



(51) International Patent Classification:

F03G 7/06 (2006.01)

G03B 3/10 (2021.01)

G02B 7/02 (2021.01)

(21) International Application Number:

PCT/GB2022/050713

(22) International Filing Date:

22 March 2022 (22.03.2022)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

2103940.9

22 March 2021 (22.03.2021)

GB

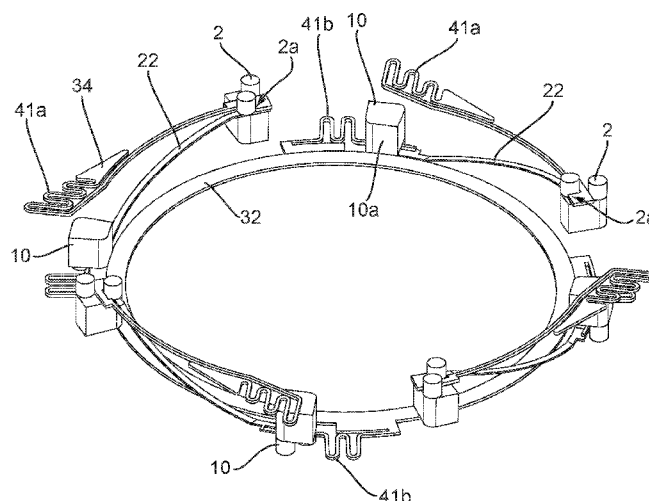
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(54) Title: ACTUATOR ASSEMBLY

Fig. 4A



(57) Abstract: An actuator assembly (1) comprising a support structure (2); a movable part (10) movable relative to the support structure; a bearing arrangement (20) supporting the movable part on the support structure and arranged to guide helical movement of the movable part with respect to the support structure about a helical axis (H), wherein the bearing arrangement includes at least one flexure (22) which is arranged to flex to cause said guiding; and at least one actuator component connected between the support structure and the movable part and arranged, on contraction, to drive rotation of the movable part around the helical axis, said rotation being converted into helical movement around the helical axis by the bearing arrangement, wherein the actuator assembly includes a resilient portion (41a, 41b), the resilient portion being configured not to deform during normal operation of the assembly, and which is such that, when the assembly is subject to external loads exceeding those of normal operation, the resilient portion is arranged to



(81) **Designated States** (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, IT, JM, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) **Designated States** (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— with international search report (Art. 21(3))

deform and to thereby permit movement of the movable part relative to the support structure in a plane orthogonal to the helical axis.

ACTUATOR ASSEMBLY

The present invention generally relates to an actuator assembly in which at least one actuator component drives movement of a movable part with respect to a support structure to produce helical movement and which is adapted to reduce or avoid damage to the assembly during drop testing and particularly to shape memory alloy (SMA) actuator assemblies. The present invention also relates to a method of manufacturing such an actuator assembly.

Actuator assemblies may be used to drive translational movement of a movable part with respect to a support structure. Such actuator assemblies may be used for example in an optical device such as a camera for driving translational movement of a camera lens element along its optical axis, for example to effect focussing (autofocus, AF) or zoom. Some examples of an actuator assembly of this type are disclosed in WO 2007/113478. Herein, the movable part is a camera lens element supported on a support structure, and an SMA wire is connected at its ends to the support structure and hooked over a hook on the camera lens element for driving the translational movement.

Miniaturisation is an important design criteria in many types of actuator assembly, including SMA actuator assemblies. In many applications, it is desirable to minimise the size of the actuator assembly in the movement direction. For example, where the actuator assembly comprises a lens element that is moved along the optical axis, it is desirable to minimise the size along the optical axis.

WO 2019/243849 A1 discloses an exemplary actuator assembly comprising a helical bearing arrangement which guides helical movement of the movable part with respect to the support structure. Such helical movement involves rotation around a helical axis together with an overall translation along the helical axis. SMA wire is connected between the support structure and the movable part so as to drive rotation of the movable part around the helical axis. The rotation driven by contraction of the SMA wire is converted by the helical bearing arrangement into helical movement of the movable part. Thus, translational movement of the movable part is achieved along the helical axis as part of the helical movement.

Actuator assemblies may comprise a bearing arrangement arranged between the support structure and the movable part which guides the movement of the movable part within a

desired range of motion. The bearing arrangement may contain a plurality of flexures arranged between the support structure and the movable part which are arranged to flex in order to permit and guide the movement of the movable part.

- 5 However, under even moderate tensile or compressive loads, flexures are susceptible to damage. Excessive tensile or compressive loads can cause a flexure to stretch or compress non-elastically thus permanently damaging the bearing arrangement. Significant tensile or compressive loads may be experienced when the assembly (or the device which it is part of) is subject to drop-testing, or if a device having an actuator assembly is dropped or subject to
10 sudden high lateral forces for other reasons.

If the large inertial forces generated by such motion are borne by the bearing arrangement this may lead to damage, for example through indenting or irreversible bending or stretching.

- 15 An object of the present invention is to provide an actuator assembly which is adapted to reduce or avoid damage during drop testing or other impacts which exert loads on the actuator assembly exceeding those of normal operation.

- A first aspect of the present invention provides an actuator assembly comprising a support
20 structure, a movable part movable relative to the support structure, a bearing arrangement supporting the movable part on the support structure and arranged to guide helical movement of the movable part with respect to the support structure about a helical axis, wherein the bearing arrangement includes at least one flexure which is arranged to flex to cause said guiding; and at least one actuator component connected between the support structure and the
25 movable part and arranged, on contraction, to drive rotation of the movable part around the helical axis, said rotation being converted into helical movement around the helical axis by the bearing arrangement, wherein the actuator assembly includes a resilient portion, the resilient portion being configured not to deform during normal operation of the assembly, and which is such that, when the assembly is subject to external loads exceeding those of normal
30 operation, the resilient portion is arranged to deform and to thereby permit movement of the movable part relative to the support structure.

The resilient portion may be configured to deform by compressing, extending, flexing or deforming in any other manner.

Normal operation of the assembly refers to movement of the movable part relative to the support structure due to actuation by the actuator component and flexing of the flexure of the bearing arrangement. The resilient portion is arranged not to deform due to forces imparted on the bearing arrangement due to actuation by the actuator component. When the assembly is subject to external loads that exceed those imparted by the actuator component (or, more generally, forces other than those imparted by the actuator component), for example forces that are above a certain threshold (e.g. above the maximum force applied by the actuator component), the resilient portion may deform so as to prevent or reduce any undesired deformation and damage to the flexures. Such forces above a certain threshold may be reached when the actuator assembly is dropped. The resilient portion may deform only during impact events on the actuator assembly, for example when experiencing drops or other impacts.

The resilient portion may allow the movable part to move relative to the support structure in a manner which is not permitted by normal operation of the bearing arrangement. Normal operation of the bearing arrangement may allow for movement of the movable part relative to the support structure along a helical path around the helical axis. When the actuator assembly is subjected to external loads exceeding those of normal operation (abnormal loads), such as during drop testing or an impact, the movable part can depart or diverge from the helical path.

Preferably, the resilient nature of the resilient portion enables the movable part to return to its normal position and normal range of movement when the actuator assembly is no longer subject to abnormal loads.

The deforming of the resilient portion may be arranged to be in preference to deformation of the flexure, or to the portion of the flexure which flexes during normal operation of the actuator assembly. The resilient portion may thus protect the flexure, or the operative parts of the flexure, from damage when the assembly is subjected to abnormal loads.

The bearing arrangement may comprise a movable plate that is mechanically connected to the movable part and a support plate that is mechanically connected to the support structure. The at least one flexure may be arranged between the movable plate and the support plate to guide helical movement of the movable plate with respect to the support plate about the helical axis.

Preferably, the bearing arrangement comprises a plurality of flexures, for example four or more flexures. This may allow more accurate and/or reliable guiding of the movable part relative to the support structure.

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The resilient portion may take a variety of forms and may be located in a variety of positions within the actuator assembly.

The resilient portion may be arranged in mechanical series with the bearing arrangement.

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The resilient portion may thus, for example, be arranged between the bearing arrangement and the movable part (in particular between the movable plate of the bearing arrangement and the movable part). Alternatively or additionally, the resilient portion may be arranged between the bearing arrangement and the support structure (in particular between the support plate of the bearing arrangement and the movable part).

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The resilient portion here may, for example, take the form of a compliant adhesive used to adhere the bearing arrangement to the movable part and/or support structure. Alternatively, the resilient portion may take the form of a spring or other elastic element arranged between the bearing arrangement and the movable part and/or support structure. The resilient portion may be formed as an extension to the bearing arrangement, and may be integrally formed with the bearing arrangement, for example.

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The resilient portion may form part of the bearing arrangement, i.e. be incorporated in the bearing arrangement. For example, the movable plate of the bearing arrangement may be formed as an annulus that comprises the resilient portion. The annulus may be connected to the flexures at first angular positions and to the movable part at second angular positions that are offset from the first angular positions. Preferably, the circular annulus is connected to the movable part in between (e.g. in the middle) of the connection points to the flexures. The portions of the circular annulus between the connection points to the flexures and the connection points to the movable part may be resilient, so as to deform during drops or other impact events.

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The resilient portion may be arranged in mechanical series with the flexure of the bearing arrangement. Preferably, the assembly comprises a plurality of resilient portions, each in

mechanical series with a respective flexure of the plurality of flexures of the bearing arrangement. A resilient portion may be arranged between each flexure and the movable plate and/or between each flexure and the support plate. So, a resilient portion may be arranged between each flexure and the movable part and/or between each flexure and the support structure.

The resilient portion may be integrally formed with the bearing arrangement. For example, the bearing arrangement (including the movable plate, support plate and flexures) and the resilient portion may be integrally formed from sheet material, such as sheet metal.

There may thus be a single resilient portion, or a plurality of resilient portions. Where there is a plurality of resilient portions, they may be arranged to deform in different directions to each other so as to enable the actuator assembly to respond to external loads in different directions. Where there is a plurality of resilient portions, some, all or none of the resilient portions may be arranged to compress when subject to external loads exceeding those of normal operation, whilst some, all or none of the resilient portions may be arranged to extend when subject to such loads and some, all or none of the resilient portions may be arranged to flex when subject to such loads. The actuator assembly may contain any combination of resilient portions which are arranged to extend, compress or flex.

In certain embodiments the resilient portion may be arranged between the bearing arrangement and the movable part. Thus, under abnormal loads, the resilient portion allows movement of the movable part relative to both the bearing arrangement and support structure.

In certain embodiments the resilient portion is arranged between the bearing arrangement and the support structure. Thus, under abnormal loads, the resilient portion allows movement of the bearing arrangement and the movable part relative to the support structure.

In certain embodiments the resilient portion is part of the bearing arrangement. Thus, the resilient portion can allow a different range of movement of the movable part relative to the support structure under abnormal loads than is usually allowed by the bearing arrangement in normal operation.

The bearing arrangement includes at least one flexure, and may include a plurality of flexures. Using flexures in the bearing arrangement may reduce friction compared to a bearing arrangement that comprises, for example, a plain bearing or a roller bearing.

- 5 The actuator assembly may include a plurality of said resilient portions and each resilient portion may be coupled to only one of said flexures. The actuator assembly may also include multiple resilient portions, for example two resilient portions, per flexure.

10 The resilient portion or portions may be arranged to permit a range of motion. In certain devices, motion in certain directions or in certain planes may be particularly desirable when the actuator assembly is subject to abnormal loads. A plurality of resilient portions may be provided and arranged so as to permit motion in a range of different directions (e.g. along the helical axis or in a plane orthogonal to the helical axis) by compression, extension or flexing of different combinations of the plurality of resilient portions.

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For example, the resilient portion may deform in a plane orthogonal to the helical axis. The resilient portion may be constrained from deforming in a direction along the helical axis. This may reduce the height of the actuator assembly along the helical axis, and so may be particularly advantageous in compact actuator assemblies, such as those used in mobile
20 devices.

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Alternatively, the resilient portion may be allowed to deform in a direction parallel to the helical axis. The resilient portion may be constrained from deforming in any direction orthogonal to the helical axis.

The resilient portions may be arranged to deform to allow movement of the movable part in at least two opposite directions. For example, when resilient portions are arranged on both ends of a flexure, one of the resilient portions may allow movement of the movable part in a first direction, and the other of the resilient portions may allow movement of the movable
30 part in a second direction opposite to the first direction.

Alternatively or additionally, the resilient portion may be arranged to deform to allow movement of the movable part in at least two orthogonal directions.

The resilient portion is configured not to deform during normal operation of the assembly, but to deform when the assembly is subject to external loads exceeding those of normal operation. This may be achieved in a variety of different ways.

- 5 The stiffness of the resilient portion may be higher than the stiffness of the flexures of the bearing arrangement. This may prevent or constrain the resilient portion from deforming during normal operation of the assembly. The stiffness of the resilient portion may be chosen so that the resilient portion is allowed to deform when being subject to external loads exceeding those of normal operation. Deformation of the resilient portion during abnormal
- 10 loads may thus at least reduce deformation of the flexures during abnormal loads, thus reducing the risk of damage to the flexures.

In preferable embodiments, the resilient portion is pre-loaded, such that it does not deform until it is subjected to a force exceeding a pre-determined amount. In such embodiments, the

15 stiffness of the resilient portion (once it is subjected to a force exceeding a pre-determined amount) may be less than the stiffness of the flexures. This can mean that the resilient portion is not “engaged” until the assembly is subject to a force exceeding a pre-determined amount. This can ensure that provision of the resilient portion does not affect the normal operation of the assembly and in particular the normal operation of the bearing arrangement in guiding the

20 movement of the movable part.

Pre-loading may be accomplished in a variety of ways.

For example, in some arrangements the resilient portion may be pre-loaded by biasing the

25 resilient portion in a direction opposite to a direction of movement permitted by the resilient portion. The resilient portion may be pre-loaded against a surface of the movable part or against a surface of the support structure. The resilient portion may thus be in engagement with (i.e. abut) the movable part or the support structure during normal operation, and may separate from the movable part or the support structure during drops or other impact events.

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In such arrangements at least one flexure in the bearing arrangement may have a first end portion at one end of the flexure and a second end portion at the other end of the flexure to the first end portion and said first and second end portions may comprise the resilient portion. The first end portion may be formed such that it is biased in a first direction (e.g. towards the

movable element) and the second end portion may be formed such that it is biased in a second direction opposite to said first direction (e.g. towards the support structure). The first end portion may be biased against a surface of the movable part, and the second end portion may be biased against a surface of the support structure.

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The end portions may be biased due to being fastened to the apparatus such that they are bent away from their unstressed configuration.

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The end portions may be arranged such that a force causing tension in the flexure causes one of said end portions to deform and a force causing compression in the flexure causes the other of said end portions to deform.

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Preferably, the resilient portion may be pre-loaded in the plane that is orthogonal to the helical axis. The resilient portion may deform in the plane that is orthogonal to the helical axis. This may reduce the size of the actuator assembly in a direction along the helical axis, which may be desirable in actuator assemblies for mobile devices, such as mobile phones.

Alternatively, the resilient portion may be pre-loaded in a direction parallel to the helical axis.

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Alternatively or additionally, the resilient portion may be pre-loaded by releasable attachment to the actuator assembly, the releasable attachment being such that under normal operation the resilient portion is attached to the actuator assembly, and when subjected to a force above the pre-determined amount, the resilient portion is released from the attachment. For example, a magnetic attachment may be provided, such that the resilient portion is held by the magnetic force of the attachment, but when the actuator assembly is subject to a force exceeding that magnetic force, the resilient portion is released and can deform.

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The actuator assembly may further include a guide mechanism arranged to guide one or more of: the movable part, the bearing arrangement, the flexure or the resilient portion back to a normal position after the resilient portion has compressed or extended. This can allow the actuator assembly to easily revert to its normal position after being subject to abnormal load. Examples of the guide mechanism include self-centring components, such as an aperture seated on a conical protrusion.

The actuator assembly may further include an end stop which is arranged to prevent movement of the movable part in at least one direction. The bearing arrangement may be configured such that the movable element does not contact the end stop during the normal range of movement of the movable element. The resilient portion may be configured to allow the movable element to move so as to contact the end stop when the assembly is subject to external loads exceeding those of normal operation.

In such arrangements, when the assembly is subject to an abnormal load, the resilient portion permits the movable part to move in a controlled fashion to contact the end stop or end stops. The end stop(s) prevents further movement of the movable part in that direction and thus can prevent damage to the movable part and/or the bearing arrangement.

The actuator assembly may further include a damping element which is arranged to increase the resilience of the flexure when the assembly is subjected to external loads exceeding those of normal operation. This damping element may be arranged such that the resilient element deforms in preference to deformation of the flexure. For example, the damping element may be connected to the flexure or form part of the flexure and be arranged to cause the resilience of the combination of the damping element and the flexure to increase when the flexure is subject to a high force (which causes a quick motion), and thus exceed the resilience of the resilient element to forces acting in the same direction.

The actuator assembly of this aspect may include some, all or none of the above-described optional and preferred features of this aspect in any practical combination.

A further aspect of the present invention provides a camera apparatus comprising: the actuator assembly of the above aspect, including some, all or none of the optional and preferred features of that aspect; and an image sensor that is fixed relative to the support structure of the actuator assembly; wherein the movable part of the actuator assembly comprises a lens assembly having one or more lenses that is configured to focus an image onto the image sensor.

The camera apparatus may further include a controller arranged to control the position of the lens assembly relative to the image sensor by controlling the actuator component. The

controller may thus effect focussing (such as autofocus, AF) and/or zoom in the camera apparatus using the actuator assembly.

Embodiments of the present invention will now be described by way of example with
5 reference to the accompanying drawings in which:

Fig. 1 is a schematic view of an actuator assembly according to an embodiment of the present invention;

10 Fig. 2 is a plan view of the bearing arrangement of the actuator assembly shown in Fig. 1;

Figs. 3A-3C show, schematically, motions permitted in actuator assemblies according to embodiments of the present invention;

15 Figs. 4A-4C show bearing arrangements used in actuator assemblies according to embodiments of the present invention;

Figs. 5A-5E show parts of an actuator assembly according to another embodiment of the present invention;

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Figs. 6A-6C show parts of an actuator assembly according to an embodiment of the present invention;

Fig. 7 shows, schematically, the use of damping in embodiments of the present invention;

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Fig. 8 shows part of a bearing arrangement which forms part of an actuator assembly according to an embodiment of the present invention;

Figs. 9A and 9B show arrangements of part of an actuator assembly according to an
30 embodiment of the present invention;

An actuator assembly 1 that is incorporated in a camera apparatus is shown schematically in Fig. 1. The actuator assembly 1 comprises a support structure 2 that has an image sensor 3 mounted thereon. The support structure 2 may take any suitable form, typically including a

base 4 to which the image sensor 3 is fixed. The support structure 2 may also support a controller 5. The controller 5 may be an integrated circuit (IC) chip 5.

The actuator assembly 1 also comprises a movable part 10 that comprises a lens assembly in this example. The lens assembly comprises a lens 11, although it may alternatively comprise plural lenses. The lens assembly has an optical axis O aligned with the image sensor 3 and is arranged to focus an image on the image sensor 3.

The actuator assembly 1 may be a miniature device. In some examples of a miniature device, the lens 11 (or plural lenses, when provided) may have a diameter of at most 20mm, preferably at most 15mm, further preferably at most 10mm. However, larger lenses 11 may be used in alternative embodiments.

Although the actuator assembly 1 in this example is incorporated in a camera apparatus, that is not essential. In some examples, the actuator assembly 1 may be incorporated in an optical device in which the movable part 10 comprises a lens assembly but there is no image sensor. In other examples, the actuator assembly 1 may be incorporated in an apparatus of a type that is not an optical device, and in which the movable part 10 does not comprise a lens assembly and there is no image sensor. Examples include apparatuses for depth mapping, face recognition, game consoles, projectors and security scanners, or haptics.

The actuator assembly 1 comprises a bearing arrangement 20 (shown schematically in Fig. 1) that supports the movable part 10 on the support structure 2. The bearing arrangement 20 in this embodiment is arranged to guide a helical movement of the movable part 10 with respect to the support structure 2 around a helical axis H. The movable part 10 may move relative to the support structure 2 along a helical path M. The helical axis H in this example is coincident with the optical axis O and the helical movement is shown in Fig. 1 by the arrow M. Preferably, the helical motion is along a right helix, that is a helix with constant radius, but in general any helix is possible. The pitch of the helix may be constant or vary along the helical motion. Preferably, the helical movement is generally only a small portion (less than one quarter) of a full turn of the helix.

The helical motion of the movable part 10 guided by the bearing arrangement 20 includes a component of translational movement along the helical axis H and rotational movement

around the helical axis H. The translational movement along the helical axis H is the desired movement of the movable part 10, for example to change the focus of the image on the image sensor 3 and/or to change the magnification (zoom) of the image on the image sensor 3 when incorporated into a camera apparatus. The rotational movement around the helical axis H is in this example not needed for optical purposes, but is in general acceptable as rotation of a lens assembly comprised by the movable part 10 does not change the focus of the image on the image sensor 3.

Fig. 2 shows a plan view, i.e. viewed along the axis O, H of the actuator assembly 1 shown in Fig. 1, of the bearing arrangement 20 according to an embodiment of the present invention.

The bearing arrangement 20 includes a movable plate 32. The movable plate 32 is mechanically connected to the movable part 10 in the actuator assembly 1. So, the movable part 10 is mounted on the movable plate 32, and the movable part 10 is fixed relative to the movable plate 32. The movable plate connects to each of a plurality of flexures 22. The bearing arrangement 20 further includes a support plate 34, which is formed in the depicted example of five separated pads. In the actuator assembly 2, the support structure 2 is mounted to the support plate 34, so the support structure 2 is fixed relative to the support plate 34. Although a single, common movable plate 32 and individual support plates 34 are shown in Fig. 2, in some embodiments there may be multiple individual movable plates 32 (e.g. one per flexure 22). In some embodiments, there may be a single, common support plate 34. Using a single, common movable plate or support plate may make assembly of the bearing arrangement easier, because the relative position of the flexures 22 may be fixed.

The bearing arrangement 20 includes a plurality of flexures 22 (or flexure arms 22). The plurality of flexures 22 may be arranged equidistantly around the circumference of the movable plate 32 or movable part 10. In alternative embodiments, for example in actuator assemblies with a rectangular footprint, the flexures may not be arranged equidistantly around the circumference of the movable plate 32 or movable part 10. In the depicted example, the bearing arrangement comprises five flexures 22, such that the bearing arrangement exhibits five-fold rotational symmetry around the helical axis H. However, in general any number of flexures 22 may be provided. In some embodiments, the bearing arrangement may comprise four flexures 22. The flexures 22 are generally arc-shaped so that they extend around part of a circle of slightly larger diameter than the exterior of the movable

part 10 and are each attached at a first end 24 to the movable plate 32 and at a second end 26 to the support plate 34.

The flexures 22 translate horizontal force applied to the movable part 10 by an actuator component (such as one or more SMA actuator wires (not shown)) into a helical motion about the central axis O, H.

Embodiments of the present invention provide a (and often more) resilient portion within the actuator assembly 1 which is arranged to deform (e.g. to compress, extend and/or flex) when the actuator assembly is subject to external loads which exceed those of normal operation (abnormal loads). The resilient portion or portions can be arranged in a number of different ways and can take a number of different forms. It will be appreciated that the embodiments described below seek to illustrate, often schematically, possible different configurations and arrangements for the resilient element, but cannot cover every possible implementation.

In particular, for efficiency, the resilient portions in many of the embodiments below are depicted schematically as a spring. However, the invention is not limited to the use of springs as such and covers any form of resilient element or component.

Further, such “springs” may take many different forms and may, for example, be embodied in material properties or mechanical configurations.

Figs. 3A to 3C show, schematically, the configuration of a part of the actuator assembly 1 in which two pre-loaded springs 41a, 41b are provided at opposite ends of one of the flexures 22 of the bearing arrangement which connects the movable part 10 to the support structure 2.

For ease of illustration, the flexure 22 in Figs. 3A-3C is shown as a straight line, but it may be arcuate as shown in Fig. 2. Both springs 41a, 41b are pre-loaded so that they will not extend until subject to a force exceeding a predetermined threshold.

Fig. 3A shows the actuator assembly during normal operation, with the movable part 10 not contacting the support structure 2. Operation of the bearing arrangement 20 will guide the motion of the movable part 10 relative to the support structure 2.

Fig. 3B shows the actuator assembly when it has been subjected to a sudden and abnormal force acting horizontally from the right as viewed in Fig. 3B. The spring 41a which is connected between one end of the flexure 22 and the support structure 2 has extended, in preference to stretching of the flexure 22, and has permitted the movable part 10 to move outside the normal range of movement permitted by the bearing arrangement so as to contact an end stop 40b. The end stop 40b is part of the support structure 2 on the right-hand side of the assembly 1 as viewed in Fig. 3B and prevents further motion of the movable part 10 in that direction.

Fig. 3C shows the actuator assembly when it has been subjected to a sudden and abnormal force acting horizontally from the left as viewed in Fig. 3C. In this situation the spring 41b which is connected between one end of the flexure 22 and the movable part 10 has extended, in preference to compression of the flexure 22, and has permitted the movable part 10 to move outside the normal range of movement permitted by the bearing arrangement so as to contact an end stop 40a. The end stop 40a is part of the support structure 2 on the left-hand side of the assembly 1 as viewed in Fig. 3B and prevents further motion of the movable part 10 in that direction.

In general terms, in various embodiments, the resilient portion can be provided so that it is mechanically located in one or more of the following locations within the actuator assembly:

- a) between the support structure 2 and the bearing arrangement 20, such that, when subjected to abnormal loads, the bearing arrangement 20 and the movable part 10 move together relative to the support structure 2;
- b) within the bearing arrangement 20, such that, when subjected to abnormal loads, the bearing arrangement 20 permits the movable part 10 to move relative to the support structure 2 in a manner which is outside the normal range of motion permitted by the bearing arrangement 20;
- c) between the bearing arrangement 20 and the movable part 10, such that, when subjected to abnormal loads, the movable part 10 can move relative to the bearing element 20 (and thus relative to the support structure 2).

Embodiments showing certain of these arrangements will now be described, although it will be appreciated that many of the concepts presented are of general application and not limited to the specific configuration or positioning of the resilient portion.

Figs. 4A-C show a perspective view of embodiments of the present invention. In the depicted embodiments, the resilient portion 41 is arranged to deform in the plane orthogonal to the helical axis H. This may reduce the height of the actuator assembly 1 along the helical axis, compared to using resilient portions 41 that allow deformation along the helical axis H. In Fig. 4A, only the main components of the bearing arrangement 20 are shown and many of the other elements of the actuator assembly (including the support structure 2 and the movable part 10) are omitted for clarity.

In the embodiment of Fig. 4A, the bearing arrangement includes a plurality of resilient portions 41a, 41b which are provided at the ends of each of the flexures 22. Each resilient portion 41a is mechanically (rigidly) connected at one end to the support structure 2 via support plate 32 and at the other end connected to a respective flexure 22. Each resilient portion 41b is mechanically (rigidly) connected at one end to the movable part 10 via movable plate 32 (which, in the depicted embodiment, is formed as an annulus 32) and at the other end connected to a respective flexure 22.

Resilient portions 41a are pre-loaded against surface 2a of the support structure 2. During normal operation, the resilient portions 41a ensure that the static end of each flexure 22 remains stationary relative to the support structure 2. Resilient portions 41a are positioned and configured to permit movement of the flexures 22 (in particular of the static end of the flexures) relative to the support structure in the event of abnormal loads.

Resilient portions 41b are pre-loaded against surface 10a of the movable part 10. During normal operation, the resilient portions 41b ensure that the movable end of each flexure 22 remains stationary relative to the movable part 10. Resilient portions 41b are positioned and configured to permit movement of flexures 22 (in particular of the movable end of the flexures) relative to the movable part 10. The resilient portions 41c, 41d are arranged deform in a plane orthogonal to the helical axis H.

By providing resilient portions 41a, 41b on all of the flexures 22 and on each end of each flexure, the movable plate 32 can be permitted in all directions in the plane of the movable plate 32 (the "X-Y" plane) when the assembly is subjected to abnormal loads. One or more

resilient portions 41a, 41b may be involved in permitted such movement depending on the exact direction of the force experienced.

Figs. 4B and 4C schematically depicts another embodiment of resilient portions 41a, 41b that allow deformation in the plane orthogonal to the helical axis H. Fig. 4B shows the entire bearing arrangement 20 as connected between the movable part 10 and the support structure 2. Fig. 4C shows the detail of the resilient portion 41 at the connection point between movable part 10 and bearing arrangement 20.

As shown in Fig. 4C, the resilient portion 41a is pre-biased against a surface 10a of the movable part 10. In the depicted embodiment, the surface 10a of the movable part 10 against which the resilient portion 41 is pre-loaded is provided on a protrusion extending from the movable part 10. During normal operation, the surface 10a remains in direct contact with the bearing arrangement 20. During impact events, the resilient portion 41 may deform in a manner allowing the surface 10a to disengage from the bearing arrangement 20. So, the movable end of the flexure 22 may be allowed to move relative to the movable part 10. This may prevent or reduce deformation of the flexure 22, and thus prevent or reduce damage to the flexure 22 during impact events.

The surface 10a may be sloped relative to the helical axis H and relative to the plane orthogonal to the helical axis H. This ensures that the surface 10a may remain in contact with the bearing arrangement 20 when subject to forces along or perpendicular to the helical axis H. The sloped surface 10a also allows the bearing arrangement 20 to return to its position after deformation of the resilient element 41a.

In the embodiment of Fig. 4B and 4C, the preload force may be achieved by rotating the movable plate 32 of the bearing arrangement 20 during assembly. Such rotating may first bring the bearing arrangement 20 into abutment with the surface 10a of the movable part 10. Further rotation will lead to deformation and preloading of the resilient portion 41. The circular annulus may then be fixed to the movable part 10, for example using adhesive.

Although not shown in detail, the resilient portion 41b is pre-biased against a surface 2a of the support structure 2, in a manner similar to that described in relation to the resilient portion 41a.

Figs. 5A-5E show, schematically, further embodiments of the present invention. For ease of illustration, only a single flexure 22 is depicted in Figs. 5A-5E, but it will be appreciated that the bearing arrangement 20 may in general comprise a plurality of flexures 22. Compared to the embodiment of Fig. 4, the resilient portions 41c, 41d are arranged to deform in a direction parallel to the helical axis H.

Fig 5A schematically depicts a flexure 22 arranged between the support structure 2 and the movable part 10. The resilient portion 41 is arranged between the flexure 22 and the movable part 10, in particular between the flexure 22 and the movable plate of the bearing arrangement that mechanically connects to the movable part 10. In the depicted embodiment, the resilient portion 41 has a higher spring constant than the flexure 22, by virtue of being wider than the flexure 22 (in particular the parts of the flexure 22 that flex during normal operation). The resilient portion may have a spring constant that is high enough to avoid any substantial deflection during normal operation, but low enough to deflect under impact events (abnormal loads) so as to avoid or reduce damage to the flexure 22. Thus, in this design there is a compromise on the stiffness of the resilient portion 41.

Fig. 5B schematically depicts a further embodiment. Unlike the embodiment in Fig. 5A, the resilient portion 41 here is pre-loaded. The bearing arrangement comprises a first resilient portion 41a on one end of each flexure 22, and a second resilient portion 41b at the other end of each flexure 22. The first resilient portion 41a may be pre-loaded (in particular in a direction parallel to the helical axis H) against a surface 2a of the support structure 2. The second resilient portion 41b may be pre-loaded (in particular in a direction parallel to the helical axis H) against a surface 10a of the movable part 10. The first resilient portion 41a may be preloaded in a direction opposite to the direction in which the second resilient portion 41b is preloaded. In the depicted example, the first resilient portion 41a may deform due to impacts forcing the movable part 10 in an upward direction, whereas the second resilient portion 41d may deform due to impacts forcing the movable part 10 in a downward direction.

Figs. 5C and 5D show an arrangement of a flexure 22 as used in certain embodiments of the present invention and illustrate how the resilient portions can be pre-loaded by biasing. Figs. 5C shows the flexure 22b in its natural, unloaded configuration. The flexure 22b has three regions, a central region 25b arranged between two outer regions 32, 34. Fixing points 24b,

26b are provided at the ends of the outer regions for attachment of the flexure to the movable element 10 and the support structure 2 respectively.

Fig. 5D shows the same flexure 22b when the actuator assembly is assembled and the flexure 22b has been attached to the movable element 10 and the support structure 2 by fixings 21, such as heat stakes, passing through the fixing points 24b, 26b.

As can be seen in Fig. 5D, in order to conform to their positioning relative to the movable element 10 and the support structure 2, the two outer portions 32, 34 are deformed from their natural shape (shown in Figs. 5C) by the attachment of the fixing points 24b, 26b and projections 31, 33 on the movable element 10 and support structure 2. This deformation results in pre-loading of the outer regions 32, 34 such that they are biased in a direction towards the movable element 10 or support structure 2.

Accordingly, in normal operation, in which the movable element 10 and thus the flexure 22b are subject to forces below a predetermined level (and lower than the forces biasing the outer regions 32, 34 into contact with the projections 31, 33), the motion of the movable element 10 is guided by the range of motion permitted by the central region 25b of the flexure 22b. Together with the other flexures (not shown in Fig. 5D), this guides the motion of the movable element 10 in the helical fashion described above.

However, when the actuator apparatus 1 is subject to lateral forces above a predetermined level, for example during drop-testing, these forces are sufficient to cause further bending of one of the outer regions 32, 34 and thus provide for a different range of motion of the movable element 10.

For example, as shown in Fig. 5E, in the event of the movable element being subject to a significant force acting horizontally to the right as shown in Fig. 5E, the outer region 34 which is normally in contact with the support structure 2 is caused to bend further such that it disengages from the projection 33. Such bending will occur when the moment of the significant force transmitted to the outer region 34 exceeds the bias force which results from the bending of the outer region 34 in the pre-loaded arrangement. By determining the extent to which the outer region 34 (and the corresponding outer region 32 at the movable element

end of the flexure 22b) is bent during assembly, the magnitude of force required to cause this disengagement can be selected.

When disengagement of the outer region 34 of the flexure 22b from the projection 33 occurs,
5 the movable element 10 can then move laterally in the direction of the applied force until it contacts a portion of the support structure 2 which is configured as an end stop 4. This allows the movable element 10 to contact the end stop 4 before the applied forces cause damage to the bearing arrangement, for example by irreversibly stretching the flexure 22b.

10 It will be appreciated that, in the event of a significant force acting in the opposite direction (horizontally to the left as shown in Fig. 5E), the other outer region 32 will disengage from the projection 31 on the movable element 10, thus permitting lateral movement of the movable element 10 horizontally to the left until it encounters an end stop (not shown) on the support structure 2.

15 In an alternative arrangement, rather than pre-loading the outer regions 32, 34 of the flexure 22b against the movable element 10 and the support structure 2, the outer regions have a higher stiffness than the central region 25b. This higher stiffness may be obtained, for example, by making these outer regions thicker than the central region, or by reinforcement,
20 or by variation in or choice of material. Such higher stiffness means that the outer regions do not bend or otherwise contribute to the operation of the flexure 22b when subjected to the forces required for normal movement of the movable element 10, but when the movable element 10, and thus the flexure 22b is subjected to significant forces, they bend, thus permitting an additional range of movement, for example to allow the movable element to
25 move laterally to contact an end stop as shown in Fig. 5E.

Figs 6A-6C show further embodiments of the present invention, schematically depicting alternative manners of forming the resilient portion. In the embodiment of Fig. 6A, the resilient portion 41 takes the form of a compliant adhesive arranged between the movable
30 part 10 and the bearing arrangement 20. The stiffness of the compliant adhesive may be chosen so as to avoid deformation during normal operation of the actuator assembly, and allow deformation when the actuator assembly experiences abnormal loads. The compliant adhesive may be provided in pockets or gaps between the bearing arrangement 20 and the movable part 10.

Fig. 6B depicts an embodiment in which the bearing arrangement 20 comprises a spring element (in the form of a separate flexure) that is connected between the bearing arrangement 20 and the movable part 10. The spring element may be arranged between the bearing arrangement and the movable part 10. The stiffness of the spring element may be chosen so as to avoid deformation during normal operation of the actuator assembly, and allow deformation when the actuator assembly experiences abnormal loads.

Fig. 6C depicts a further embodiment in which the bearing arrangement 20 comprises a movable plate in the form of a circular annulus, which comprises the resilient portion. The circular annulus is connected to the flexures at first angular positions (labelled "P1") and to the movable part at second angular positions (labelled "P2") that are offset from the first angular positions. The portions of the circular annulus between the connection points to the flexures and the connection points to the movable part may be resilient, so as to deform during drops or other impact events.

In a further embodiment (not shown), the resilient portion is formed integrally within each flexure by providing one or more splits in the flexure arm, such that the flexure is not a single solid extent, but has one or more openings when viewed from one side. Such a split or splits may effectively create a spring in the flexure by reducing the resilience of the flexure to bending in a direction perpendicular to the longitudinal extent of the flexure. By combination with other flexures, this bending can allow one flexure to bend so as to allow a movement which would otherwise compress or stretch one or more other flexures in the assembly.

Thus, rather than incorporating a resilient portion which effectively protects the individual flexure from compression or stretching, in this embodiment the flexures act collectively to protect other flexures from compression or stretching.

In some embodiments, in addition to the resilient portion 41, a damping element 70 may be provided to prevent or reduce undesired deformation of the flexure 22 during impact events.

This is schematically depicted in Fig. 7. In particular, Fig. 7 shows, schematically, the use of damping gel 70 arranged between a flexure 22 and the support structure 2. When subject to a sudden, large external force, the fast motion of the flexure 22/movable element 10 assembly causes the damping gel 70 to exhibit a high resistance to motion. This causes the resilient portion 41 to stretch (or compress) instead of the load being borne by the flexure 22.

The above embodiments described certain arrangements and configurations in which the resilient portion could be pre-loaded such that it only permitted movement once the actuator assembly was subjected to a force exceeding a pre-determined amount. Fig. 8 shows, schematically, an arrangement in accordance with a further embodiment of the present invention by which such pre-loading may be provided. In Fig. 8, the flexure 22 (or at least one end of the flexure) is formed from a magnetic material. This end of the flexure 22 is attached to the support structure 2 (although the end in question could equally be the end attached to the movable part 10) by a magnet 50. The magnetic force between the magnet 50 and the flexure 22 provides the pre-loading force.

During normal operation, the magnet 50 keeps the flexure firmly attached to the support structure 2. Only once the actuator assembly has been subjected to a force which exceeds that magnetic force will the flexure 22 detach from the support structure 2 and the resilient portion can then permit movement of the movable element beyond the normal range of motion.

It is also useful if, after actuator assembly is no longer subject to the abnormal load, the movable part is able to return to its normal position, or a position within its normal range of motion, such as the position that it was in prior to the abnormal load being experienced. The resilient nature of the resilient portion(s) may, in many cases, be sufficient to return the movable part to such a position. However, in certain embodiments additional components can be provided which are configured to guide the movable part back to such a position.

Figs. 9A-9B show such an arrangement in accordance with a further embodiment of the present invention in which a flexure 22 has an aperture 60 which is arranged to mate with a conical (or frustro-conical) protrusion 61 extending from the surface of the support structure 2. The aperture 60 is sized so that it is larger than the narrowest cross-section of the protrusion 61, but smaller than the widest cross-section of the protrusion 61 (which is the point at which the protrusion contacts the main part of the support structure 2). When subject to an abnormal load, the flexure may move upwards (as seen in Fig. 8) so that the aperture 60 has greater freedom of movement around the protrusion 61. When the abnormal load is no longer experienced, the aperture 60 may settle back onto the protrusion 61 and is guided back into place by the conical form of the protrusion 61.

A “heat-staked” cap 62 which is larger than the aperture 60 may be provided on the top of the protrusion 61 to prevent the flexure 22 from slipping completely off the protrusion 61.

5 Embodiments of the present invention generally make use of an actuator component that causes movement of the movable part relative to the support structure. The actuator component may be any component capable of producing an actuation force, such as a voice coil motor (VCM), a piezo-electric element, or any other motor or actuator. In preferable
10 embodiments, the actuator component comprises at least one SMA wire that is connected between the support structure and the movable part and arranged, on contraction, to drive rotation of the movable part around the helical axis.

The term ‘shape memory alloy (SMA) wire’ may refer to any element comprising SMA. The SMA wire may have any shape that is suitable for the purposes described herein. The SMA
15 wire may be elongate and may have a round cross section or any other shape cross section. The cross section may vary along the length of the SMA wire. It is also possible that the length of the SMA wire (however defined) may be similar to one or more of its other dimensions. The SMA wire may be pliant or, in other words, flexible. In some examples, when connected in a straight line between two elements, the SMA wire can apply only a
20 tensile force which urges the two elements together. In other examples, the SMA wire may be bent around an element and can apply a force to the element as the SMA wire tends to straighten under tension. The SMA wire may be beam-like or rigid and may be able to apply different (e.g. non-tensile) forces to elements. The SMA wire may or may not include material(s) and/or component(s) that are not SMA. For example, the SMA wire may
25 comprise a core of SMA and a coating of non-SMA material. Unless the context requires otherwise, the term ‘SMA wire’ may refer to any configuration of SMA wire acting as a single actuating element which, for example, can be individually controlled to produce a force on an element. For example, the SMA wire may comprise two or more portions of SMA wire that are arranged mechanically in parallel and/or in series. In some arrangements,
30 the SMA wire may be part of a larger piece of SMA wire. Such a larger piece of SMA wire might comprise two or more parts that are individually controllable, thereby forming two or more SMA wires.

Whilst the embodiments above have described actuator assemblies which use SMA wires, the skilled person will appreciate that the features of the bearing arrangements and the flexures described can be readily used with other forms of actuator components. For example, each actuator component may be a voice coil motor (VCM) actuator, but other types of actuator are possible, for example a piezoelectric actuator, a radial motor or others.

Those skilled in the art will appreciate that while the foregoing has described what is considered to be the best mode and where appropriate other modes of performing the present disclosure, the present disclosure should not be limited to the specific configurations and methods disclosed in this description of the preferred embodiment. Those skilled in the art will recognise that the present invention has a broad range of applications, and that the embodiments may take a wide range of modifications without departing from any inventive concept as defined in the appended claims.

Claims

1. An actuator assembly comprising
a support structure;
a movable part movable relative to the support structure;
5 a bearing arrangement supporting the movable part on the support structure and arranged to guide helical movement of the movable part with respect to the support structure about a helical axis, wherein the bearing arrangement includes at least one flexure which is arranged to flex to cause said guiding; and
at least one actuator component connected between the support structure and the
10 movable part and arranged, on actuation, to drive rotation of the movable part around the helical axis, said rotation being converted into helical movement around the helical axis by the bearing arrangement during normal operation of the assembly,
wherein the actuator assembly includes a resilient portion, the resilient portion being configured not to deform during normal operation of the assembly, and which is such that,
15 when the assembly is subject to external loads exceeding those of normal operation, the resilient portion is arranged to deform and to thereby permit movement of the movable part relative to the support structure.
2. The actuator assembly of claim 1, wherein the bearing arrangement comprises a
20 plurality of flexures arranged between the movable part and the support structure to guide helical movement of the movable part with respect to the support structure about the helical axis.
3. The actuator assembly of claim 2, comprising a plurality of resilient portions, each
25 resilient portion being arranged in mechanical series with a respective flexure of the bearing arrangement, each resilient portion being configured not to deform during normal operation of the assembly, and which is such that, when the assembly is subject to external loads exceeding those of normal operation, the resilient portion is arranged to deform and to
thereby permit movement of the movable part relative to the support structure.
30
4. The actuator assembly of claim 3, wherein the plurality of resilient portions comprises resilient portions between each flexure and the support structure and resilient portions between each flexure and the movable part.

5. The actuator assembly of any preceding claim, wherein the or each resilient portion is part of the bearing arrangement, preferable wherein the or each resilient portion is integrally formed with the bearing arrangement.

5

6. The actuator assembly of any preceding claim, wherein the bearing arrangement is integrally formed from sheet material, preferably sheet metal.

7. The actuator assembly of any preceding claim, wherein the bearing arrangement comprises a movable plate that is formed as an annulus connected to one end of the or each flexure, wherein the annulus comprises the resilient portion and is attached to the movable part at angular positions that are offset from the connection to the or each flexure.

10

8. The actuator assembly of any preceding claim, wherein the resilient portion is arranged in mechanical series with the or each flexure.

15

9. The actuator assembly of any preceding claim, wherein the resilient portion is arranged in mechanical series with the bearing arrangement.

10. An actuator assembly of any preceding claim, wherein the resilient portion is arranged between the bearing arrangement and the movable part and/or between the bearing arrangement and the support structure.

20

11. An actuator assembly of any preceding claim, wherein the resilient portion is arranged to deform so as to permit movement of the movable part relative to the support structure in a manner which is not permitted by normal operation of the bearing arrangement.

25

12. The actuator assembly of any preceding claim, wherein the or each resilient portion is configured to deform in a plane orthogonal to the helical axis.

30

13. The actuator assembly of any preceding claim, wherein the or each resilient portion is configured to deform in a direction parallel to the helical axis.

14. The actuator assembly of any preceding claim, wherein the resilient portion is arranged to deform to allow movement of the movable part in at least two opposite directions.
- 5 15. The actuator assembly of any preceding claim, wherein the resilient portion is arranged to deform to allow movement of the movable part in at least two orthogonal directions.
- 10 16. The actuator assembly according to any preceding claim, wherein the or each resilient portion is pre-loaded, such that it does not deform until it is subjected to a force exceeding a pre-determined amount.
17. The actuator assembly of claim 16, wherein the resilient portion is pre-loaded in the plane orthogonal to the helical axis.
- 15 18. The actuator assembly of claim 16 or 17, wherein the resilient portion is pre-loaded by biasing the resilient portion in a direction opposite to a direction of movement permitted by the resilient portion.
- 20 19. The actuator assembly of claim 16, 17 or 18, wherein the resilient portion is pre-loaded against a surface of the movable part or against a surface of the support structure.
20. The actuator assembly of claim 16, wherein the resilient portion is pre-loaded in the plane orthogonal to the helical axis.
- 25 21. The actuator assembly of any preceding claim, wherein at least one flexure in the bearing arrangement has a first end portion at one end of the flexure and a second end portion at the other end of the flexure to the first end portion and said first and second end portions comprise the resilient portion.
- 30 22. The actuator assembly of claim 21, wherein the first end portion is formed such that it is biased towards the movable part and the second end portion is formed such that it is biased towards the support structure.

23. The actuator assembly of claim 21 or 22, wherein the end portions are biased due to being fastened to the apparatus such that they are bent away from their unstressed configuration.

24. The actuator assembly of claim 23, wherein the end portions are arranged such that a force causing tension in the flexure causes one of said end portions to deform and a force causing compression in the flexure causes the other of said end portions to deform.

25. The actuator assembly of any one of claims 16 to 24, wherein the resilient portion is pre-loaded by releasable attachment to the actuator assembly, the releasable attachment being such that under normal operation the resilient portion is attached to the actuator assembly, and when subjected to a force above the pre-determined amount, the resilient portion is released from the attachment.

26. The actuator assembly of any preceding claim, further including a guide mechanism arranged to guide one or more of: the movable part, the bearing arrangement, the flexure or the resilient portion back to a normal position after the resilient portion has deformed.

27. The actuator assembly of any preceding claim, further including an end stop which is arranged to prevent movement of the movable part in at least one direction, wherein the bearing arrangement is configured such that the movable element does not contact the end stop during the normal range of movement of the movable element, further wherein the resilient portion is configured to allow the movable element to move so as to contact the end stop when the assembly is subject to external loads exceeding those of normal operation.

28. The actuator assembly of any preceding claim, further including a damping element which is arranged to increase the resilience of the flexure when the assembly is subjected to external loads exceeding those of normal operation, such that the resilient element deforms in preference to deformation of the flexure.

29. The actuator assembly of any preceding claim, wherein the actuator component comprises at least one SMA wire connected between the support structure and the movable part and arranged, on contraction, to drive rotation of the movable part around the helical axis.

30. A camera apparatus comprising:
the actuator assembly of any preceding claim; and
an image sensor that is fixed relative to the support structure of the actuator assembly;
5 wherein the movable part of the actuator assembly comprises a lens assembly having
one or more lenses that is configured to focus an image onto the image sensor.

31. The camera apparatus of claim 30, further including a controller arranged to control
the position of the lens assembly relative to the image sensor by controlling the actuator
10 component.

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Fig. 1

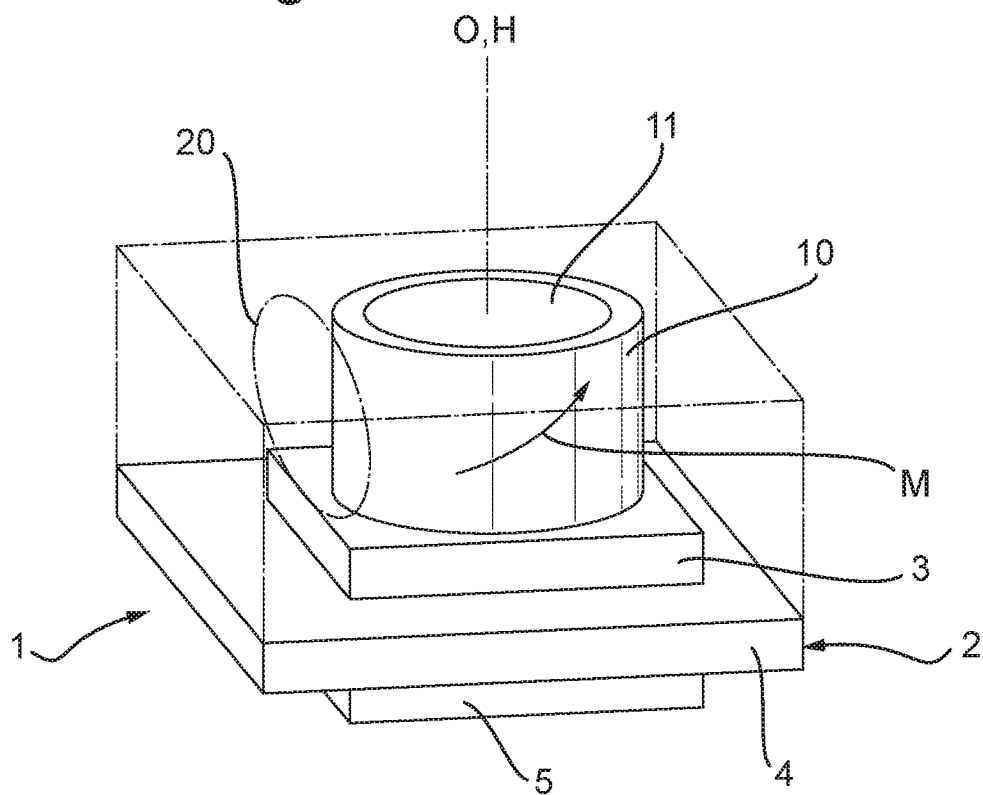
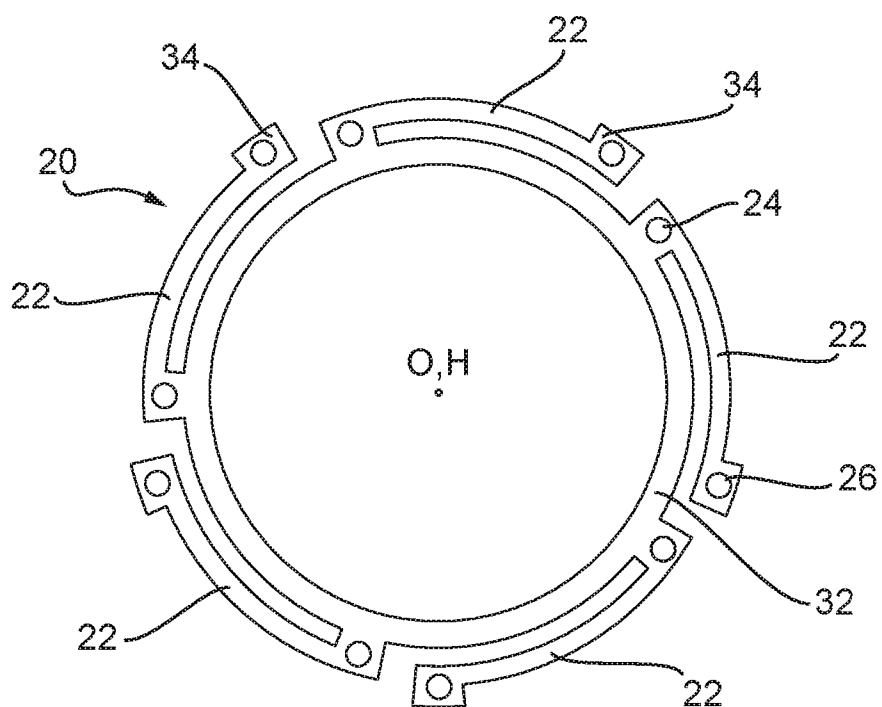


Fig. 2



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Fig. 3A

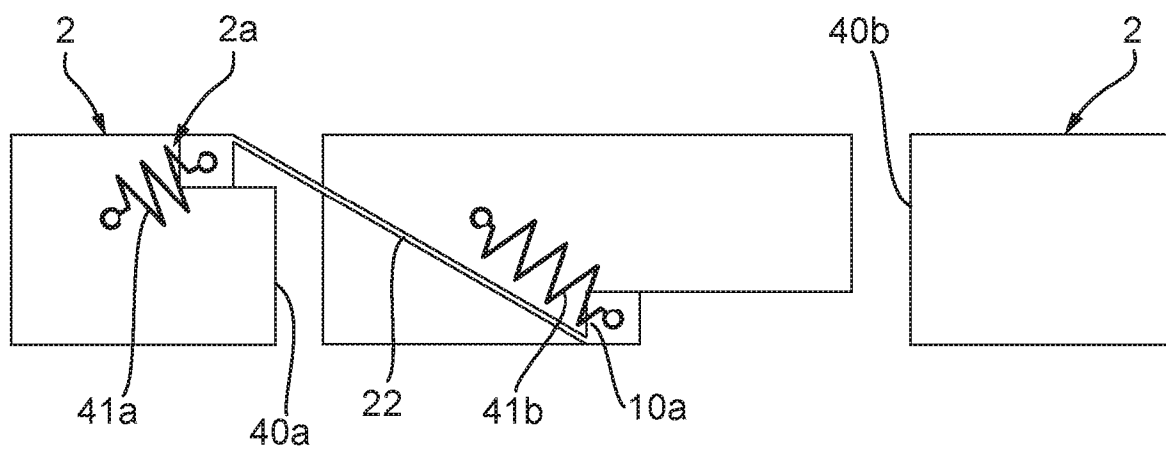


Fig. 3B

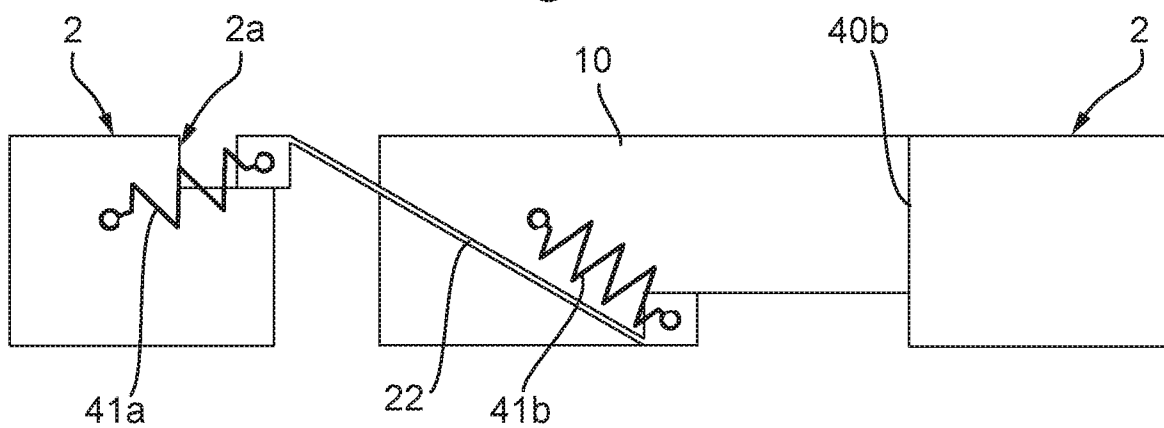


Fig. 3C

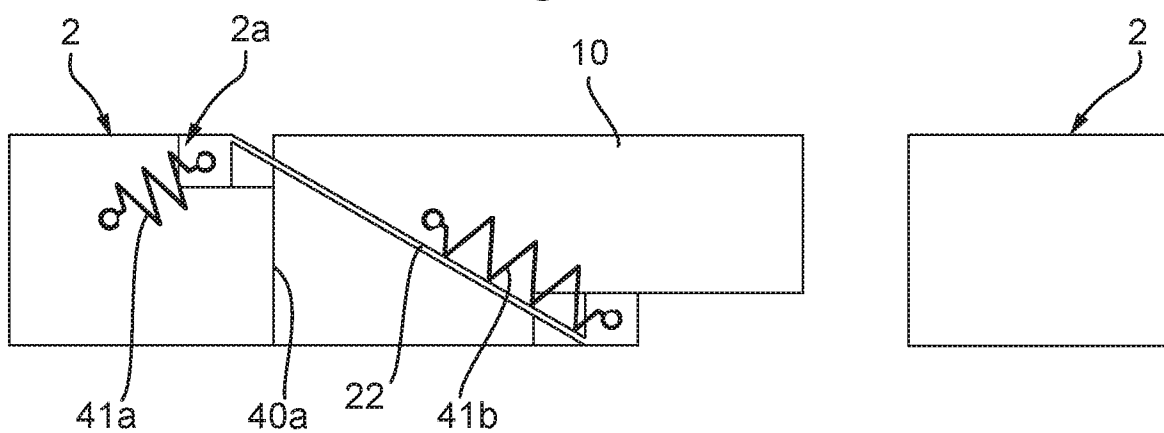
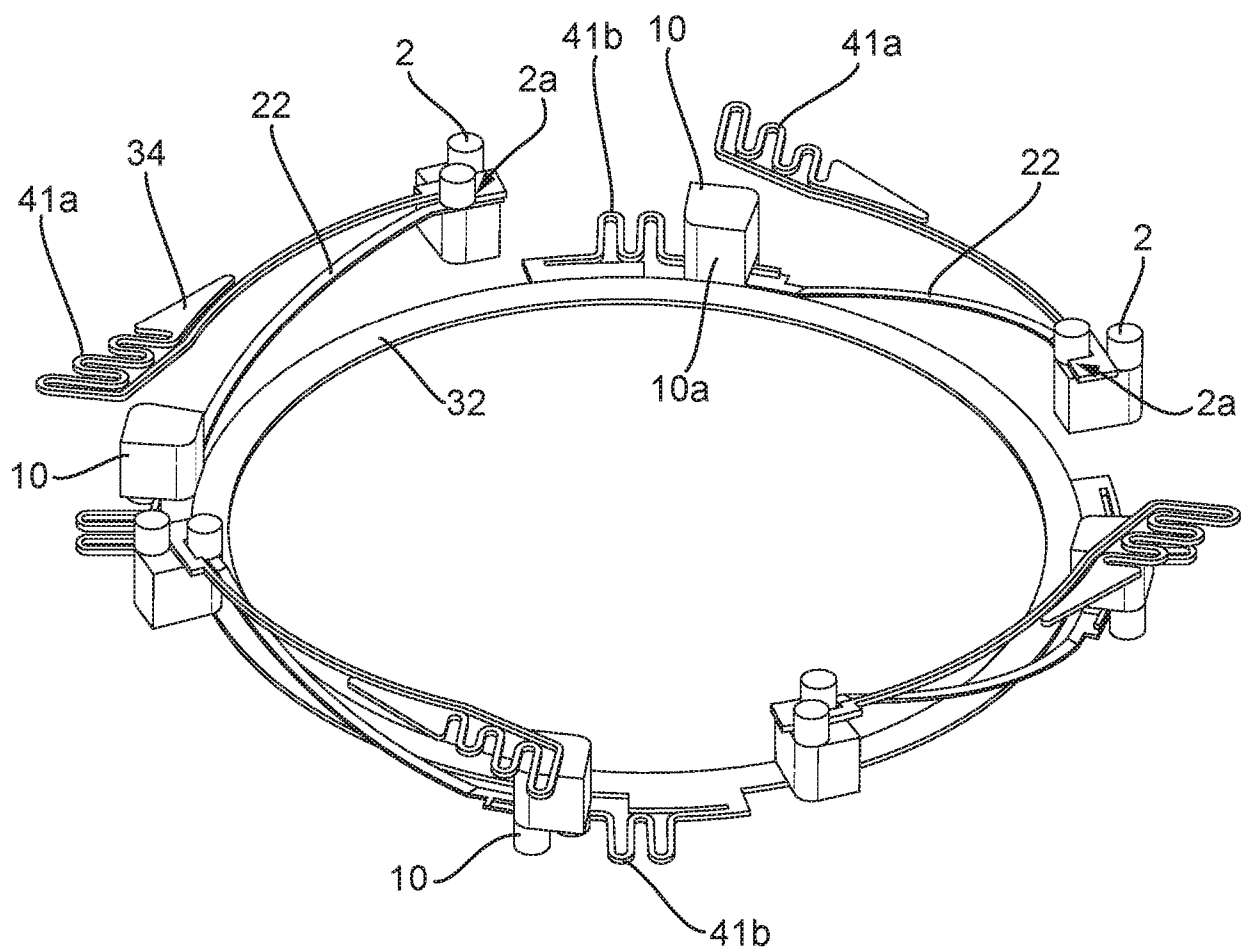


Fig. 4A



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Fig. 4B

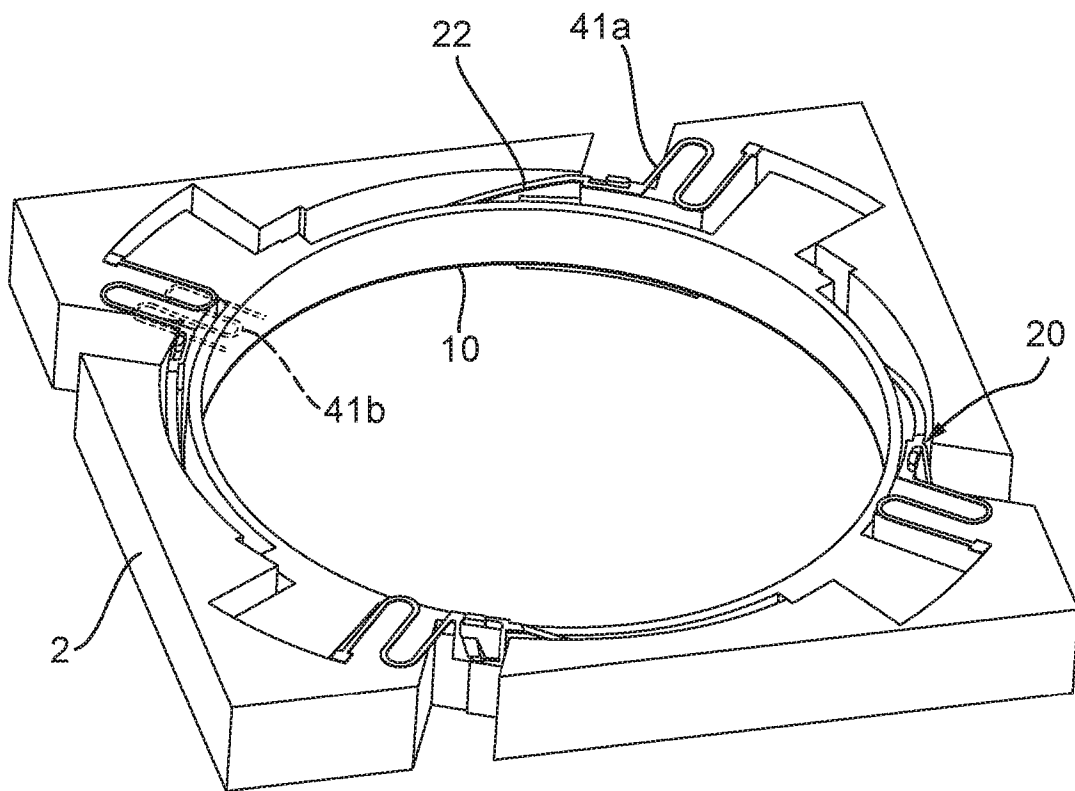
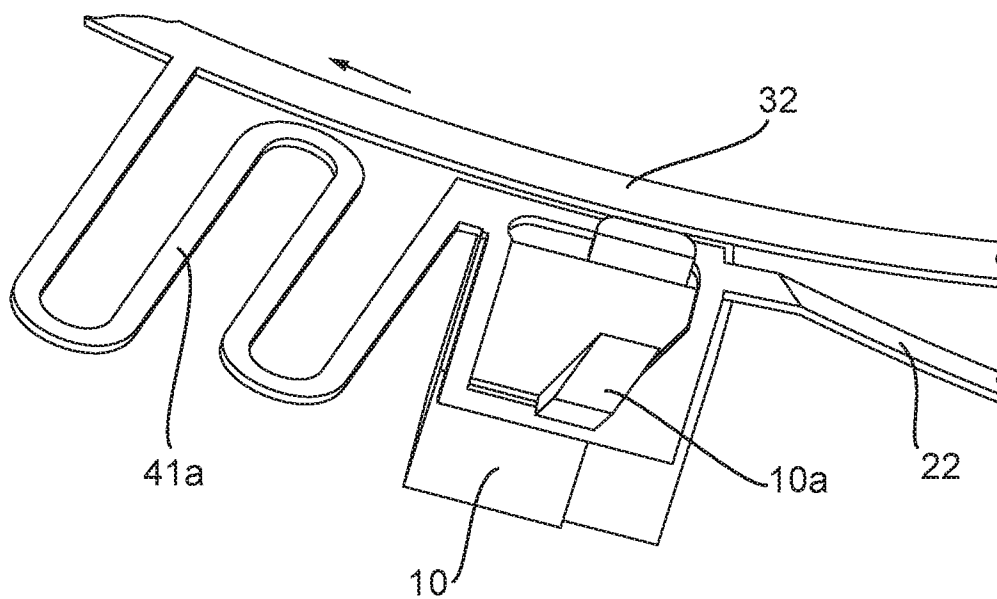


Fig. 4C



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Fig. 5A

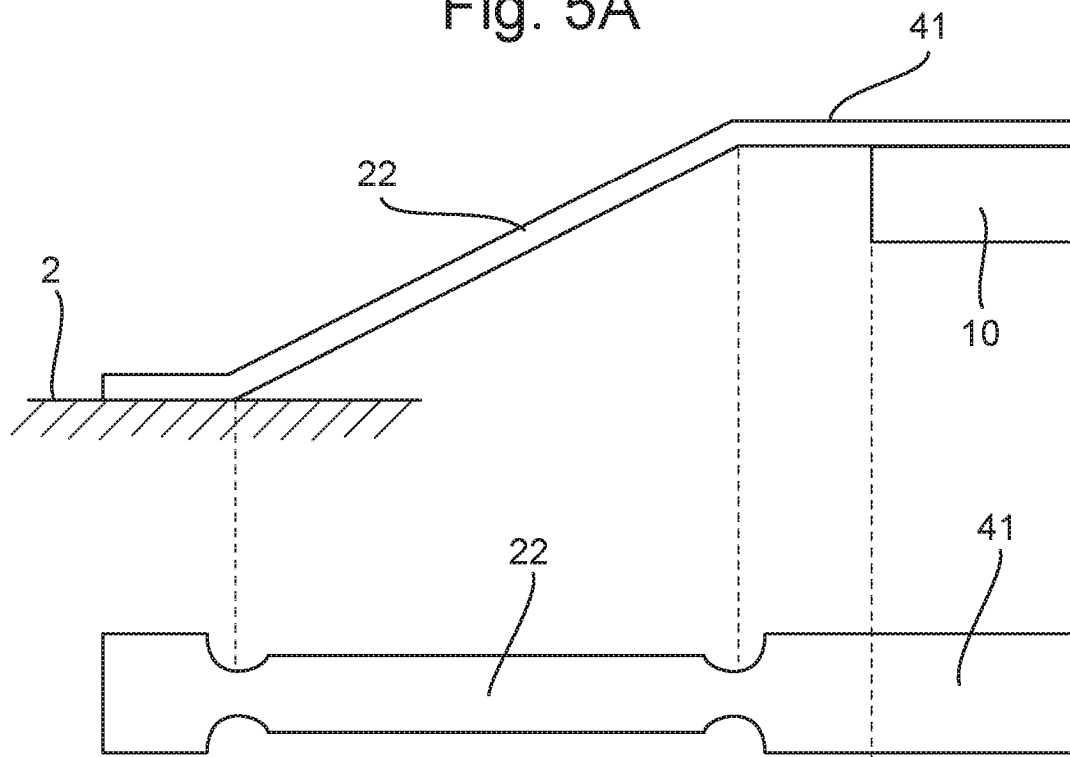
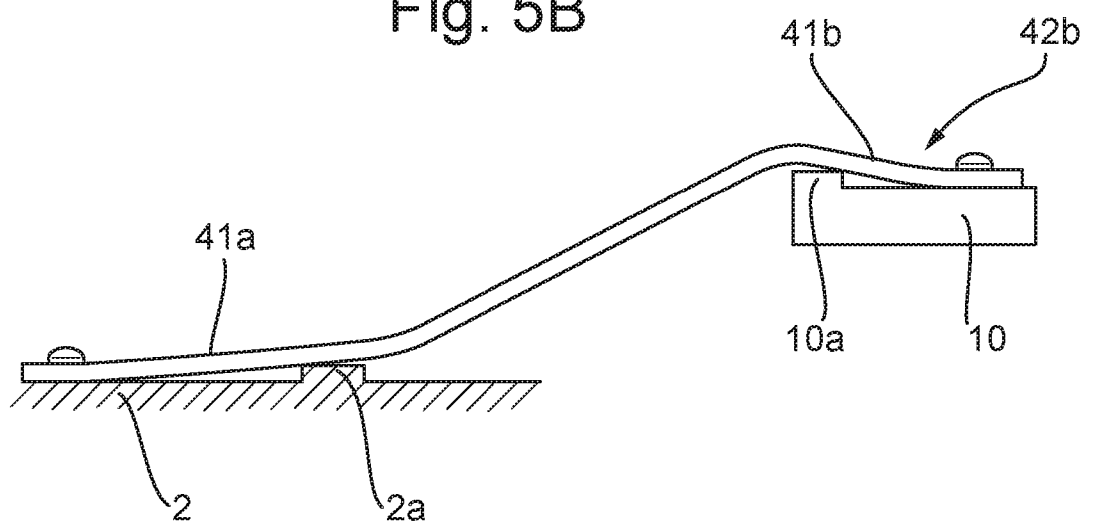


Fig. 5B



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Fig. 5C

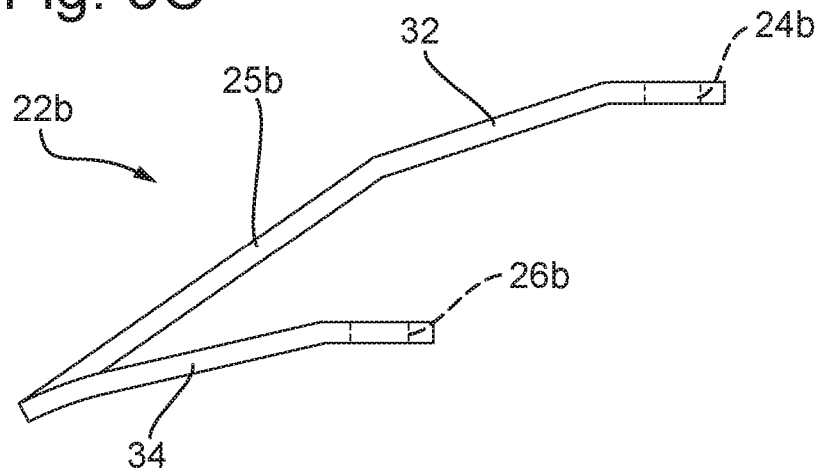


Fig. 5D

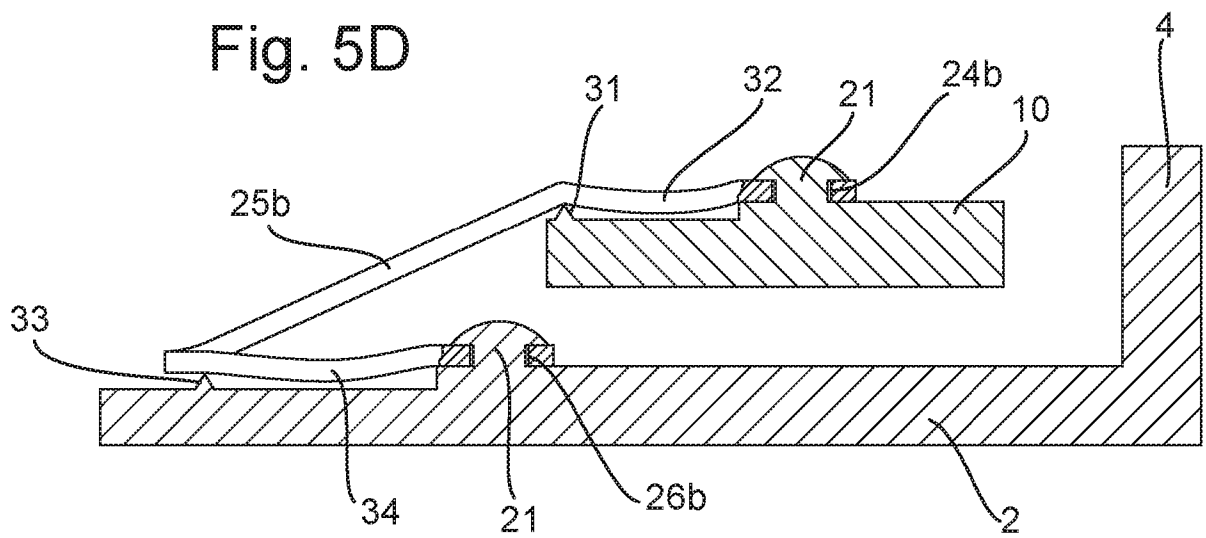


Fig. 5E

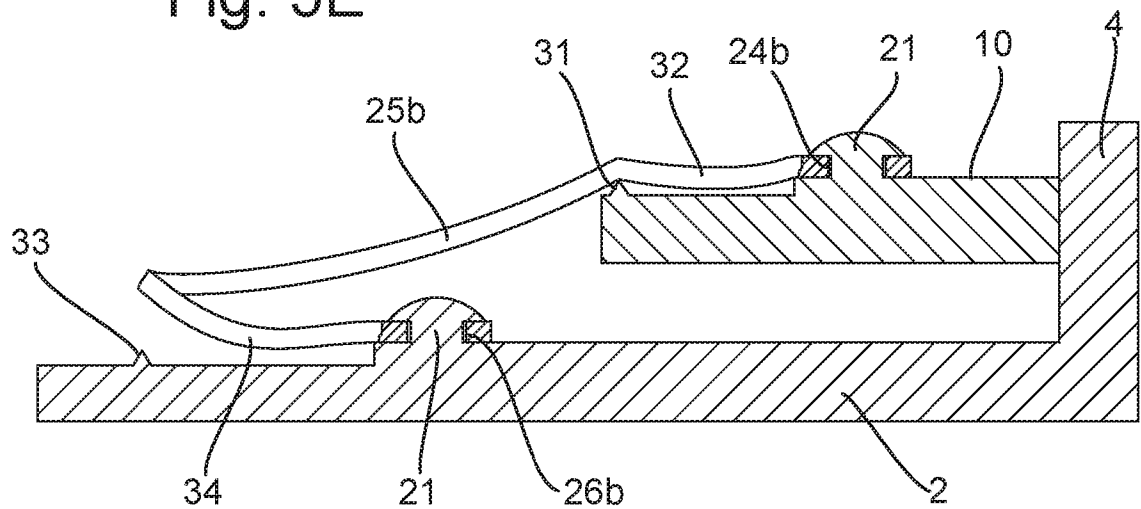


Fig. 6A

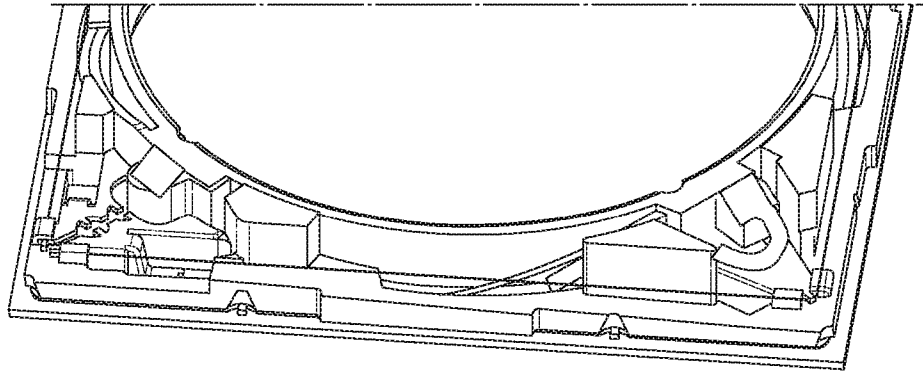


Fig. 6B

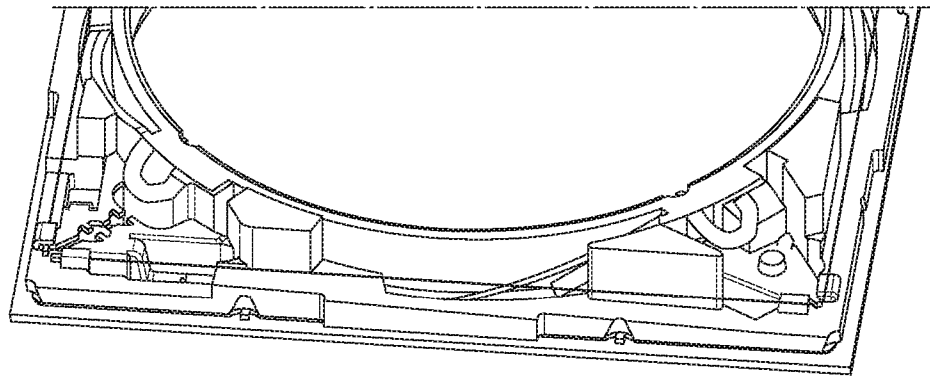
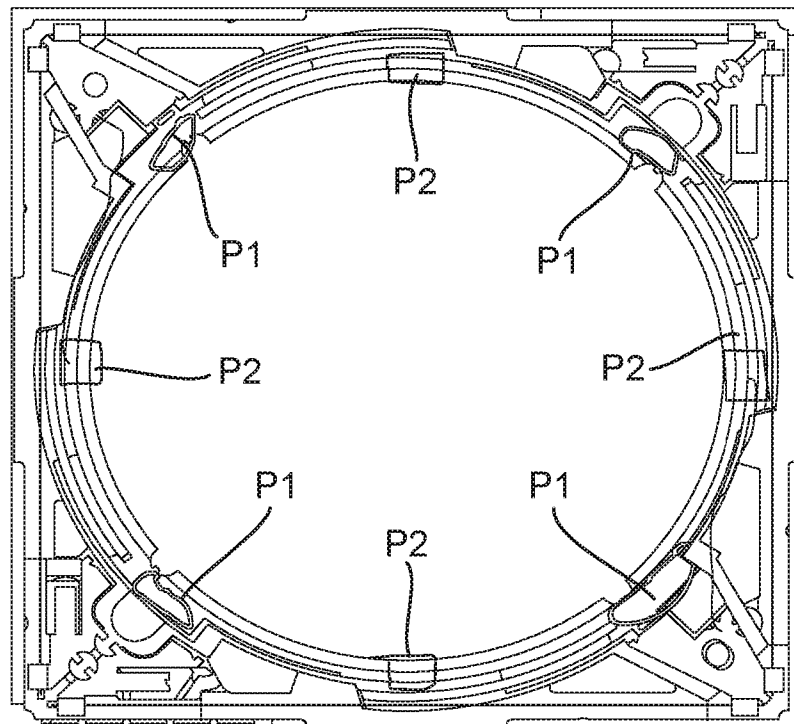


Fig. 6C



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Fig. 7

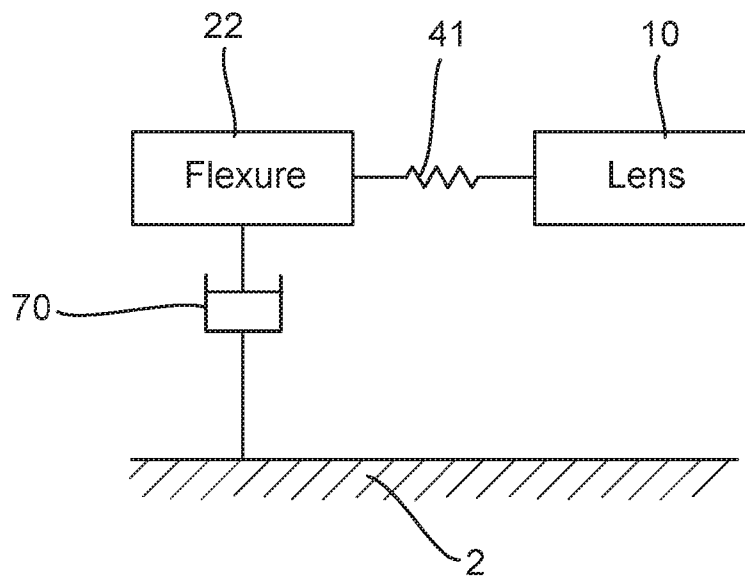
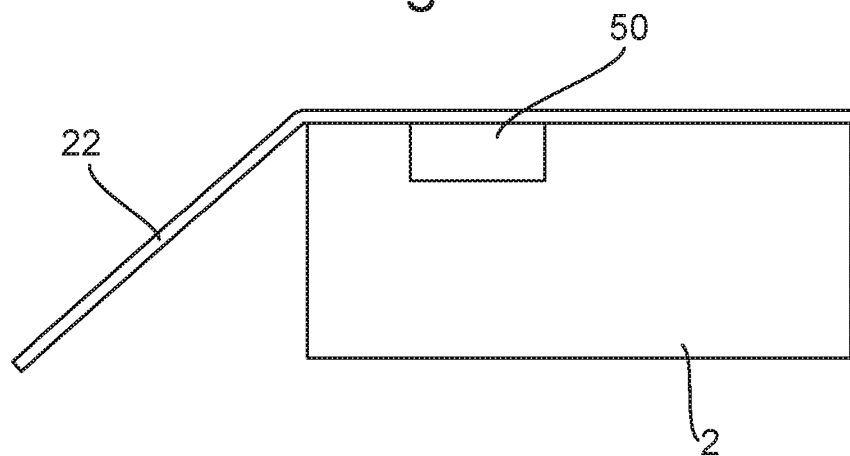


Fig. 8



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Fig. 9A

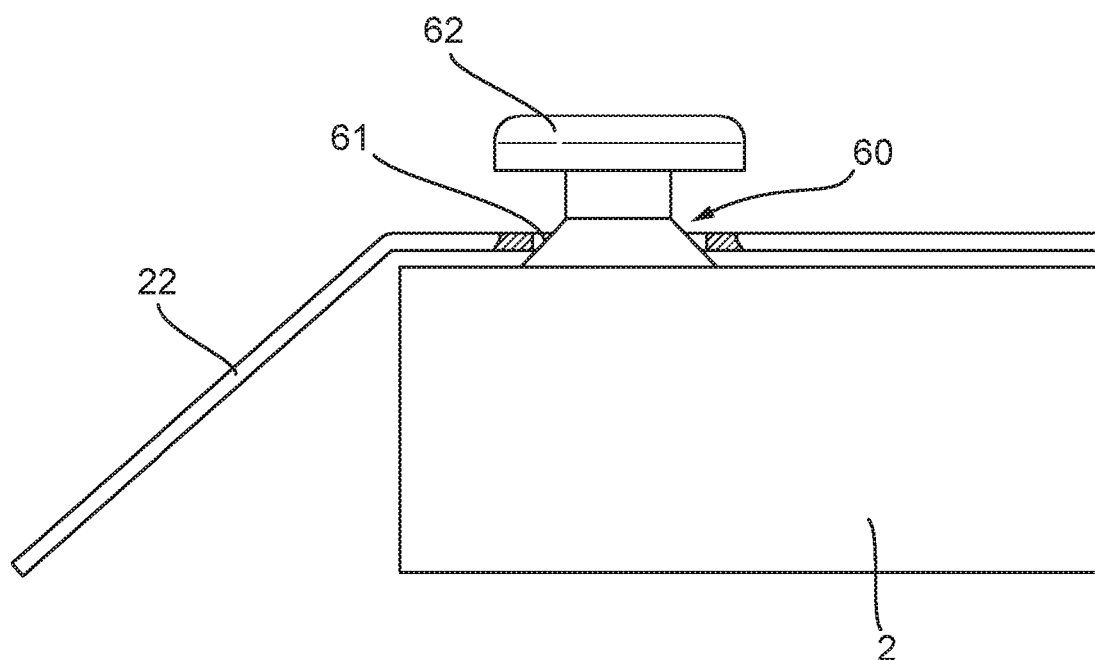
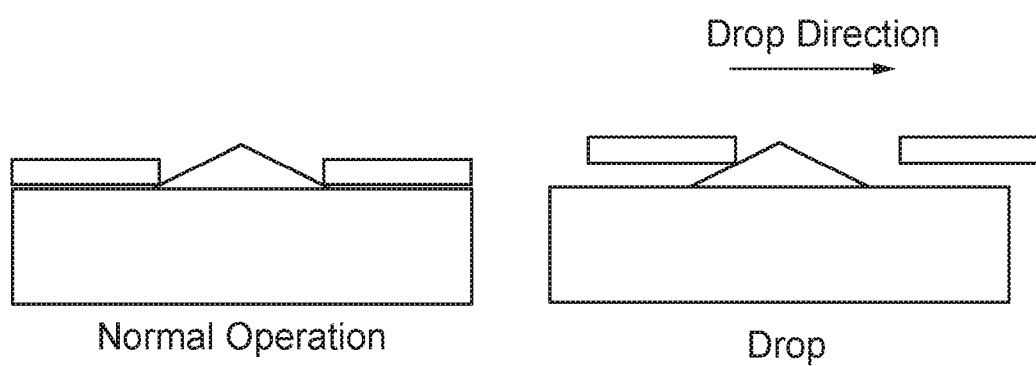


Fig. 9B



INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2022/050713

A. CLASSIFICATION OF SUBJECT MATTER

INV. F03G7/06 G02B7/02 G03B3/10
ADD.

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)

F03G G03D G02B G03B

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 practicable, 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 2007/113478 A1 (1 LTD [GB]; TOPLISS RICHARD [GB] ET AL.) 11 October 2007 (2007-10-11) cited in the application page 13, paragraph 2; figures 1,2,7 page 35, paragraph 2 - page 36, paragraph 1 -----	1-31
A	WO 2019/034860 A1 (CAMBRIDGE MECHATRONICS LTD [GB]) 21 February 2019 (2019-02-21) page 8, paragraph 3; figure 2 -----	1-31
A	WO 2010/089526 A2 (CAMBRIDGE MECHATRONICS LTD [GB] ET AL.) 12 August 2010 (2010-08-12) claim 1; figures 1,2 -----	1-31

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

☒ See patent family 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 application or patent 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

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Date of the actual completion of the international search

17 May 2022

Date of mailing of the international search report

30/05/2022

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/GB2022/050713

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