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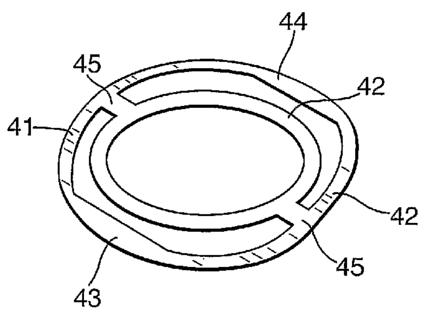
(54) **Title:** SUSPENSION SYSTEM



(57) **Abstract:** A suspension system suspends an object allowing movement of the object along a movement axis. The suspension system comprises two resilient members each suspending the object from a central point. The resilient members are integrally formed and are curved around the object as viewed from a direction along the movement axis. A support structure holds the resilient members in a flexed state with the portions of the resilient members on each side of their central points having opposite curvature as viewed from a direction perpendicular to the movement axis.

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SUSPENSION SYSTEM

This invention pertains to suspension systems for suspending an object to allow movement along a movement axis. It is particularly suited to a suspension system for use in combination with an electro-active actuator for moving the object. It is also suited for suspending an object which is a lens, for example as used in a camera system which may be employed in a mobile telephone or a mobile digital data processing and/or transmitting device.

WO-03/048831 describes a suspension system for the lens of a miniature camera, as used for example in a mobile phone. The suspension system described therein comprises two resilient members referred to as sine flexures. Each resilient member is a straight thin strip of elastic material, such as metal or plastic, supported at its ends to be held in a flexed state with portions on each side of a central point having opposite curvature so that the shape approximates to a sine wave. As is known in the art, the central point of such a flexure has very low (or even negative) stiffness in the direction normal to the strip. In the suspension system described in WO 03/048831, the lens is suspended from the central point of the flexures such that there is very little resistance to movement of the lens in the normal direction. Movements in other directions however are hindered. The suspension system therefore provides a near-frictionless suspension for the lens, allowing travel of the lens along the optic axis, as required for example in focussing and zooming.

Such lens movement is generally effected by some form of actuator, for example an electro-active actuator. A particularly advantageous form of electro-active actuator is the coiled piezoelectric actuator described in WO-01/47041and WO-02/103451. The force-displacement characteristics of such an actuator make it suitable for driving lens travel in a miniature camera, and its circular shape allows it to fit neatly around the lens of the camera.

The displacement direction of such a coiled actuator is approximately, but not perfectly, normal to the plane of the circle, which normal is approximately parallel to the optical axis of the lens system. Any off-axis movement of the actuator tends to cause sideways movement of the lens leading to misalignment. Such off-axis movement can be hindered by the provision of a suspension which is stiff in off-axis directions, while allowing free movement in the axial direction. The suspension system described above comprising two pairs of resilient members provides considerable stiffness in sideways (off-axis) directions.

However, the straight resilient members of the known suspension system do not fit neatly around the lens. The flexures are straight while the lens and actuator are circular. The footprint of the camera module as a whole is therefore necessarily rectangular. In portable electronic devices such as mobile phones, space is at a premium and compactness of individual components and modules is of prime importance.

According to a first aspect of the present invention, there is provided a suspension system for suspending an object to allow movement of the object along a movement axis, the suspension system comprising:

at least one resilient member which is arranged to suspend the object from a central point of the resilient member,

a support structure holding the resilient member in a flexed state with the portions of the resilient member on each side of the central point having opposite curvature as viewed from a direction perpendicular to the movement axis, the resilient member being curved as viewed from a direction along the movement axis.

Thus, as viewed from a direction perpendicular to the movement axis, the resilient member is held in a similar curved shape to the resilient member of the known type of suspension system disclosed in WO-03/048831 discussed above. However, in contrast to that known type of suspension system, the resilient member is also curved as viewed from a direction along the movement axis. The present invention is thus based on an appreciation that despite such a curved shape, the resilient member still displays similar properties to the known straight resilient members in the type of suspension system disclosed in WO-03/048831. In particular, the central point of the resilient member is a critical configuration point close to which the stiffness in the movement direction approaches zero. In the suspension system of the invention therefore, an object suspended at the central point can be moved axially with very little resistance. In contrast the suspension system resists movement in sideways directions. This has been demonstrated by modelling and experimentation.

The benefit of providing a curved resilient member is that the shape of the resilient member may be selected to curve around the object to be suspended. For example in the case of an object which is generally circular, as for example a lens, the curve may be an arc of a circle. Thus the present invention allows the suspension system to be more compact, providing a significant space saving.

The resilient member can be made from a variety of materials, for example metal or a plastic material.

The elastic structure is preferably a resilient strip, the width of the strip perpendicular to the movement axis being greater than the thickness of the strip. Desirably, the ratio of the width of the strip perpendicular to the movement axis to the thickness of the strip is on average at least 5, more preferably greater than 10 or even 20. Such values for this ratio provide desirable values for the relative degrees of stiffness provided by the suspension system in different directions, as discussed above.

Preferably, the suspension system comprises two resilient members each curved, as viewed from the direction along the movement axis, around a common axis. The two resilient members may be connected to each other at each end and integrally formed. The curve described by the integrally formed pair of resilient members may be a circle, or an approximation to a circle. Such a configuration has the advantage that it resists any unwanted twisting motions.

These and other aspects of the invention will be apparent from the following detailed description of non-limitative examples making reference to the following drawings.

In the drawings:

Fig. 1 is a perspective view of a microcamera assembly incorporating a known suspension system;

Figs. 2A and 2B are plan and side views of a resilient member in the suspension system of Fig. 1, in an unassembled state;

Figs. 3A and 3B are plan and side views of the resilient member of Figs. 2A and 2B, in an assembled state;

Figs. 4A and 4B are plan and side views of a resilient member applied in a first suspension system in accordance with the present invention, in an unassembled state;

Figs. 5A and 5B are plan and side views of the resilient member of Figs. 4A and 4B, in an assembled state;

Figs. 6A and 6B are plan and side views of two integrally formed resilient members applied in a second suspension system in accordance with the present invention, in an unassembled state;

Figs. 7A and 7B are plan and side views of the two integrally formed resilient members of Figs. 6A and 6B, in an assembled state;

Figs. 8A, 8B and 8C are plan, side and perspective views of two integrally formed resilient members applied in a modified form of the second suspension system, in an unassembled state; and

Fig. 9 is a cross-sectional view of a fixing arrangement for a resilient member.

Fig. 1 shows a micro-camera assembly of the type described in WO-03/048831 employing straight resilient members 12, 13 which may also be referred to as sine flexures. The assembly comprises a lens barrel 11 supporting one or more lenses and suspended by a suspension system comprising two resilient members 12, 13 in a housing 14 which may take the form of a frame and which acts as a support structure.

A piezoelectric actuator 15 is coupled between the lens barrel 11 and the housing 14. The actuator 15 is a coiled piezoelectric actuator of the type described in WO-01/47041and WO-02/103451. On activation, the actuator 15 drives the lens barrel 11 up and down in a movement direction 16 which is the axial direction of the lens barrel 16 along the optical axis.

The resilient member 12 is connected to the lens barrel 11 by a connecting piece 17 protruding sideways from the central point of the resilient member 12. The ends of the resilient member 12 are fixed to the housing 14 via fixing pieces 18. The second resilient member 13 is connected to the lens barrel and housing in a similar manner. As shown, the pair of resilient members 12,13 together with their connecting and fixing pieces 17, 18 are integrally formed to form a continuous single structure. Such a structure can be readily made by punching or cutting the appropriate shape from a flat sheet of material. On assembly, the structure does not remain flat, but rather the constraints applied to the fixing pieces 18 by the housing 14 holds the resilient members 12, 13 in a flexed state so that they each adopt a curved shape having opposite curvature on each side of their central point as viewed from the side.

Figs. 2A and 2B show schematic plan and side views of the structure formed by the resilient members 12, 13 in the suspension system of Fig. 1 in an unassembled state. Connecting pieces 17 and fixing pieces 18 are also shown. In this case the resilient members 12, 13 are not flexed. Figs. 3A and 3B show similar views of the resilient members 12, 13 in an assembled state. In this case the resilient members 12, 13 are held by the housing 14 in the flexed state. The curved shape having opposite curvature on each side of the central point is best seen in Fig. 3B. As shown, the fixing pieces 18 of the resilient members 12, 13 engage with angled slots 21 in the housing 14.

Embodiments of the present invention will now be described. In each case, the suspension system of the assembly of Fig. 1 as shown in Figs. 2A and 2B and in Figs. 3A and 3B is replaced by a different suspension system as will now be described. In each case, many parts of the suspension system such as the connecting portions 17 are unchanged and so for the common elements the same reference numrals are used and the description thereof is not repeated.

Figs. 4A and 4B show schematic plan and side views of a first such suspension system in the unassembled state. Figs. 5A and 5B show schematic plan and side views of the first suspension system in the unassembled state. The first suspension system comprises a resilient member 32 in the form of a thin strip of elastic material such as a metal or a plastics material.

The resilient member 32 is curved in plan view, that is when viewed from a direction along the movement axis 16 as shown in Figs. 4A and 5A. Although the resilient member 32 is flat in the unassembled state shown in Fig. 4B, when assembled onto the housing 14 (shown schematically only) the resilient member 32 is held by the housing 14 in a flexed state. Thus the resilient member 32 adopts a curved shape having opposite curvature on each side of its central point 34 in side view, that is from a direction perpendicular to the movement direction 16 as shown in Fig. 5B. In plan view in the assembled state, the resilient member extends around an arc of a circle as shown in Fig. 5A.

Also shown is the connecting portion 17 protruding from the resilient member 32 at the central point 34, for attachment of the lens barrel 11. The connecting portion 17 is preferably formed integrally with the resilient member 32.

Figs. 6A and 6B show schematic plan and side views of a second suspension system in the unassembled state. Figs. 7A and 7B show schematic plan and side views of the second suspension system in the unassembled state. The second suspension system comprises a circular flexure 31, itself comprising two curved resilient members 41, 42 which are integrally formed so that they are joined end to end.

In the unassembled state, the circular flexure 31 is roughly elliptical or oval in plan view as shown in Fig. 6A and flat in side view as shown in Fig. 6B. When assembled onto the housing 14, the circular flexure 31 is held by the housing in a flexed state having an approximately circular shape in plan view as shown in Fig. 7A and each resilient member 41, 42 having opposite curvature on each side of their central points in side view as shown in Fig. 5B. The circular flexure 31 is fixed into the housing 14 at two diametrically opposed locations, which locations are at right angles to two connecting pieces 17 which serve to connect to the lens barrel 11. In particular, the circular flexure 31 engages with appropriately shaped slots 18 in the housing 14.

The dimensions of the circular flexure 31 are chosen to fit neatly around the lens barrel 11 with sufficient clearance to allow the lens barrel 11 to move up and down within the inner circumference of the circular flexure 31. When used in conjunction with the piezoelectric actuator 15 as shown in Fig. 1, the circular flexure 31 has a similar radial extent as the actuator 15, being arranged in line with the actuator 15 as viewed along the movement direction 16.. It therefore adds a minimal amount or nothing to the radial extent of the assembly as a whole..

Figs. 8A, 8B and 8C show in plan view side view and perspective view a modified form of the second suspension system shown in Figs. 6A and 6B and in Figs. 7A and 7B. The modifications are as follows.

At the central point of each resilient member 41, 42 is a connecting piece 45 which connects to a collar 46. The collar 46 is shaped to fit on to a corresponding locating portion of the lens barrel 11.

The two resilient members 41, 42 of the circular flexure 31 are widened in the region where the two resilient members 41, 42 are fixed together to form fixing pieces 43, 44, shaped to facilitate fixing into the housing 14.

The width of each resilient member 41,42 decreases from the central point towards the fixing pieces 43, 44. This reduction in width near the fixing pieces 43, 44 lowers the stiffness locally and allows the circular flexure 31 to more readily assume the desired shape, shown in side view in Fig. 8B.

The perspective view of Fig. 8C shows similar features to Fig. 8A and illustrates the non-flat nature of the resilient members 41, 42, the portions to the left of the connecting pieces 45 curving downwards below the level of the collar 46 and the portions to the right curving upwards.

Advantageously, the entire circular flexure 31, comprising the resilient members 41, 42, the fixing pieces 43,44, the connecting pieces 45 and the collar 46, is formed integrally, for example by cutting from a flat sheet of elastic material such as metal or a plastics material.

To prevent tilting of the collar 46 when the circular flexure assumes its curved shape when assembled, the connecting pieces 45 are permanently twisted or bent with respect to the resilient members 41,42 so as to compensate for the inclination of the members at their mid point. The collar 46 is thus held approximately horizontally thereby facilitating the mounting and alignment of the moving object.

The following comments about the circular flexure 31 apply to both the unmodified and modified versions of the second suspension system.

The circular flexures 31 are preferably used in pairs, one at each end of the lens barrel 11 , to provide further resistance to twisting of the lens barrel 11.

In one embodiment, the circular flexure 31 is designed to be used in a micro-camera assembly incorporating a lens barrel 11 with outer diameter 11 mm. Thus the circular flexure 31 has dimensions of 15 mm outer diameter, average width about 1 mm and thickness 25 microns. It is made from hard rolled stainless steel, grade 302.

Compared to the known suspension system shown in Fig. 1, the circular flexure 31 has a considerably smaller footprint. This space saving is readily calculated from the difference in area of a square and a circle. The area saving is about 21%. This translates to a corresponding 21% saving in the volume of the micro-camera assembly as a whole. Given the tight space constraints within portable electronic devices such as mobile telephones, this is a significant benefit.

The circular flexure 31 this small and this thin can be made in a number of ways, but most conveniently by cutting it out from a sheet of material. For example, the circular flexure 31 can be stamped out using a die, or cut out using a singular cutting tool such as a laser, or most preferably etched out photochemically. Photochemical etching is particularly suited to making large numbers of devices all at once from a single large sheet of material; with one single printing the resist pattern defines a multiplicity of springs spaced across the surface of the sheet, and the etching realises them all at the same time.

In operation, all the suspension systems described above have very little resistance to movement in the movement direction 16, thereby allowing the lens barrel 11 to move freely back and forth along the optic axis. On the other hand they have very considerable stiffness in the sideways directions (perpendicular to the movement direction 16) which helps to prevent any off-axis movement of the lens barrel 11. These properties follow from the flexed shape of the resilient members 31 or 32. To optimise these properties, the resilient members 31 and 32 take the form of a strip having a width perpendicular to the movement axis being greater than the thickness of the strip. To provide optimal values for the relative degrees of stiffness in different directions, the ratio of the width of the strip perpendicular to the movement axis 16 to the thickness of the strip on average is preferably at least 5, more preferably greater than 10 or even 20. in the form of a thin strip of elastic material such as a metal or a plastics material.

Fig. 9 shows an alternative method of fixing the circular flexure 31 into the housing 14 which is easier to implement than the slot in the housing 14 shown in Fig. 7B. In this fixing method, the housing 14 is made in two parts 51,52, to be stacked vertically one above the other. The circular flexure 31 is clamped between the two parts and fixed in place by a pin 53 which extends vertically through the upper housing 51, through a hole in the circular flexure 31 and vertically through the lower housing 52. The ends of the housing parts 51,52 which are in contact with the circular flexure 31 are shaped appropriately to receive the circular flexure 31 and apply a clamping force when pinned. Such a fixing mechanism is also appropriate when a pair of circular flexures 31 is used, one at each end of the lens barrel 11. In this case, the housing 14 is made in three parts, and the upper circular flexure 31 is clamped between the upper and central part while the lower circular flexure 31 is clamped between the central and lower part.

CLAIMS

1. A suspension system for suspending an object to allow movement of the object along a movement axis, the suspension system comprising:

at least one resilient member which is arranged to suspend the object from a central point of the resilient member,

a support structure holding the resilient member in a flexed state with the portions of the resilient member on each side of the central point having opposite curvature as viewed from a direction perpendicular to the movement axis, the resilient member being curved as viewed from a direction along the movement axis.

2. A suspension system according to claim 1, wherein the at least one resilient member is a resilient strip, the width of the strip perpendicular to the movement axis being greater than the thickness of the strip.

3. A suspension system according to claim 2, wherein the ratio of the width of the strip perpendicular to the movement axis to the thickness of the strip is on average at least five.

4. A suspension system according to claim 2, wherein the ratio of the width of the strip perpendicular to the movement axis to the thickness of the strip is on average at least ten.

5. A suspension system according to any one of the preceding claims, wherein the at least one resilient member is curved along an arc of a circle as viewed from a direction along the movement axis.

6. A suspension system according to any one of the preceding claims, comprising two said resilient members each curved, as viewed from a direction along the movement axis, around a common axis.

7. A suspension system according to claim 6, wherein the two resilient members are connected to each other at each end.

8. A suspension system according to claim 7, wherein the two resilient members are integrally formed.

9. A suspension system according to any one of the preceding claims, wherein the at least one resilient member has a connection portion protruding from the central point of the resilient member.

10. A suspension system according to claim 9, wherein the protruding portion is a collar integrally formed with the at least one resilient member.

11. A suspension system according to any one of the preceding claims, further comprising the object suspended from the central portion of the at least one resilient member.

12. A suspension system according to claim 11, wherein the object is a lens .

13. A suspension system according to claim 11 or 12, further comprising an electro-active actuator coupled between the object and the support structure.

Fig.1.

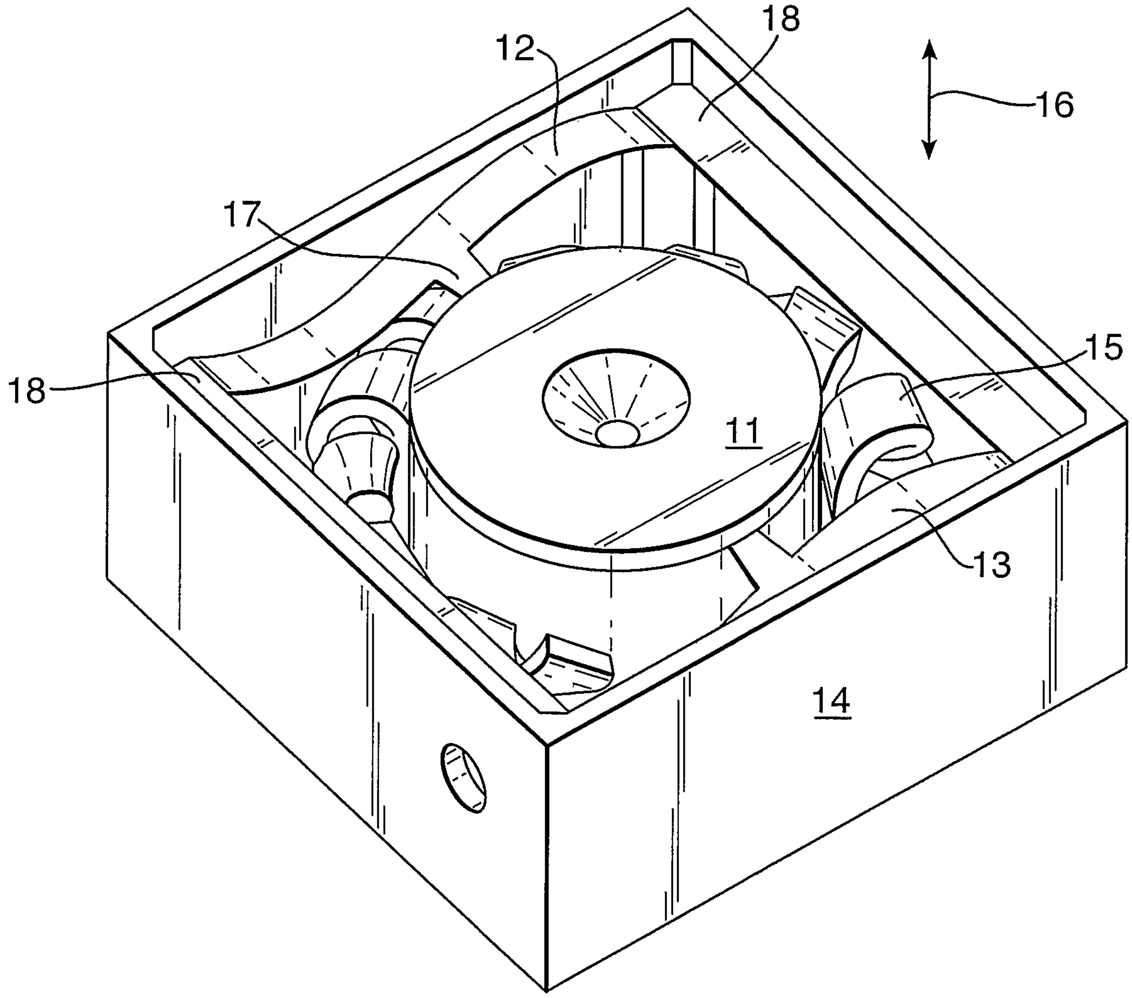


Fig.2A.

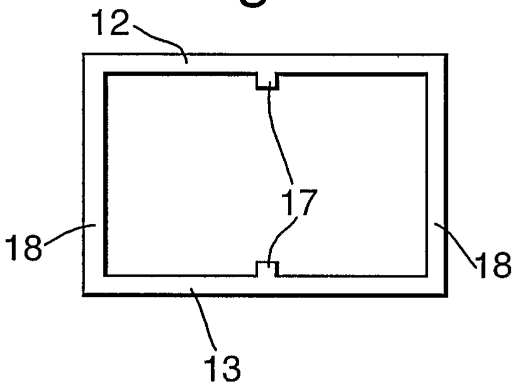


Fig.2B.

Fig.3A.

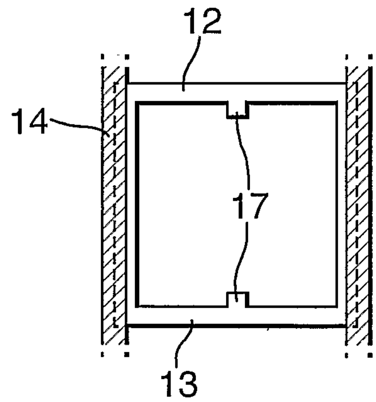


Fig.3B.

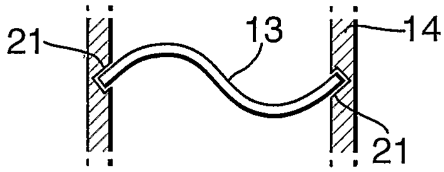


Fig.4A.

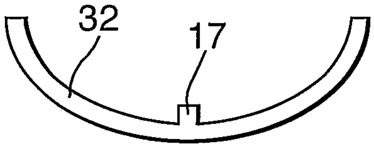


Fig.4B.

Fig.5A.

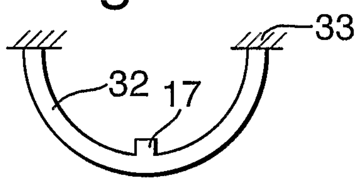


Fig.5B.

Fig.6A.

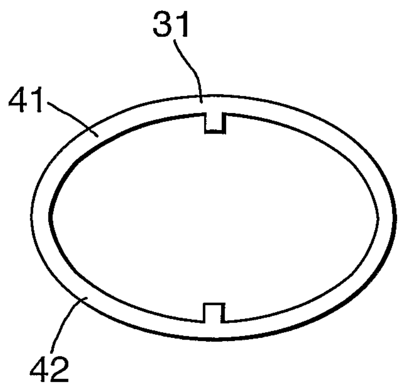


Fig.7A.

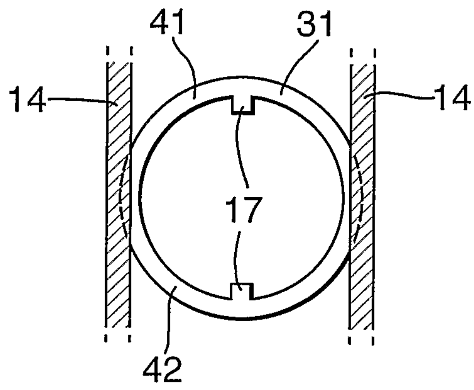


Fig.6B.

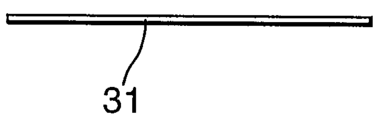


Fig.7B.

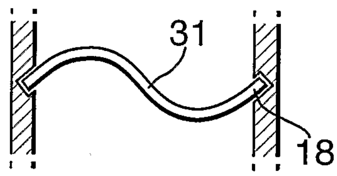


Fig.8A.

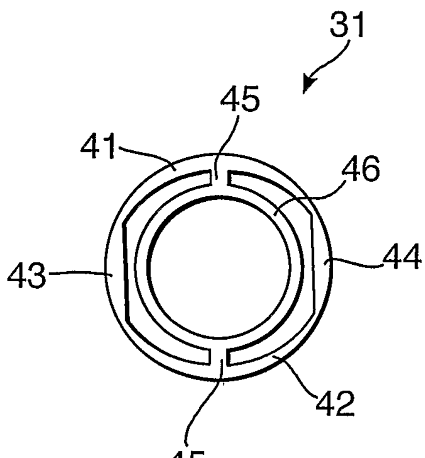


Fig.8B.

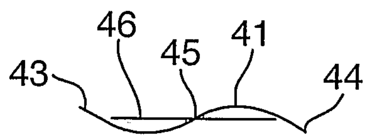


Fig.8C.

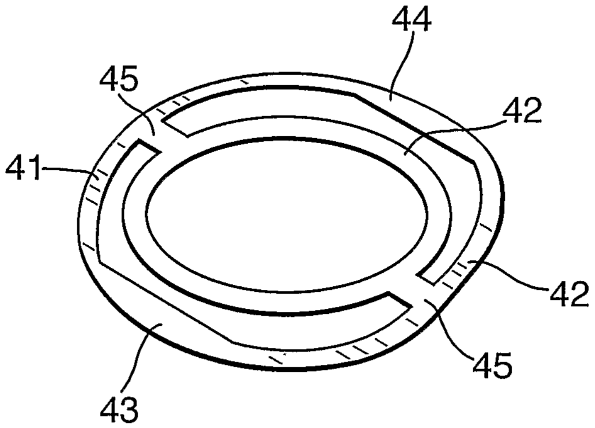
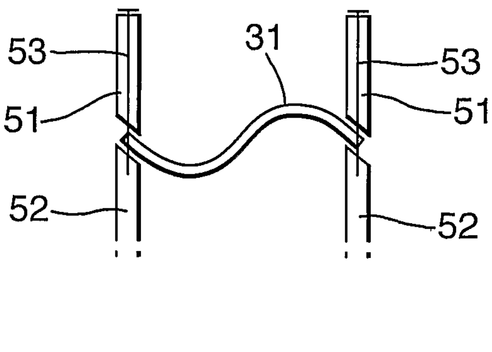


Fig.9.



INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2005/004590

A. CLASSIFICATION OF SUBJECT MATTER
G02B7/02 F16F1/02 F16F1/26 F16F3/02

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)
G02B G11B F16F

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)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 03/048831 A (1... LIMITED; ALLAN, JAMES) 12 June 2003 (2003-06-12) cited in the application the whole document	1-13

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
27 January 2006	06/02/2006

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	Pirog, P

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2005/004590

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 03048831 A	12-06-2003	AU 2002343097 A1	17-06-2003
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