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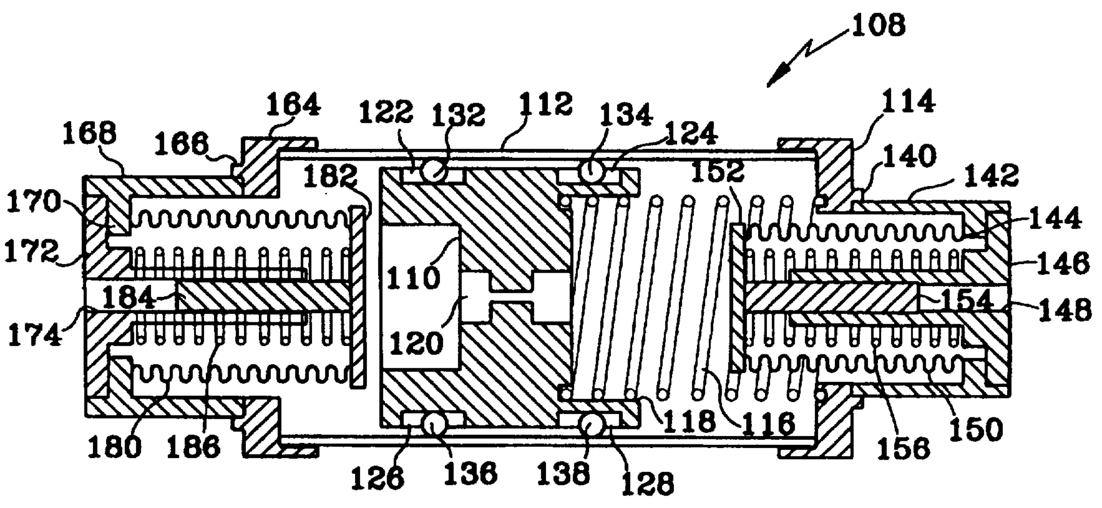
(54) Title: TUNED MASS DAMPER WITH TUNABLE DAMPING AND ANTIFRICTION ROLLING MASS



(57) Abstract

A container (12, 112) with an inside surface and a mass (10, 110) mounted for oscillation in the container (12, 112) with a pair of bellows (150, 180) in the container (12, 112) each having a bias spring (156, 186) therein and a removable end (146, 172) to expose the interior of the bellows (150, 180) to exchange the spring (156, 186) for easy tuning of the damping characteristics and a plurality of balls (132, 134, 136, 138), one each positioned in a plurality of troughs (122, 124, 126, 128) around the periphery of the mass (10, 110) proximate the ends there to bear against the inside surface so as to provide low friction oscillation of the mass (10, 110) in the container (12, 112).

TUNED MASS DAMPER WITH TUNABLE DAMPING AND ANTI FRICTION ROLLING MASS

BACKGROUND OF INVENTION

1. Field of the Invention

The present invention relates to tuned mass damping devices and more particularly to such dampers which may find use in reducing the periodic motion of elongated structures such as booms. The invention may have particular utility with booms mounted on satellites to hold measuring equipment the accuracy of which may be reduced due to the sway of the boom resulting from disturbances such as thermal distortion shock caused by, for example, transient thermal distortions of solar panels.

2. Description of the Prior Art

In the prior art, tuned mass dampers for reducing sway are known. Such dampers usually contain a mass mounted for movement in a container of fluid or a magnetic field and positioned by a spring. By proper selection of the mass and spring, the mass will have the same natural frequency as the boom, or other device to which the damper is mounted, so that when the boom experiences shock and begins to sway in a direction, the mass begins to vibrate or oscillate in the same direction and at the same frequency. However, since the boom is an input to the damper, the damper vibrates 180 degrees out of phase with the boom, which motion tends to cancel the boom motion. Since the boom is now vibrating at an off-resonant frequency and the damper has absorbed a substantial portion of its energy, the boom displacement is much smaller and is effectively damped out by the fluid or by the magnet in the damper. Such dampers are satisfactory for high frequency vibrations but because frequency is proportional to the ratio between the square root of the spring constant to the mass, at low frequencies e.g. 1.5 hertz, the mass becomes too large for the spring and cannot be effectively supported. The result is that the mass begins to sway and move in directions other than that required for proper damping.

BRIEF DESCRIPTION OF THE PRESENT INVENTION

The present invention overcomes the problems in the prior art by providing a damper with a mass which is constrained to move in the desired direction. By making the mass cylindrical and positioning it within a housing closely adjacent the mass, motion in the fluid container in only the desired direction is permitted. The fluid may be varied to make the vibration tunable and, in fact, the present invention provides for tunable damping without having to change the fluid. The tuning of the damping is accomplished by providing a pair of bellows with changeable internal springs therein to change the volumetric stiffness of the bellows and thus provide different characteristics to the fluid expansion and contraction in the chambers surrounding the mass. Thus, in testing the damping characteristics for a particular use, only the springs internal to the bellows need be changed for fine tuning. In the event that the sliding friction between the mass and the adjacent container housing is too large, a nearly frictionless motion is provided by using a linear bearing with, for example, circulating balls. A specific improvement to the ball bearing mounting is shown in the present invention by the use of a plurality of linear troughs in the mass each of which entraps a single ball so that there is no sliding friction between the mass and the walls or between adjacent balls.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows an example of the basic tuned damper of the present invention; and,

FIG. 2 shows a second embodiment of the present invention incorporating both the fine tuning of damping and reduction of friction with motion of the mass.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

In FIG. 1 a damper 8 is shown comprising a hollow moveable mass 10, slideably mounted in a cylindrical container 12 having a first end piece 14 fastened to cylinder 12 by conventional means, such as bolts, not shown and sealed to prevent fluid loss by a grommet 16. A second end piece 18 is fastened at a second end in a recess 20 of cylinder 12 by conventional means such as bolts, also not shown. The cylinder 12 and end pieces 14 and 18 form a chamber 22 within which mass 10 may move back and forth.

A spring 30 of predetermined stiffness is fastened at one end thereof to a protrusion 32 of end piece 14 and at the other end thereof to a recess 34 in mass 10 so that mass 10 will be positioned by spring 30 until subjected to a force allowing mass 10 to oscillate, only horizontally, back and forth in chamber 22 at a frequency determined by the size of mass 10 and stiffness of spring 30.

The first end piece 14 has a filling port 36 therethrough which allows the introduction of a damping fluid, shown by arrow 38, into the chamber 22. After filling, port 36 is sealed in conventional manner.

At the second end of cylinder 12, in recess 20, a thermal expansion bellows 40 is connected at one end thereof to a protrusion 42 in end piece 18 and at the other end thereof to a sealing member 44. End piece 18 has a small opening 48 therethrough connecting the interior of bellows 40 to chamber 22. This allows transfer of fluid from chamber 22 to the interior of bellows 40 to accommodate expansion and contraction of the fluid under modest temperature variations.

In one application of the apparatus of Figure 1, the damper may be used to compensate for unwanted vibrations of, for example, a boom shown in Figure 1 by reference numeral 50. The unwanted oscillations will be transverse to the length of the boom and accordingly it is desired that the mass 10 move in the same direction, i.e. from right to left in Figure 1. Accordingly, the damper 8 is shown mounted to boom 59 horizontally as indicated by dashed lines 52 and 54 and, as explained above, will vibrate 180 degrees out of phase with the boom to help cancel the boom motion.

For many applications, the apparatus of Figure 1 will perform satisfactorily, but for some high accuracy or specialized uses, there may be inaccuracies or unnecessary costs associated with the Figure 1 damper. For example, in order to provide the exactly correct amount of damping, the damping fluid 38 in chamber 20 is first chosen to have a viscosity which is believed to provide the best absorption of energy from the oscillating system and provide the desired amount of damping for the specific intended use. The boom and the damper are then tested to check the damping characteristics and, if they are not right, the fluid has to be drained and new fluid with different viscosity inserted for a re-test. This process is repeated until the desired damping characteristics of the system are obtained. Such a procedure is quite costly and time consuming and adds considerable cost to the damper.

Another difficulty with the Figure 1 damper is a result of mass 10 sliding in chamber 22 because too much friction may be involved for optimum damping effectiveness. Conventional linear bearings may be used to reduce the friction and in some cases may be sufficient. However, even using conventional linear bearings between mass 10 and the interior of cylinder 12 there may be too much friction because of contact between the balls. These problems are overcome with the improvements of Figure 2.

In Figure 2, a damper 108 (which may also be attached to a beam as in Figure 1 but not shown in Figure 2 for simplicity) is shown comprising a moveable mass 110, slideably mounted in a cylindrical container 112 having a first cylindrical end piece 114 fastened to the right end of cylinder 112 by conventional means, not shown. A spring 116 has a first end fastened in a recess 118 of mass 112 and a second end fastened to end piece 114 so that mass 110 is positioned thereby. Mass 110 is shown having an orifice 120 extending between its left and right sides in Figure 2 so as to permit the passage of the damping fluid therethrough. The damping fluid may be inserted in the cylindrical container 112 in a manner similar to that shown in Figure 1. As was the case in Figure 1, the mass 110 and the spring 116 are chosen to have the frequency of oscillation matching the particular use to which it is to be put e.g. the frequency of the boom to which it will be mounted.

A plurality of troughs 122, 124, 126 and 128 are shown in the outer edge of mass 110 and are cross-sectionally shaped to constrain the movement of balls such as 132, 134, 136 and 138 in all but the desired direction, horizontally in Figure 2. For example, the grooves may be of slightly greater diameter than the balls as is shown in Figure 3a where a semicircular groove 122a supports the ball 132a, or, as shown in Figure 3b, may be a "V" shaped groove 122b supporting a ball 132b. In either case, the ball is constrained for motion only into and out of the plane of the paper. The plurality of balls 132, 134, 136 and 138 in the troughs 122, 124, 126 and 128 respectively engage the inner surface of cylinder 112 and provide rolling motion for mass 110. The lengths of the troughs are made to accommodate the amount of motion expected of mass 110 oscillating back and forth in use. In the event that the mass 110 moves more than expected, the balls (although moving less distance than the mass) may nevertheless reach the ends of the trough where they may encounter greater friction due to the worming effect and/or tolerance errors. However, the device is completely self centering so that when the motion decreases to the expected limits, the balls will move to the center and at rest assume the position shown in Figure 2. This feature assures the device will remove the maximum amount of energy from the system by minimizing mass friction. There should be at least two troughs around the diameter of mass and preferably three or more to prevent any contact between the outer surface of mass 110 and the inner surface of cylinder 112. Using the balls eliminates the sliding friction between the mass 110 and the cylinder 112 and since a single ball is used, there is no friction between balls. Thus the possible excessive friction of the Figure 1 damper has been avoided.

Cylindrical end piece 114 has an abutment 140 and a first cylindrical end member 142 is seated thereon. Cylindrical end member 142 has an inwardly extending ledge 144 and a removable end cap 146 with a hole 148 extending centrally therethrough. End cap 146 is mounted against ledge 144. A first bellows 150 has a right end which is fixed to the ledge 144 and extends to the left towards the interior of cylindrical container 112. The left end of bellows 150 is sealed to a circular plate 152 which has a central rod 154 extending back to the right so as to be guided in the hole 148. A spring 156 is positioned in the interior of bellows 150 between the circular plate 152 and the end cap 146 and provides additional volumetric stiffness to the bellows 150.

The left end of damper 108 in Figure 2 is similar to the right end. A second cylindrical end piece 164 is fastened to the left end of cylindrical container 112 by conventional means, not shown. End piece 164 has an abutment 166 and a second cylindrical end member 168 is seated thereon. Cylindrical end member 168 has an inwardly extending ledge 170 and a removable end cap 172 with a hole 174 extending therethrough. End cap 172 is mounted against ledge 170. A second bellows 180 has a left end which is fixed to the ledge 170 and extends to the right towards the interior of cylindrical container 112. The right end of bellows 180 is sealed to a circular plate 182 which has a central rod 184 extending back to the left so as to be guided in the hole 174. A spring 186 is positioned in the interior of bellows 180 between the circular plate 182 and the end cap 172 and provides additional volumetric stiffness to the bellows 180.

It is seen that as the mass 110 moves to the right and left in Figure 2, the fluid pushes against circular plates 152 and 182 to collapse bellows 150 or 180 against the force supplied by spring 156 or 186. The amount of damping that this provides to the system is controlled in part by the stiffness of the springs 156 and 186 so all that is needed to change or fine tune the damping effect, is to remove the end caps 146 and 172 and replace springs 156 and 186 with springs having different stiffness. Thus, testing of the damper is considerably easier, much less time consuming and less expensive than the draining and replacement of the fluid as in Figure 1.

It is thus seen that we have provided a damper that is constrained to move only in the desired direction for proper damping at low frequencies. We have also provided a damper that is easily fine tuned and has a minimum of friction between the moving mass and the container. Although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention. For example, in the event that it is desired to accommodate the damper to extreme forces, as, for example, the force exerted on the equipment upon take off from a launching site, additional springs located near the interior portions of end pieces 114 and 164 may be employed to provide a soft stop for mass 110. Also, if reduced rolling friction is desired but extreme accuracy is not required, the first and second bellows may be omitted and a single temperature compensating bellows such as shown in Figure 1 employed. Furthermore, when the oscillations to be damped may occur in more than one plane, two dampers mounted on the member at right angles to each other may be employed.

CLAIMS

The embodiments of the invention in which an exclusive property or right is claimed are as follows:

1 . A damper comprising a hollow cylinder having an inner surface, a first end with a hole therethrough to permit the introduction of fluid to the interior of the container and a second end having a hole therethrough to permit restricted fluid flow therethrough;

a bellows having an interior and sealably fastened to the second end so that fluid from the interior of the housing can flow through the hole to the interior of the bellows to accommodate expansion of the fluid due to temperature changes;

a mass having first and second ends and an outer surface slightly smaller than the inner surface of the cylinder; and

spring means mounting the mass to the first end to allow oscillatory motion of the mass only in first and opposite directions within the container.

2. Apparatus according to claim 1 further including mounting means fastening the damper to a boom which may be subject to undesired oscillations, the mounting means positioning said damper so that the undesired oscillations of the boom produce oscillatory motion of the mass at substantially the same frequency but substantially 180 degrees out of phase so as to produce damping of the undesired oscillations.

3. Apparatus according to claim 1 further including a plurality of balls mounted between the inner surface of the cylinder and the outer surface of the mass to provide less friction to the oscillations of the mass.

4. Apparatus according to claim 3 wherein the plurality of balls are positioned in a plurality of grooves in the mass.

5. Apparatus according to claim 4 wherein there are at least three grooves proximate each of the first and second ends of the mass.

6. A damper for use in damping oscillatory motions of a member to which the damper is mounted comprising:

a container having side portions and end portions;

a mass positioned in said container for oscillatory motion between the end portions;

spring means connected to one end portion and to the mass to position the mass at a central rest position, the stiffness of the spring means and the size of the mass being chosen to provide an oscillatory motion at a desired predetermined frequency;

first and second bellows one mounted at each end portion of the container with each bellows containing a bias spring of predetermined stiffness: and

removable means sealing the ends of each bellows so that the bias springs may be removed and replaced with alternate bias springs of different stiffness to alter the damping characteristics of the damper and the member.

7. Apparatus according to claim 6 further including a fluid of predetermined viscosity in the container, the viscosity being chosen to approximate the desired damping characteristics and the change of bias springs providing fine tuning of the damping characteristics.

8. Apparatus according to claim 6 further including a plurality of trough around the periphery of the mass; and

a plurality of balls, one located in each trough and bearing against the side portions of the container to provide minimum friction for the motion of the mass.

9. Apparatus according to claim 7 further including a plurality of troughs around the periphery of the mass; and

a plurality of balls, one located in each trough and bearing against the side portions of the container to provide minimum friction for the motion of the mass.

10. Apparatus according to claim 9 wherein the container is a circular cylinder of a first interior correctional diameter and the mass is a cylinder of cross-sectional diameter

(Claim 10 continued)

less than the first interior cross-section by an amount sufficient to entrap the balls between the trough and the interior of the container.

11. Apparatus according to claim 10 wherein the damper is mounted on a boom which has the predetermined frequency of oscillation the damper operating to remove energy from the oscillating boom and provide optimum damping.

12. Apparatus according to claim 11 including a second damper mounted on the boom at right angles to the damper to damp oscillations in transverse directions.

13. Apparatus for minimizing friction between a mass having an exterior surface and the interior surface of a container in which the mass is to oscillate comprising:

a plurality of troughs formed in the surface of the mass around the periphery thereof; and

a plurality of balls, one positioned in each trough and bearing against the interior surface of the container to allow low friction oscillation of the mass in the container.

14. Apparatus according to claim 13 wherein there are at least three troughs spaced around the periphery of the mass on each end thereof.

15. Apparatus according to claim 14 wherein the container and mass comprise a damper for use in damping the oscillatory motion of a member to which the damper is mounted.

16. Apparatus according to claim 15 further including a fluid of predetermined viscosity in the container on either side of the mass.

17. A tunable damper comprising:

a cylinder having an interior surface of predetermined diameter circular cross-section and first and second ends;

first and second end covers closing the first and second ends of the container, said first and second end covers having a first and second bellows respectively extending into the interior of the container, said bellows having a first and second springs respectively of predetermined stiffness biasing the bellows and a removable end piece exposing the interior of the bellows to facilitate changing of the spring to one of a different stiffness;

a fluid of predetermined viscosity in the interior of said cylinder;

an oscillatory member having a circular exterior surface of predetermined diameter less than the interior surface of the cylinder, said oscillatory member having a predetermined mass and having first and second ends with an orifice therebetween;

a third spring of predetermined stiffness connected between one end cover and said oscillatory member to position said oscillatory member for oscillatory motion in the fluid in said container;

at least three troughs in the exterior surface of the oscillatory member, spaced around the periphery thereof proximate the ends and of length chosen to accommodate the amount of oscillatory motion of the oscillatory member; and

a plurality of balls, only one in each trough and bearing against the interior surface of the circular cylinder to provide low friction self centering motion of the oscillatory member in the container.

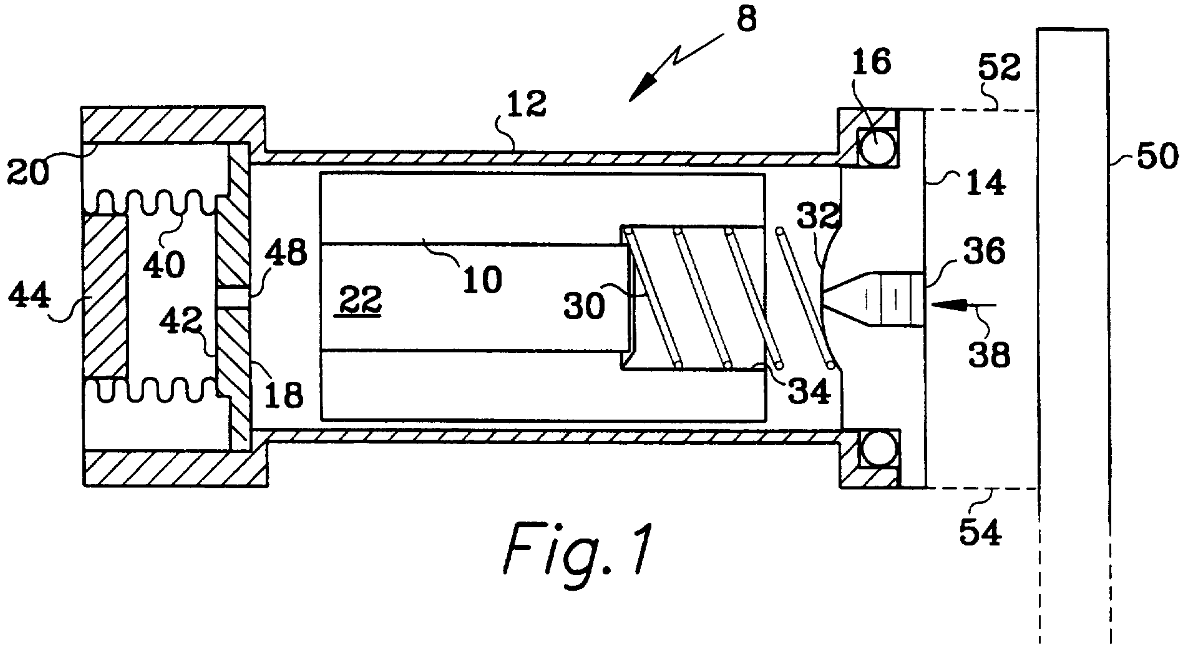

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Fig. 1

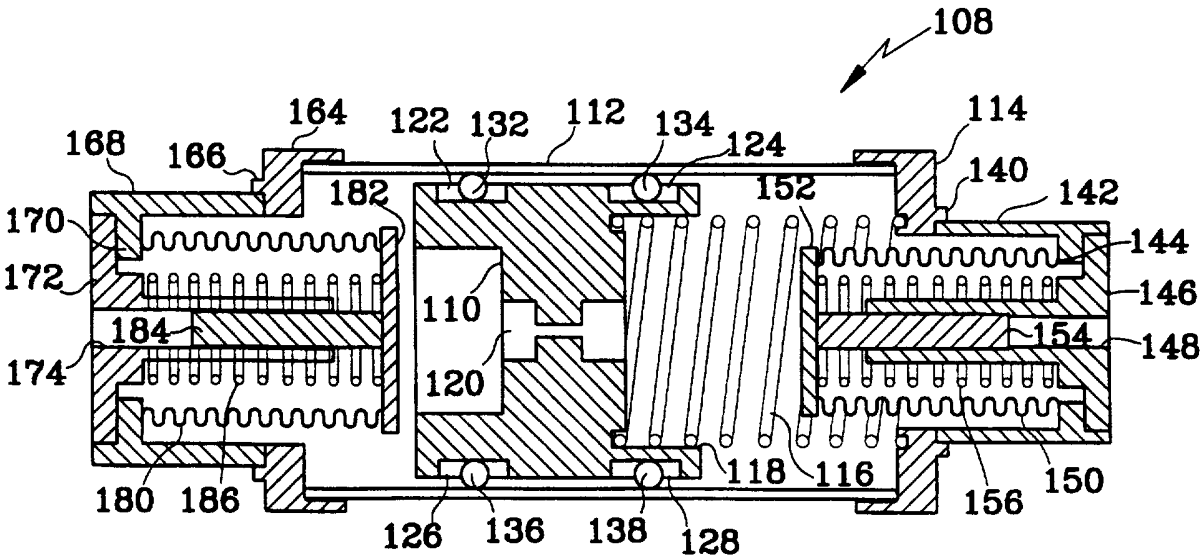
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Fig. 2

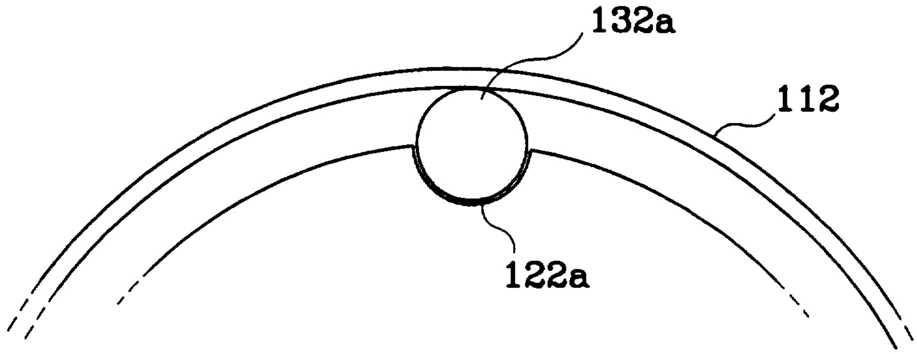

Fig. 3A

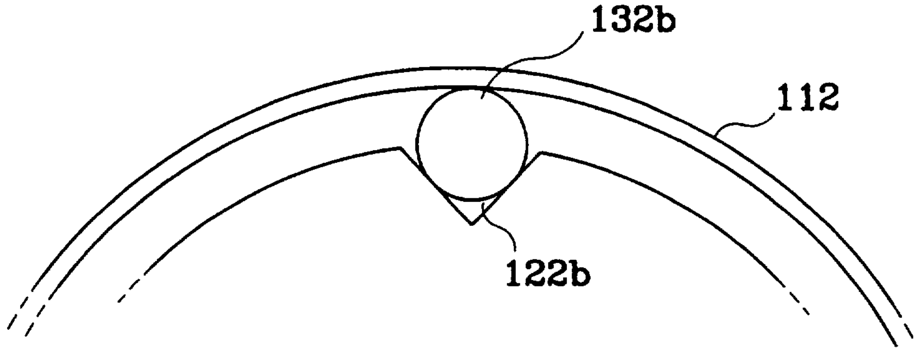

Fig. 3B

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 96/18224

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 F16F7/10 F16F7/112 F16F7/116

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G05G F16C F16F G05D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 530 518 A (NEWTON ALAN R) 23 July 1985 see the whole document	1,3-5, 13-16
Y		2,7-10
A		17

X	ATZ, vol. 56, no. 4, 4 April 1954, page 114 XP002026008 "Federung, Dynamische Stossdämpfer" see page 114, left-hand column, paragraph 11	6
Y		2,7-10

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

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Date of the actual completion of the international search	Date of mailing of the international search report
24 February 1997	05.03.97

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Van der Veen, F

Form PCT/ISA/210 (second sheet) (July 1992)

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 3 259 212 A (K. NISHIOKA ET AL.) 5 July 1966 see the whole document	13-16
A		2,4,5, 7-12,17
A	US 3 911 199 A (FISCHER EDWARD G) 7 October 1975 see the whole document	1-3, 11-13

1

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 96/ 18224

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

SEE SHEET B

1. ☐ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. ☒ As all searchable claims could be searches without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 96/ 18224

The Search Division considers that the present European patent application does not comply with the requirement of unity of invention and relates to several inventions or groups of inventions, namely:

Claim 1-5,17: Dynamic damper having adaptations for filling and expansion of damping fluid.

Claim 6-12,17: Dynamic damper having adaptations for modifying spring properties.

Claim 13-16,17: Dynamic damper having means for minimizing friction by means of a linear ball bearing.

INTERNATIONAL SEARCH REPORT

I. ational Application No
PCT/US 96/18224

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US 4530518 A	23-07-85	CA 1209488 A	12-08-86
		US 4687225 A	18-08-87
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		GB 1509223 A	04-05-78
		JP 997313 C	20-05-80
		JP 50149976 A	01-12-75
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