to consequently provide a desired response of said damping system to vibrations of a building structure, particularly vibrations of the building structure at a fundamental mode of vibration and hence provide a desired response (i.e. a desired transient and frequency response) of the building structure in relation to damping of vibrations of the building structure.

More particularly, as it would be easily understood by one of ordinary skill in the art of structural control systems, the damping system of the present invention can be modelled as a second order system in frequency domain, with the natural frequency of oscillation of the damping system, being determined by the mass of the moveable mass **10** of the translational tuned mass damper system **100** and the stiffness of the pair of spring members **20**. The damping ratio of the damping system of the present invention, being determined by the head-loss and energy dissipation imposed on the piston head **11aa**, **11ba** of each piston member **11a**, **11b** extending from the moveable mass **10** as each piston head **11aa**, **11ab** reciprocates within the passageways **52a**, **52b** that each respectively contain an orifice with an adjustable degree of opening and that each extend from the main body **51a**, **51b** of each liquid storage tank **50a**, **50b** of the damping system when subject to a vibrational excitation. In contrast to tuned mass damping systems of the prior art in which the natural frequency of oscillation of the damping system is tuned, the damping system of the present invention provides for adjustable tuning of the damping of the translational tuned mass damper **100**.

The head loss and energy dissipation experienced by the piston heads **11aa**, **11ba** of the pair of piston members **11a**, **11b** extending from the moveable mass **10** of the tuned mass damper **100** due to reciprocating motion within the passageways **52a**, **52b**, occurs because of a sudden change in cross sectional area in the local vicinity of said orifice within each passageway **52a**, **52b** extending from the main body **51a**, **51b** of each liquid storage tank **50a**, **50b** through which the piston heads **11aa**, **11ba** travel. The amount of head loss and energy dissipation being dictated by a degree of opening of the orifices that result due to actuation of each orifice member **54a**, **54b** in each passageway **52a**, **52b**.

It should be understood that the damping system of the present invention, is a passive damping system in which the openings of the orifices obstructed by respective orifice members **54a**, **54b** disposed in respective passageways **52a**, **52b** extending from main bodies **51a**, **51b** of each liquid storage tank **50a**, **50b** are adjusted during or after installation of the damping system on a building structure, but not during the period the building structure experiences a vibrational excitation presumably due to cross winds or seismic events.

In accordance to a preferable embodiment of the damping system of the present invention, the pair of liquid storage tanks **50a**, **50b** are further tuned to dampen oscillations or vibrations of a building structure that correspond to the resonant frequency or fundamental mode of vibration of the building structure. More particularly, as one of ordinary skill in the art of structural control systems would understand, the pair of liquid storage tanks **50a**, **50b** of the damping system of the present invention, can be configured to behave as tuned liquid dampers (TLD’s), in which the resonant frequency or natural frequency of oscillation is dependent on the height of liquid in said liquid storage tanks **50a**, **50b**. Said resonant frequency or natural frequency corresponding to the resonant frequency or natural frequency of liquid sloshing of liquid disposed within said liquid storage tanks **50a**, **50b**. Specifically, in accordance to a preferable embodiment of the damping system of the present invention, the pair of liquid storage tanks **50a**, **50b** are open liquid storage tanks **50a**, **50b** in which the resonant frequency or natural frequency of liquid sloshing is determined by the depth of fluid contained in each liquid storage tank **50a**, **50b**.

In accordance to a preferable embodiment of the damping system of the present invention, water is utilized as the liquid in the liquid storage tanks **50a**, **50b** of the damping system due to its low cost and fire retarding and extinguishing properties.

With reference to figure 5, as mentioned in a preceding paragraph of the detailed description, in accordance to a preferable embodiment, the pair of orifice members **54a**, **54b** are electro-mechanically actuated orifice members **54a**, **54b**, such as control valves which have the capability to provide feedback in the form of electrical signals and receive electrical signals for actuating to effect remote monitoring and actuating of a degree of opening of said control valves and hence a degree of opening of an orifice obstructed by said control valves to/from a remote actuating and monitoring system **60**.

More particularly, as mentioned in a preceding section of this specification, figure 5 is a schematic of a damping system in accordance to a preferable embodiment of the present invention in which the pair of orifice members **54a**, **54b** are electro-mechanically actuated orifice members **54a**, **54b** such as control valves that are capable of receiving electrical input actuating signals to actuate a degree of opening of said control valves and hence actuate a degree of opening of an orifice obstructed by said control valves and further capable of providing electrical output signals to provide feedback on a present degree of opening of said control valves and hence a present degree of opening of an orifice obstructed by said control valves to a remote monitoring and actuating system **60** to effect adjustability to a degree of opening of an orifice to enable adjustable damping of the translational tuned mass damper **100** of the damping system of the present invention during or after installation on a building structure.

Said remote monitoring and actuating system **60** in accordance to a preferable embodiment comprising an operator station (not shown) that allows an operator to monitor a degree of opening of an orifice in a given passageway **52a**, **52b** extending from a given main body **51a**, **51b** of a given liquid storage tank **50a**, **50b** through feedback signals provided by the electro-mechanically actuated orifice members **54a**, **54b** to said remote monitoring and actuating system **60** and further allowing said operator through said operator station to electromechanically actuate a degree of opening of each orifice in each passageway **52a**, **52b** through electrical signals fed to each of said electromechanically actuated orifice members **54a**, **54b**. Specifically the remote actuation and monitoring system **60** including a central processing unit and an I/O card that serve to enable reception and transmission of electrical signals received from and transmitted to said pair of electromechanically actuated orifice members **54a**, **54b**.

Many modifications and variations may be made in the embodiments described herein and depicted in the accompanying drawings without departing from the concept of the present invention. Accordingly, it is understood that the embodiments described and illustrated herein are illustrative only and are not intended as a limitation upon the scope of this invention.

CLAIMS

1. A damping system for damping vibrations of a building structure comprising a translational tuned mass damper (100) including:

a moveable mass (10) that is laterally restrained by a spring member (20a, 20b) and that is tuned at a fundamental mode of vibration of a building structure; and a dashpot (70a, 70b) that serves to dampen vibrations of the moveable mass of the translational tuned mass damper (100), comprises:

a piston member (11a, 11b); and

a liquid storage tank (50a, 50b) that includes a passageway (52a, 52b) being configured to snugly receive the piston member (11a, 11b);

characterized in that;

the dashpot (70a, 70b) is configured to provide adjustable damping to hence provide a measure of control to the damping of the vibrations of the building structure that include vibrations at or near a fundamental mode of vibration of the building structure when subjected to a vibrational excitation.

2. A damping system according to claim 1, wherein the translational tuned mass damper (100) includes a pair of dashpots (70a, 70b).

3. A damping system (150) according to claim 1, wherein the translational tuned mass damper (100) includes a pair of spring members (20a, 20b).

4. A damping system (150) according to claim 1, wherein the dashpot (70a, 70b) of the tuned mass damper (100) comprises:

a piston member (11a, 11b) extending from the moveable mass (10) of the translational tuned mass damper (100) with the piston member (11a, 11b) comprising of a piston rod (11aa, 11ab) and piston head (11ba, 11bb); and

a liquid storage tank (50a, 50b) that includes a main body (51a, 51b) and a passageway (52a, 52b) extending from the main body (51a, 51b), the passageway (52a, 52b) being configured to snugly receive a piston head (11ba, 11bb) of the piston member (11a, 11b) extending from the moveable mass (10); the passageway (52a, 52b) including an orifice member (54a, 54b) that can be actuated to control a degree of opening of an orifice defined by a cross sectional area of the passageway (52a, 52b) and that is obstructed by the orifice member (54a, 54b).

5. A damping system according to claim 4, wherein the liquid storage tank (51a, 51b) is tuned to dampen vibrations of a building structure.

6. A damping system according to claim 4, wherein the orifice member (54a, 54b) is an electro-mechanically actuated orifice member (54a, 54b) such as a control valve.

7. An damping system according to claim 6, wherein the damping system further includes an actuating and monitoring system (60) for actuating the electro-mechanically actuated orifice member (54a, 54b) to control a degree of opening of the orifice obstructed by the electro-mechanically actuated orifice member (54a, 54b) to enable tuning of a damping characteristic of the damping system.

ABSTRACT

DAMPING SYSTEM

A damping system for damping vibrations of a large civil structure due to cross-winds and seismic events comprising a translational tuned mass damper (100) including a moveable mass (10) that is laterally restrained by a spring member (20a, 20b) and that is tuned at a fundamental mode of vibration of a building structure and a dashpot (70a, 70b) that serves to dampen vibrations of the moveable mass (10) of the translational tuned mass damper (100), wherein said pair of dashpots (70a, 70b) are configured to provide adjustable damping to hence provide a measure of control to the damping of the vibrations of the building structure that include vibrations at a fundamental mode of vibration.

Figure 4

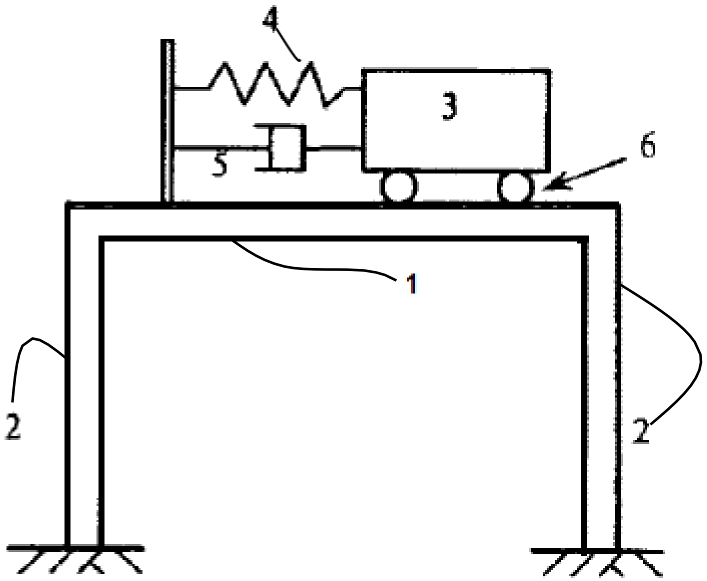

Figure 1 (Prior Art)

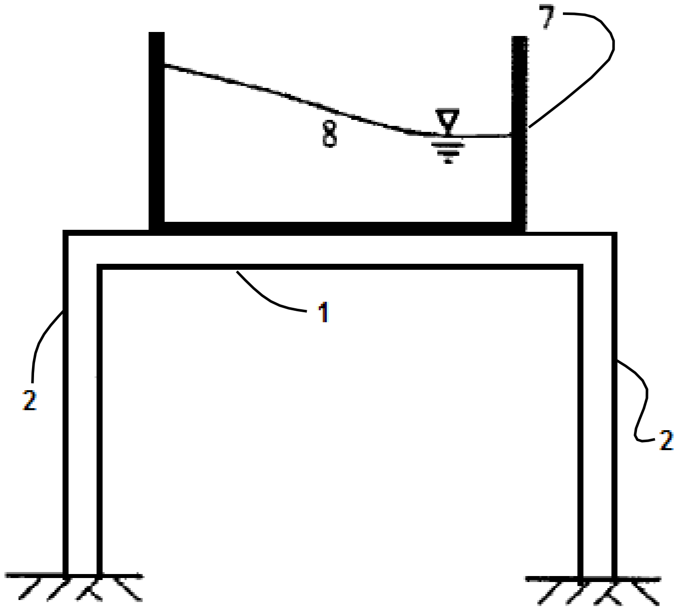

Figure 2 (Prior Art)

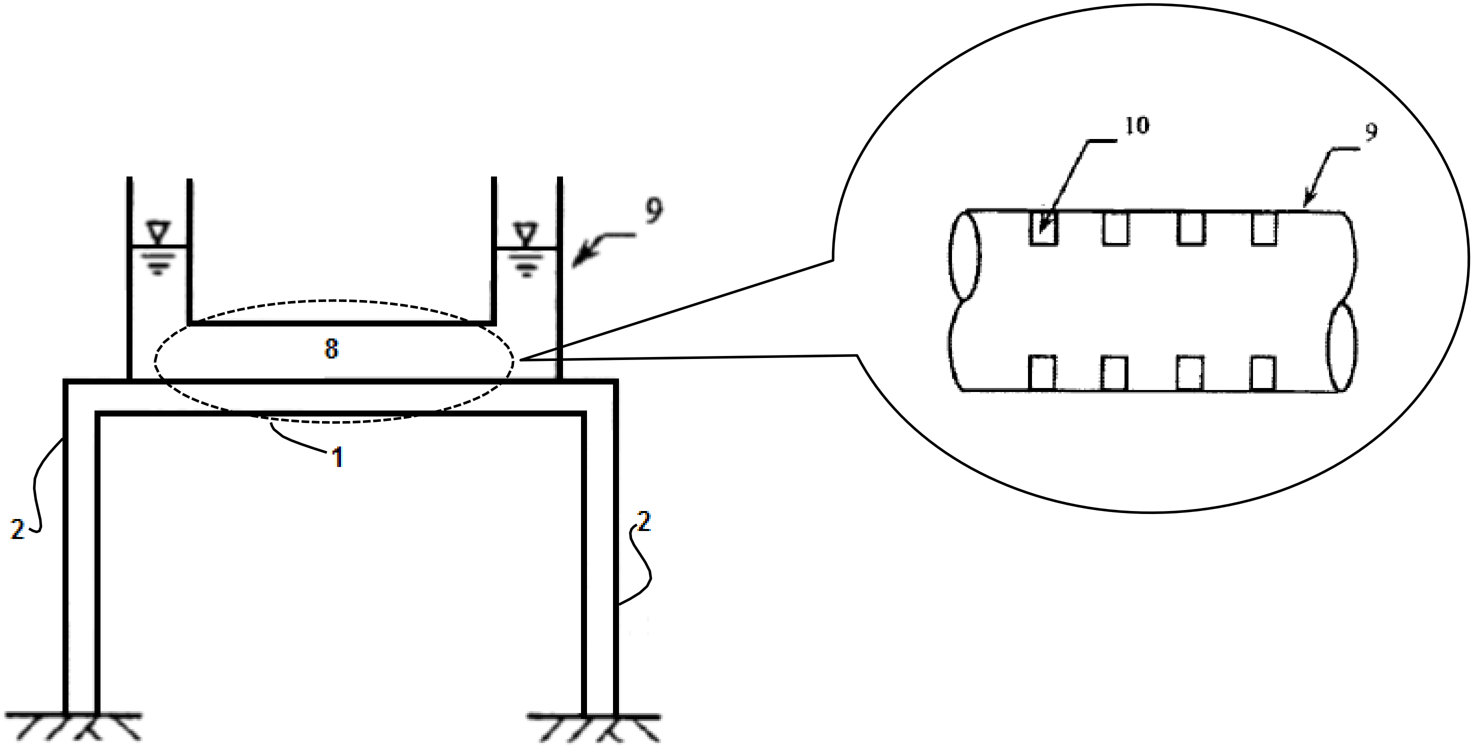

Figure 3 (Prior Art)

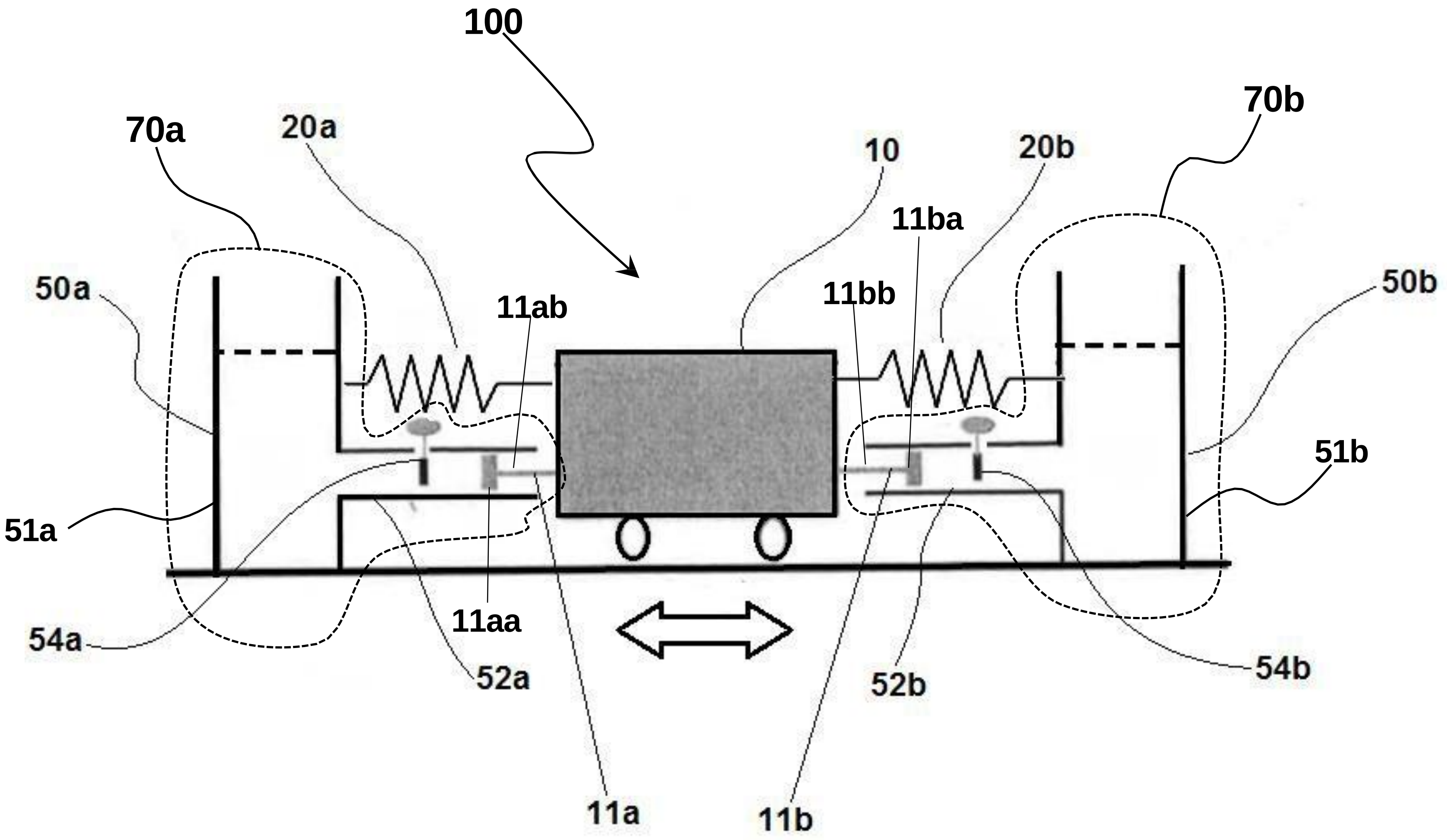
100
70b
70a
20a
10
20b
11ba
50a
11bb
50b
11ab
51b
51a
54a
11aa
52a
54b
52b
11a
11b

Figure 4

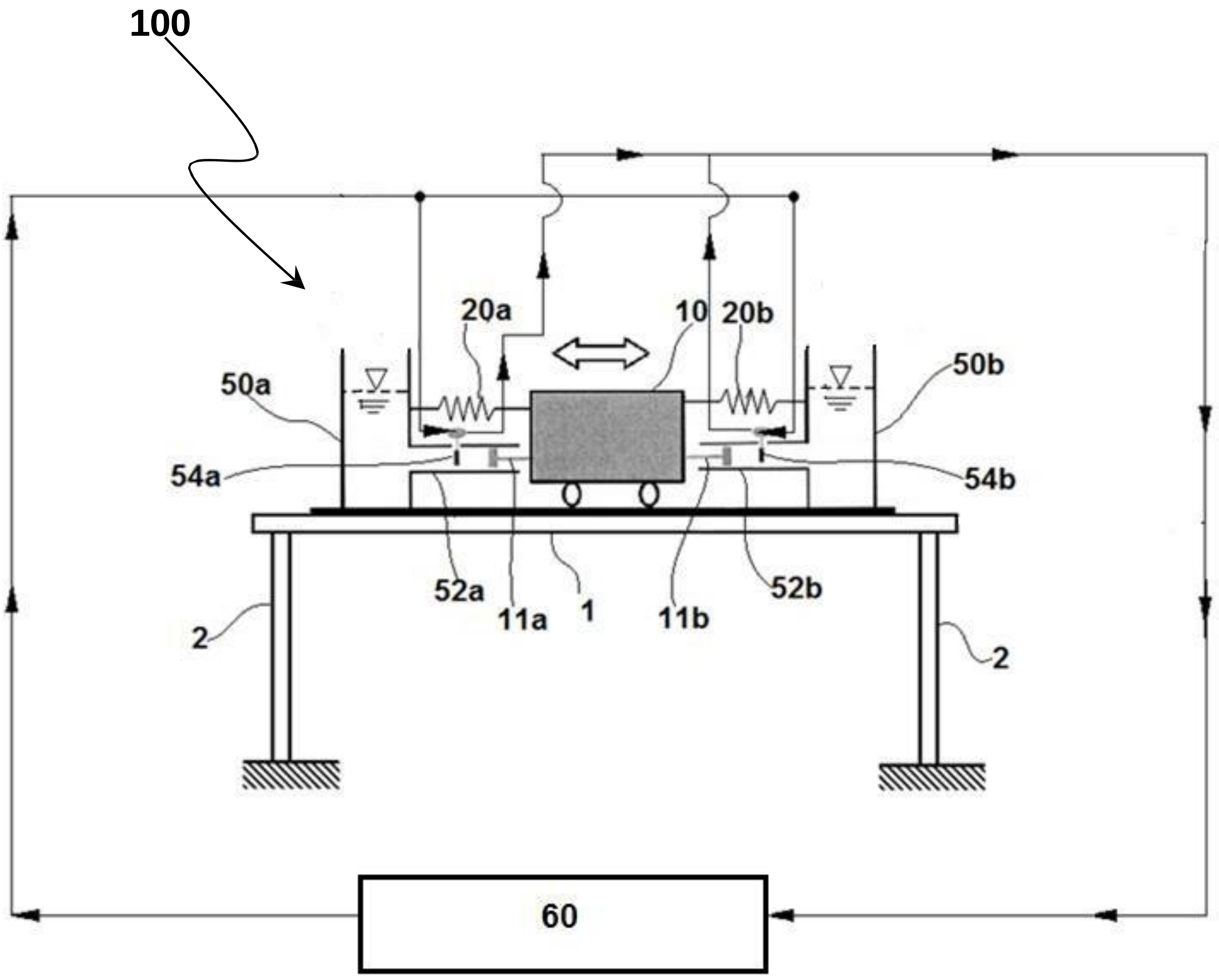

Figure 5