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(54) Residual-current device

(57) A residual current device comprising an actuator which is operatively connected to kinematic elements for opening contacts following the detection, by a sensor, of an earth fault current. The actuator comprises a bistable metallic element which is operatively connected to the kinematic elements and to which at least one piezoelectric element is coupled, the piezoelectric element being excited by an electrical signal as a consequence of the detection of the fault current and inducing a movement of the bistable metallic element from a first stable equilibrium position to a second stable equilibrium position. The device further comprises reset elements which are suitable to return the bistable metallic element into the first stable equilibrium position before the contacts close again.

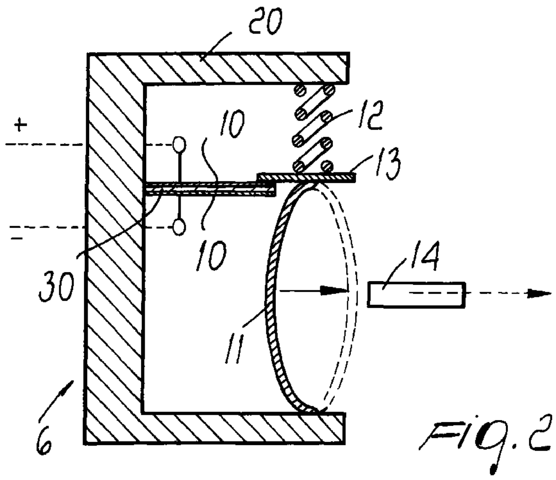

Fig.2

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Description

[0001] '[he present invention relates to a residual-current device, such as for example a residual-current circuit breaker, having improved functional characteristics.

[0002] In general, a residual-current device is a device which is suitable to directly or indirectly interrupt the flow of current in an electrical circuit when a residual current occurs. A typical example of residual-current device is constituted by a residual-current circuit breaker, and particular reference is made hereinafter to this specific embodiment without thereby intending in any way to restrict the scope of application of the device according to the present invention.

[0003] It is known that a residual-current circuit breaker is an automatic circuit breaker for AC circuits which opens when the vector sum of the currents in the conductors of the circuit, which is zero in normal conditions, exceeds a preset value; the main characteristic of said circuit breakers is that they achieve extremely short circuit opening and closure times.

[0004] Residual-current circuit breakers are generally meant to prevent metallic parts, such as for example the enclosures of electrical appliances and the metallic masses of the protected area which are connected to an earth system of appropriate resistance, from becoming live: indirect protection is thus achieved. Moreover, if said circuit breakers are sufficiently sensitive and fast-acting, in certain conditions they can also provide protection against contact with normally live parts, thus providing direct protection.

[0005] A residual-current circuit breaker is shown schematically in Figure 1. Said circuit breaker comprises a sensor 1 for detecting the residual fault current, generally constituted by a magnetic core in which the neutral 2 and the phase 3 pass, said neutral and phase being connected to a load (not shown), and by a secondary winding 4 across which a voltage is generated when the fault current is present. If an earth fault current occurs, the voltage generated across the secondary winding is supplied to an actuator 6 by means of a suitable electronic coupling system 5 which is interposed between the sensor 1 and the actuator 6. In turn the actuator actuates a release or disengagement mechanism 7 which opens the contacts 8 and 9 of the circuit and thus interrupts the power supply.

[0006] One of the main drawbacks of conventional residual-current circuit breakers is the fact that the actuators currently in use are of the electromagnetic type, typically electromagnetic relays of the demagnetization type. These relays are in fact sensitive to magnetic fields and this can cause several drawbacks: for example, the presence of a magnetic field can cause unwanted and unwarranted actuation of the actuator, or an external magnetic field might alter the magnetization of the electromagnetic relay, consequently modifying the sensitivity of the residual-current circuit breaker and negatively affecting its performance.

[0007] Another drawback is the fact that electromagnetic actuators have a mechanically complicated structure which is sensitive to impacts and vibrations: this can cause untimely interventions of the circuit breaker and negatively affects its overall reliability. The cost is also high.

[0008] The aim of the present invention is to provide a residual-current device which is insensitive to external magnetic fields, so as to avoid untimely interventions.

[0009] Within the scope of this aim, an object of the present invention is to provide a residual-current device which comprises an actuator which has a simplified structure and is insensitive to impacts and vibrations, so as to improve the performance and overall reliability of said circuit breaker.

[0010] Another object of the present invention is to provide a residual-current device which is highly reliable, relatively easy to manufacture and at competitive costs.

[0011] This aim, these objects and others which will become apparent hereinafter are achieved by a residual-current device which comprises an actuator which is operatively connected to kinematic means for opening contacts following the detection, by a sensor, of an earth fault current, characterized in that said actuator comprises a bistable metallic element which is operatively connected to said kinematic means and to which at least one piezoelectric element is coupled, said piezoelectric element being excited by an electrical signal as a consequence of the detection of said fault current and inducing a movement of the metallic element from a first stable equilibrium position to a second stable equilibrium position, the bistable metallic element actuating said kinematic means by way of said movement; said device further comprising reset means which are adapted to return the bistable metallic element to the first stable equilibrium position before the contacts close again.

[0012] In this manner, by using a piezoelectric actuator, the device according to the invention is insensitive to external magnetic fields and is therefore immune to untimely and unwanted interventions.

[0013] Further characteristics and advantages of the device according to the invention will become apparent from the following detailed description of preferred but not exclusive embodiments thereof, illustrated only by way of non-limitative example in the accompanying drawings, wherein:

Figure 1 is a block diagram of a residual-current circuit breaker;

Figure 2 is a schematic view of a first embodiment of an actuator which can be applied in the residual-current device according to the present invention;

Figure 3 is a schematic view of a second embodiment of the actuator that can be used in the residual-current device according to the present invention;

Figure 4 is a schematic view of a third embodiment of the actuator that can be used in the residual-current device according to the present invention;

Figure 5 is a view of a detail of the actuator of Figure 4:

Figure 6 is a schematic view of a fourth embodiment of the actuator that can be used in the residual-current device according to the present invention;

Figure 7 is a schematic view of a fifth embodiment of the actuator that can be used in the residual-current device according to the present invention:

Figure 8 is a schematic view of a sixth and preferred embodiment of the actuator, operatively associated with means suitable to reset said actuator:

Figure 9 is a side view of the actuator of Figure 8, in which the bistable metallic element has reduced transverse cross-sections:

Figure 10 is a plan view of the actuator of Figure 8, in which the bistable metallic element has thinner transverse cross-sections produced by means of notches;

Figure 11 is a view of a second embodiment of the reset means of the actuator used in the device according to the present invention:

Figure 12 is a view of a third embodiment of the reset means of the actuator used in the device according to the present invention.

[0014] With reference to Figure 1, the residual-current circuit breaker comprises an actuator 6 which is operatively connected to kinematic means 7 for opening the contacts 8 and 9 of the circuit breaker following the detection of an earth fault current by a sensor 1.

[0015] Advantageously, in the device according to the invention the actuator 6 comprises a bistable metallic element which is operatively connected to the kinematic means 7 and with which at least one piezoelectric element is operatively associated. If an earth fault current occurs, the voltage generated across the secondary winding 4 of the sensor 1 is supplied to the piezoelectric element, either directly or preferably by means of a suitable electronic coupling system 5 interposed between the sensor 1 and the actuator 6. The electrically activated piezoelectric element undergoes deformation, inducing a movement of the bistable metallic element from a first stable equilibrium position to a second stable equilibrium position. By way of this movement, the bistable metallic element transmits a movement to the kinematic means 7, which open the contacts and interrupt the power supply.

[0016] In a first embodiment, shown in Figure 2, the actuator 6 comprises a bistable element which is constituted by a metallic lamina 11 in which a first end is connected to a supporting body 20, for example the case of the circuit breaker: suitable compression means act on a second end of the lamina 11 which is opposite and substantially parallel to the first one so as to keep the lamina loaded in a first stable equilibrium position. Said compression means comprise, for example, an abutment element 13 which is fixed to the second end of the lamina and a loading spring 12 which is interposed between the supporting element 20 and the abutment element 13. Advantageously, at least one piezoelectric element 10 is arranged in contact with the abutment element 13: in a preferred embodiment, the piezoelectric element 10 is a bimorph element, i.e., it is constituted by two mutually parallel layers of piezoelectric material. In this manner, when an electrical stress is applied, one piezoelectric element layer deforms by contracting while the other one deforms by elongating. As shown in Figure 2, an element 30 which acts as an electrode is interposed between the two piezoelectric layers.

[0017] In case of earth fault, the piezoelectric element 10 is supplied by the voltage generated across the secondary winding 4 of the current sensor 1, either directly or preferably by means of the electronic coupling system 5. The electric power supply induces a deformation in the two layers that constitute the piezoelectric element 10: this allows to reduce the loading force that retains the metallic element 11 below its critical threshold, i.e., the threshold beyond which the metallic element passes from a first stable equilibrium configuration, shown in solid lines, to a second stable equilibrium position, shown in dashed lines.

[0018] The movement from the first position to the second position actuates an actuation element 14. For example a pin, which is meant to actuate the kinematic means 7 for opening the contacts of the circuit protected by the residual-current device.

[0019] As shown in Figure 3, in a second embodiment of the actuator used in the device according to the invention the bistable metallic lamina, now designated by the reference numeral 111, is substantially M-shaped. In particular, the lamina 111 has two end portions, which are substantially straight and mutually parallel and are fixed to a supporting element 120, and an arc-shaped central portion which in practice reproduces the configuration of the lamina 11 of Figure 1. In this manner, the lamina 111 is arranged in a first stable equilibrium position and makes it unnecessary to use the spring 12 and the abutment element 13. The arc-shaped central portion has, on one of its faces, two mutually spaced piezoelectric elements 100, each element being constituted by one or more layers of piezoelectric material. In this case, as a consequence of the supply of the voltage due to a fault current, the piezoelectric elements 100 undergo deformation, transmitting a bending moment to the metallic lamina 111, which snaps from the initial stable equilibrium configuration to the second stable equilibrium position , shown in dashed lines, and actuates an actuation element 14.

[0020] Also in this case, it is possible to arrange the layers of piezoelectric material in a mutually bimorph configuration.

[0021] Figure 4 is a view of a third embodiment of the actuator 6, in which the lamina made of metallic material, now designated by the reference numeral 211, is kept in a first stable equilibrium position by means of a compression spring 212 which is arranged between two L-shaped elements of an external supporting body 220.

[0022] The piezoelectric elements are constituted, in this case, by two pairs of layers of piezoelectric material, designated by the reference numerals 200a and 200b respectively, which face each other and have the lamina 211 interposed between them, as shown in detail in Figure 5.

[0023] Figure 6 illustrates a fourth embodiment of the actuator 6, which differs from the embodiment of Figure 4 in that on the lamina made of metallic material, here designated by the reference numeral 311, there are, on a same face of the lamina, a first piezoelectric element and a second piezoelectric element, both designated by the reference numeral 300, which are mutually spaced on the face of said lamina.

[0024] Figure 7 is a view of a fifth embodiment of the actuator 6, which differs from the embodiment shown in Figure 3 in that it has two piezoelectric elements 400 which are arranged on the substantially straight portions of the M-shaped lamina 411.

[0025] Figure 8 illustrates a sixth particularly preferred embodiment of the actuator 6 used in the residual-current device according to the invention. In this case, the lamina 511 has two substantially parallel ends which are fixed, preferably by interlocking coupling, to a supporting element 520, for example the case of the circuit breaker: two piezoelectric elements 500 are fixed to the two opposite faces of one of said parallel ends, are arranged in a mutually bimorph configuration and are also at least partially fixed to the support. In this manner, the lamina is kept in a first stable equilibrium position, shown in solid lines in Figure 8: when an earth fault condition occurs, the piezoelectric elements 500 are excited by a supply voltage, as described earlier, and by undergoing deformation they generate a bending moment which induces the movement of the lamina from the first stable equilibrium position in the second stable equilibrium position, shown in dashed lines in Figure 8. By at least partially fixing to the support the piezoelectric elements as well, in practice a rigid mutual coupling of the piezoelectric elements and the lamina occurs in which the piezoelectric elements behave like a pivot and allow the optimum transfer of the bending moment only to the useful part of the free lamina.

[0026] The lamina, in moving from the first equilibrium position to the second equilibrium position, actuates an actuation element 14, for example a pin, which is meant to actuate the kinematic means 7 for opening the contacts of the circuit protected by the residual-current device.

[0027] Advantageously, as shown in Figures 9 and 10, the lamina 511 includes one or more functional hinges 530 in its structure which are obtained by means of a local reduction in its transverse cross-section. In particular, the hinges can be provided either by means of notches having a suitable shape, obtained by removing material as shown in Figure 10, or by reducing the thickness of the lamina, for example by lamination or electrical discharge machining, as shown in Figure 9. The hinges 530 can be formed proximate to the section of the lamina that is coupled to the piezoelectric elements 500, proximate to the opposite end of the lamina 511 which is rigidly coupled to the support, or in both of said regions, and have a dual function: proximate to the end of the lamina that is not associated with the piezoelectric elements 500, they facilitate the optimum movement of the lamina from the first equilibrium position to the second one: proximate to the piezoelectric elements, they instead allow to stabilize the lamina in the two chosen equilibrium positions. Moreover, the simultaneous presence of the hinges in both regions allows their mutual cooperation in performing the above described functions.

[0028] Clearly, the hinges, as well as the fixing of the lamina and of the piezoelectric elements, can be used in all the embodiments previously described.

[0029] Another advantageous aspect of the invention is the fact that the two ends of the lamina are fixed to the support 520 in two positions which are mutually staggered with respect to a median plane 550 of the lamina in the non-deformed configuration. This solution allows to minimize the amount of energy required for the lamina to snap from the first equilibrium position to the second equilibrium position and allows to utilize in an optimum manner the limited energy that can be obtained from the fault.

[0030] Also in this case, the movement of the metallic lamina 511 actuates a pin 14 for transferring motion and force to the kinematic means 7 for opening the contacts. Advantageously, the residual-current device according to the invention comprises reset means which allow to reset the actuator and therefore to prepare said device for a new intervention before the contacts are closed again.

[0031] Said reset means can be obtained by using the pin 14, with which a shaped head 15 is associated, said head having a shape which is suitable to perform the correct resetting of said actuator. In this case, resetting can be achieved directly after actuation, following the rebound of said pin assisted by a return spring 16 which is controlled for example by a lever for restoring electrical continuity, such as for example the lever for closing the contacts of the circuit breaker again. When the circuit breaker opens, the lever disengages the spring 16, which transfers its energy to the pin 14 either directly or by means of the interposition of a transmission mechanism suitable for the purpose. As a consequence of the movement of the pin 14, the shape of the head 15 couples geometrically to the surface of the lamina and induces its precise movement to the first stable equilibrium position. In this position the actuator is ready for a new intervention.

[0032] As shown schematically in Figure 11, in an alternative embodiment of the actuator reset means the pin 14 only has the purpose of transferring motion and force to the kinematic system for opening the contacts: in this case, the reset function is performed by a cam 521 which is pivoted in the support 520 of the actuator. In practice, by restoring the device by acting for example on the lever for closing the main contacts of the circuit breaker, the rotary motion of the lever is transmitted to the cam 521, for example by means of two pulleys, not shown, one pulley being keyed on the axis of the closure lever, the other pulley being keyed on the rotation axis of the cam. The cam 521, by rotating about its own axis in the direction indicated by the arrow 522, makes contact with the lamina 511, forcing the end section of the piezoelectric elements 500 to bend downward; said bending is sufficient to exceed the value required to restore the operating conditions for release. At the same time, the head of the cam moves along the lamina, facilitating the reloading action by means of the tangential component of the thrust force applied thereby, without forcing excessively the cross-section at the piezoelectric elements and therefore avoiding possible breakage. Snap action of the lamina is thus achieved while the cam is still pushing against it, maintaining the end section of the piezoelectric elements beyond the bending required for correct resetting. Once the snap action or resetting the lamina has occurred, the cam moves away from contact with the lamina, thus allowing the piezoelectric elements to return to the operating condition for intervention. At the end of the resetting operation, the cam has turned through 360 degrees, so as to be ready for the subsequent resetting of the lamina and so as to be in such a position that it does not interfere with a subsequent snap action of said actuator. Said rotation can be achieved by correct choosing the dimensions of the mechanism for transmitting motion from the circuit breaker closure lever to said cam.

[0033] This solution ensures exact repeatability of the reloading action over time: moreover, by means of an appropriate shaping of the cam head it is possible to achieve optimum values of the force components applied by the cam to the lamina, avoiding impacts with the piezoelectric elements which might damage the actuator and shorten its operating life.

[0034] A further embodiment of the reset means is shown in Figure 12. In this case, during the opening of the main contacts a pin 14 moves in a track 701 formed in the supporting structure 520 and transmits motion to the kinematic means 7 for opening the contacts; at the same time, suitable guides 702 associated with the pin move beyond a first unidirectional spring 710 which prevents the pin from falling back along the same section of the track 701.

[0035] By acting on the closure lever of the main contacts, the movement of the lever is transmitted by means of appropriate kinematic systems to the guides 702, which slide along a track 703 until the pin is placed at a section which is proximate to the piezoelectric elements. In this position, the head of the pin begins to push against the lamina: by following the rotation of the lever, the pin moves in the track 703 and its head simultaneously slides along said lamina.

[0036] A position is thus reached in which the configuration is not stable and the lamina snaps, returning into the initial stable equilibrium position. Once resetting has been performed, the pin continues to slide along the track 703 and abandons contact with the lamina, avoiding any interference during the subsequent snap action thereof. At the end of the movement, the pin resumes the operating position for release, while the guides 702 move beyond a second unidirectional spring 711 so that they cannot return along the track 703 during release. The shape of the tracks can obviously be configured differently according to specific requirements.

[0037] Clearly, the reset means for resetting the actuator can be used in an equivalent manner in all the embodiments previously described.

[0038] In practice it has been observed that the device according to the invention fully achieves the intended aim and objects, since it has an actuator which is fully insensitive to external magnetic fields, thus allowing to avoid untimely interventions: moreover, its structure is constructively simple and allows to considerably increase the overall reliability of the device, allowing in particular to have high repeatability of the opening interventions and correct and precise resetting of said device. Further, the device can be constituted by a residual-current circuit breaker, as previously described, or by a residual-current block, i.e. a block which is generally coupled to a thermomagnetic circuit breaker.

[0039] Attention is also drawn to the fact that all the innovative functions and the inventive aspects of the device can be achieved by using commonly commercially available elements and materials with extremely low costs.

[0040] The device thus conceived is susceptible of numerous modifications and variations, all of which are within the scope of the inventive concept: all the details may also be replaced with other technically equivalent elements.

[0041] In practice, the materials employed, so long as they are compatible with the specific use, as well as the dimensions, may be any according to requirements and to the state of the art.

Claims

1. A residual-current device comprising an actuator which is operatively connected to kinematic means for opening contacts following the detection, by a sensor, of an earth fault current, characterized in that said actuator comprises a bistable metallic element which is operatively connected to said kinematic means and to which at least one piezoelectric element is operatively coupled, said piezoelectric element being excited by an electrical signal as a consequence of the detection of said fault current and inducing a movement of the bistable metallic element from a first stable equilibrium position to a second stable equilibrium position, the metallic element actuating said kinematic means by way of said movement: said device further comprising reset means which are adapted to return the bistable metallic element into the first stable equilibrium position before the contacts close again.

2. The residual-current device according to claim 1, characterized in that said bistable metallic element comprises a metallic lamina which has two opposite ends which are fixed to a supporting structure so as to assume said first stable equilibrium position, two piezoelectric elements arranged in a mutually bimorph configuration being fixed correspondingly on the two opposite faces of one of said opposite ends.

3. The residual-current device according to claim 2, characterized in that said two opposite ends are fixed to the supporting structure in mutually staggered positions with respect to a median plane of the lamina in the non-deformed configuration.

4. The residual-current device according to claim 1, characterized in that said bistable metallic element comprises a metallic lamina having a first end which is fixed to a supporting structure and a second end which is opposite to the first end and on which compression means act, said compression means being suitable to apply an axial stress to the lamina and to keep it in said first stable equilibrium position.

5. The residual-current device according to claim 4, characterized in that said compression means comprise an abutment element which is fixed to said second end of the lamina and on which a loading spring acts, two piezoelectric elements arranged in a mutually bimorph configuration further acting on said abutment element.

6. The residual-current device according to claim 1, characterized in that said bistable metallic element comprises a metallic lamina having two opposite ends which are fixed to a supporting structure which comprises two parts which are mutually connected by way of the interposition of a loading spring, said loading spring being suitable to apply an axial stress to the metallic lamina in order to keep it in said first stable equilibrium position.

7. The residual-current device according to claim 6, characterized in that a first piezoelectric element and a second piezoelectric element are arranged on a same face of said metallic lamina and are mutually spaced.

8. The residual-current device according to claim 6, characterized in that two pairs of piezoelectric elements are fixed on said metallic lamina, each one of said pairs being constituted by at least two mutually facing and mutually parallel laminae made of piezoelectric material, the metallic lamina being interposed between them.

9. The residual-current device according to claim 1, characterized in that said bistable metallic element comprises a metallic lamina which is substantially M-shaped and has two substantially straight and mutually parallel ends, which are fixed to a supporting structure, and a curved central portion, on one face of which two piezoelectric elements are fixed, each piezoelectric element being constituted by one or more laminae made of piezoelectric material.

10. The residual-current device according to claim 1, characterized in that said bistable metallic element comprises a substantially M-shaped metallic lamina which has a central curved portion and two substantially straight and mutually parallel ends which are fixed to a supporting structure, at least one piezoelectric element being associated with each one of said straight ends.

11. The residual-current device according to one or more of claims 2 to 10, characterized in that hinges are provided on the surface of the bistable metallic element.

12. The residual-current device according to claim 11, characterized in that said hinges comprise shaped notches which are provided on the surface of the bistable metallic lamina.

13. The residual-current device according to claim 11, characterized in that the bistable metallic element has a transverse cross-section whose thickness varies along its longitudinal extension in order to

provide said hinges.

14. The residual-current device according to claim 1, characterized in that the reset means comprise a pin which is operatively associated with a return spring, said pin having a shaped head which is suitable to interact geometrically with the surface of said bistable metallic element.

15. The residual-current device according to claim 1, characterized in that the reset means comprise a cam which is pivoted to a supporting structure and is operatively connected to a contact closure lever.

16. The residual-current device according to claim 1, characterized in that the reset means comprise a pin which can slide in tracks formed in a supporting element of the actuator and has a shaped head which is suitable to interact with the surface of the bistable metallic element, said tracks containing unidirectional springs for guiding said pin during the repositioning of the bistable metallic element in the first stable equilibrium position.

17. The residual-current device according to one or more of the preceding claims characterized in that it is a residual-current circuit breaker or by a residual-current block.

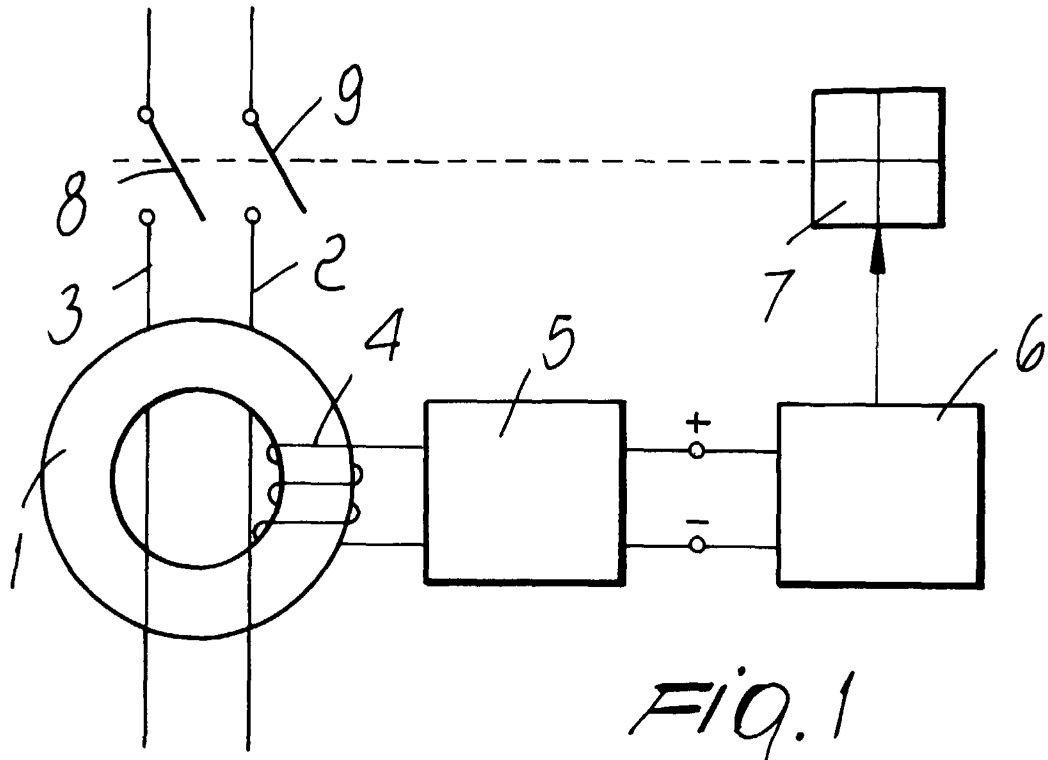

Fig.1

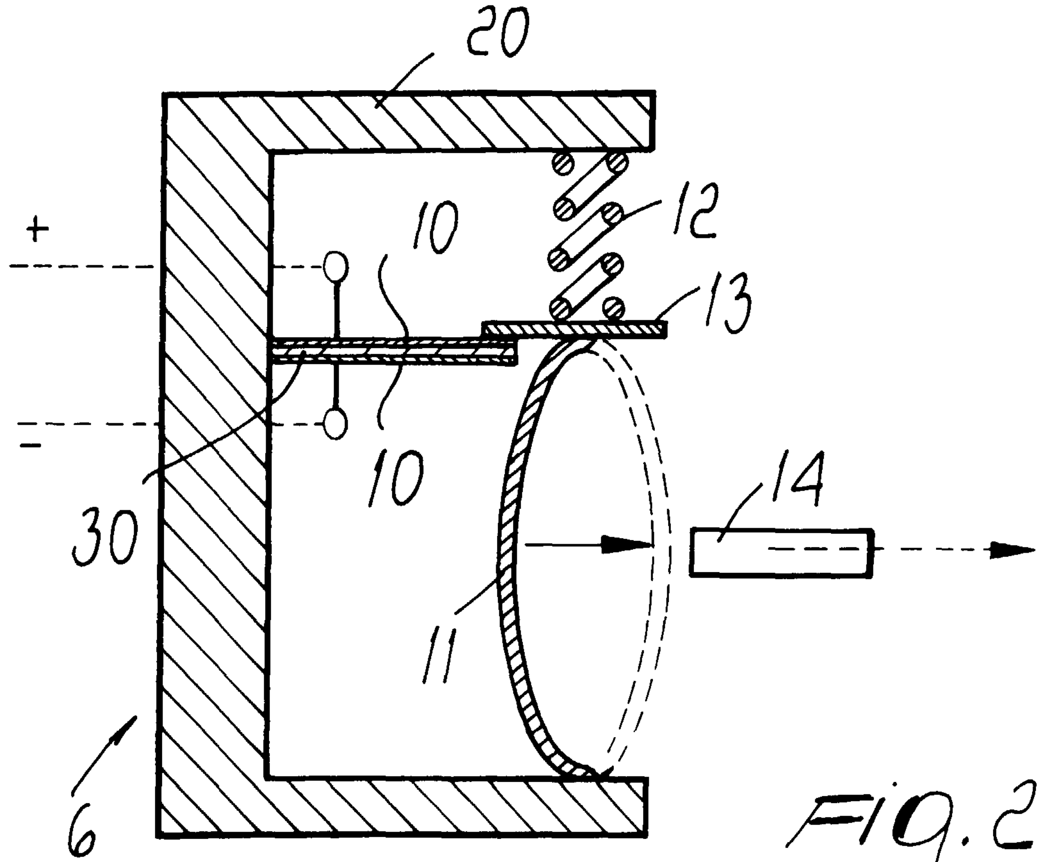

Fig.2

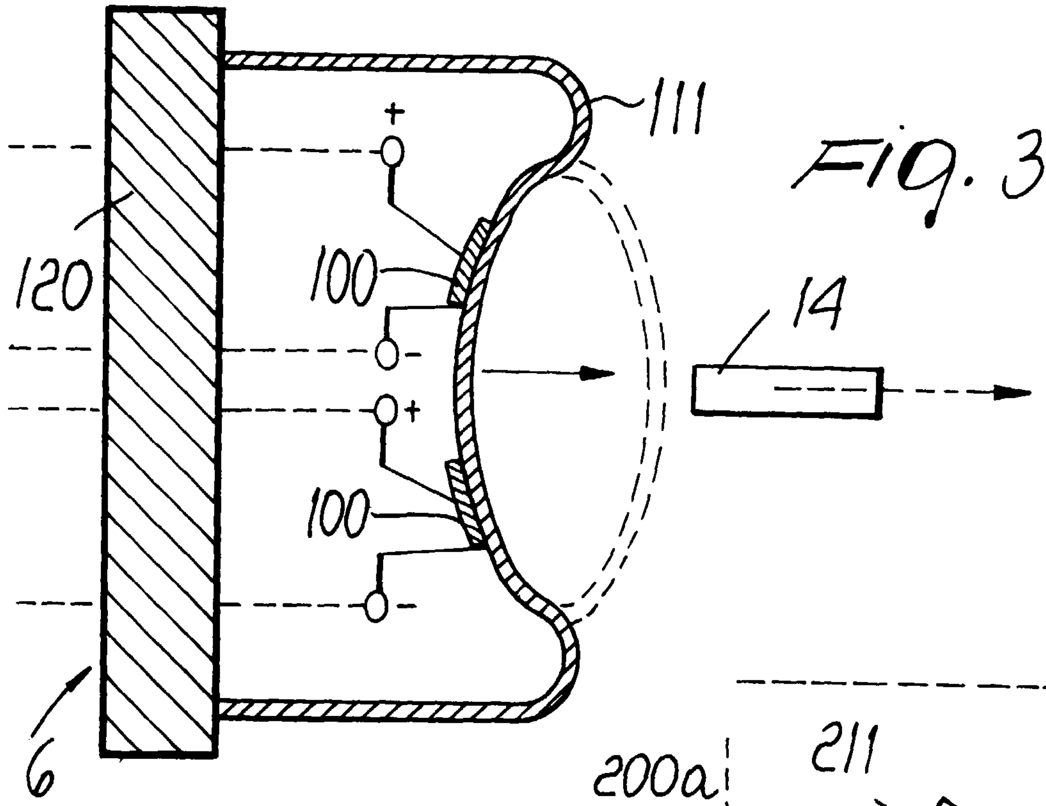

Fig. 3

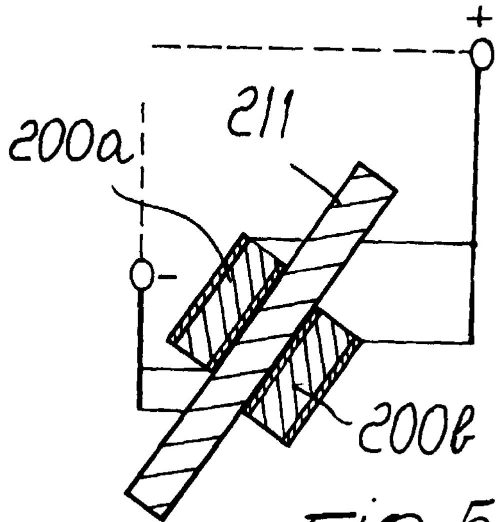

Fig. 5

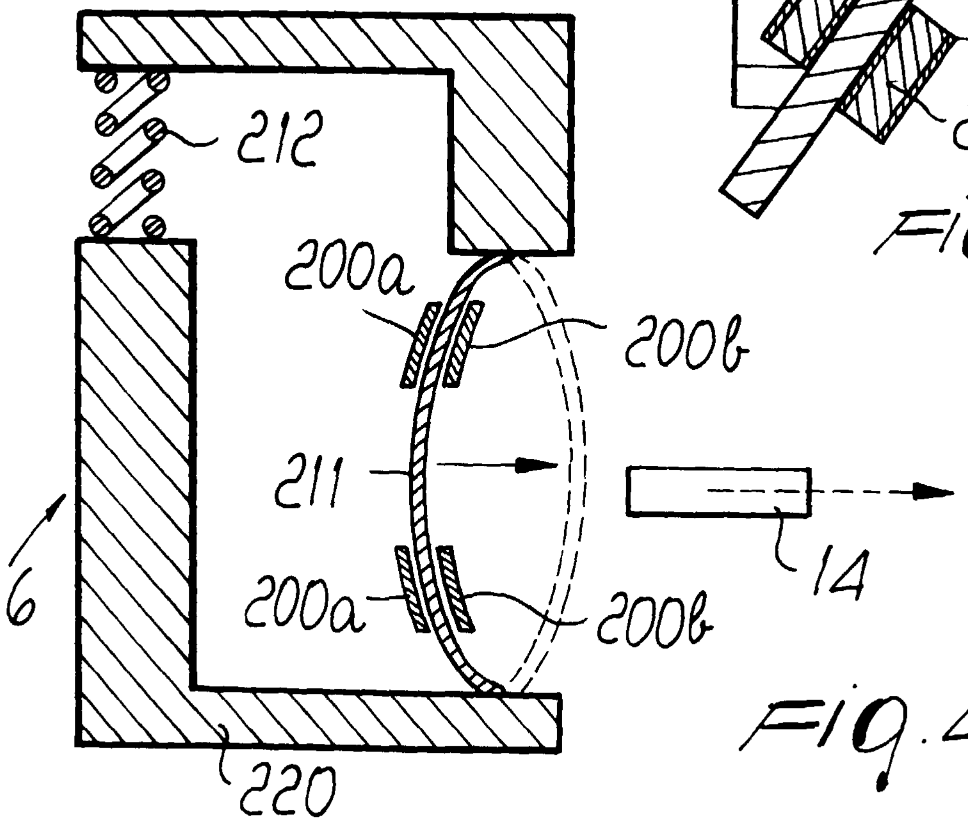

Fig. 4

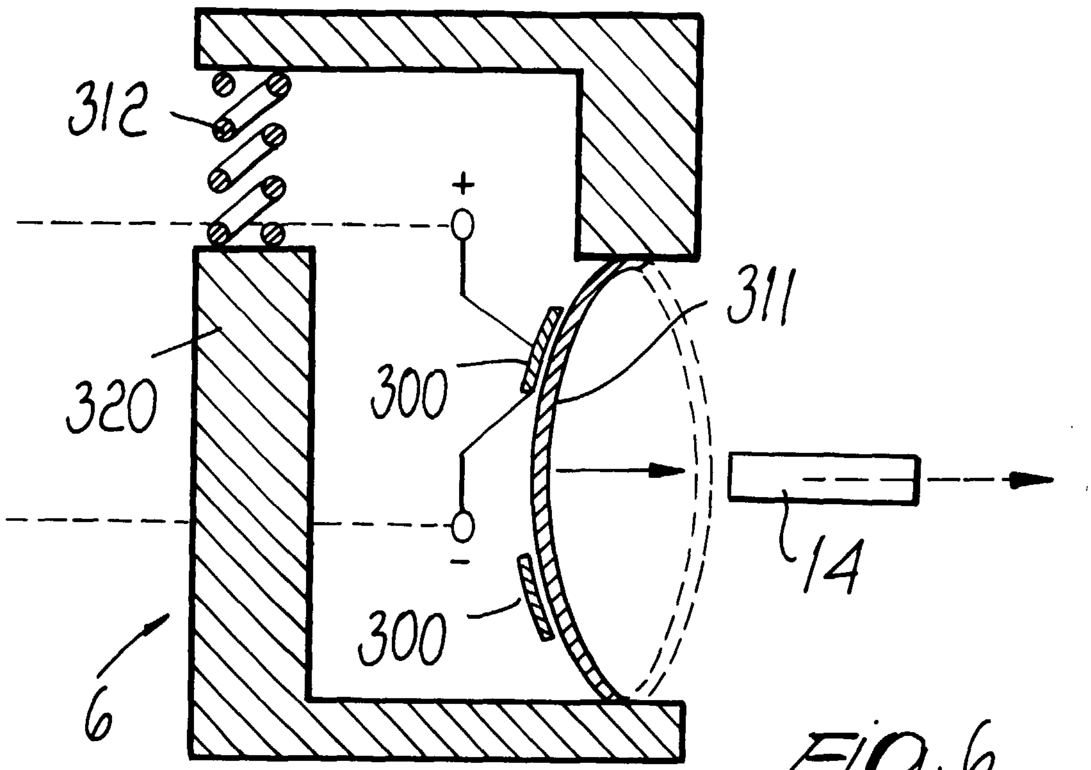

Fig. 6

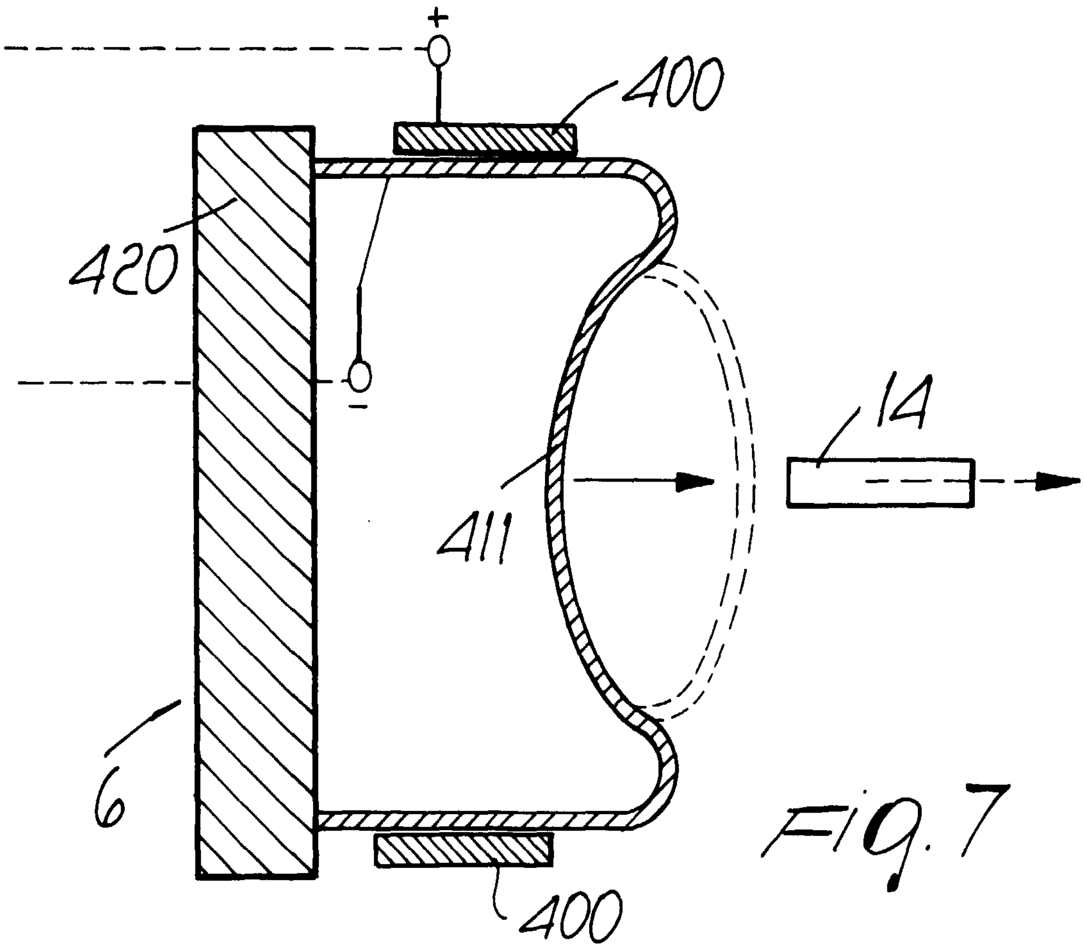

Fig. 7

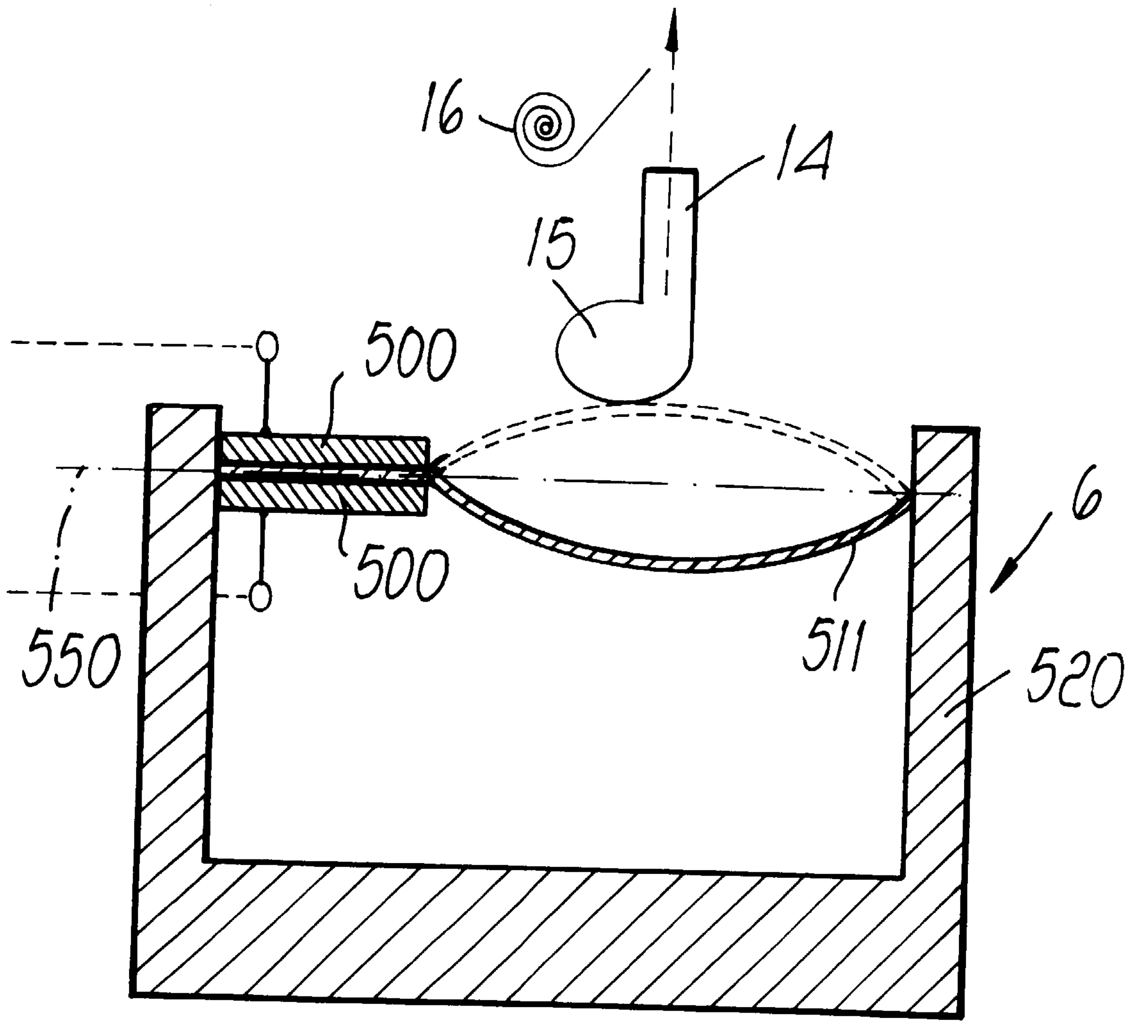

Fig. 8

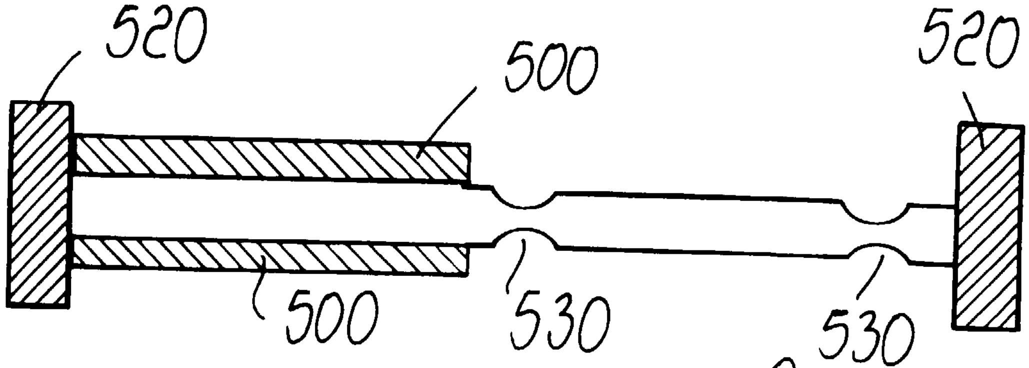

Fig. 9

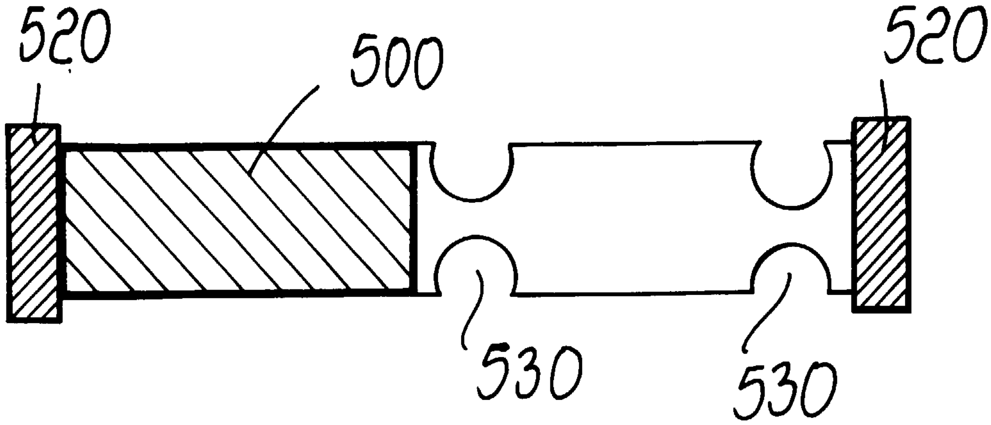

Fig. 10

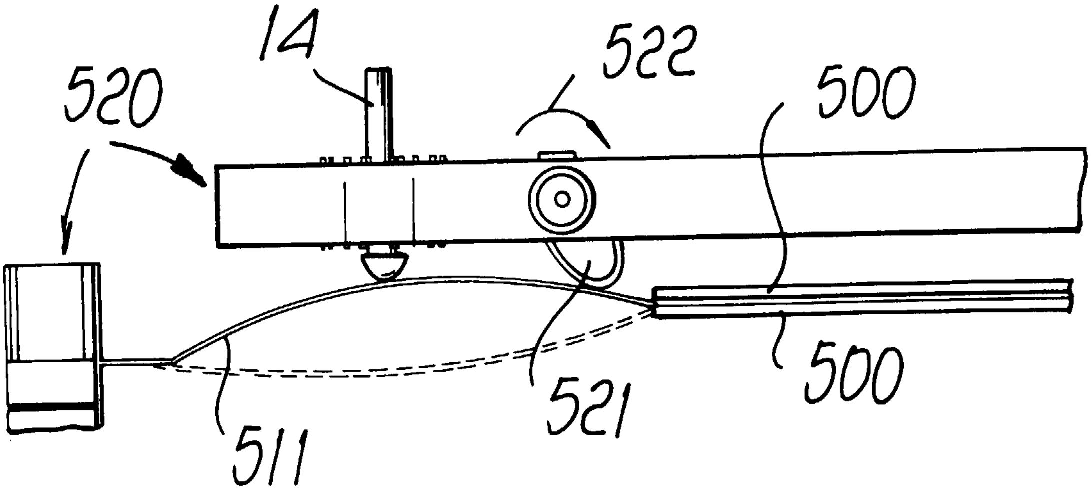

Fig. 11

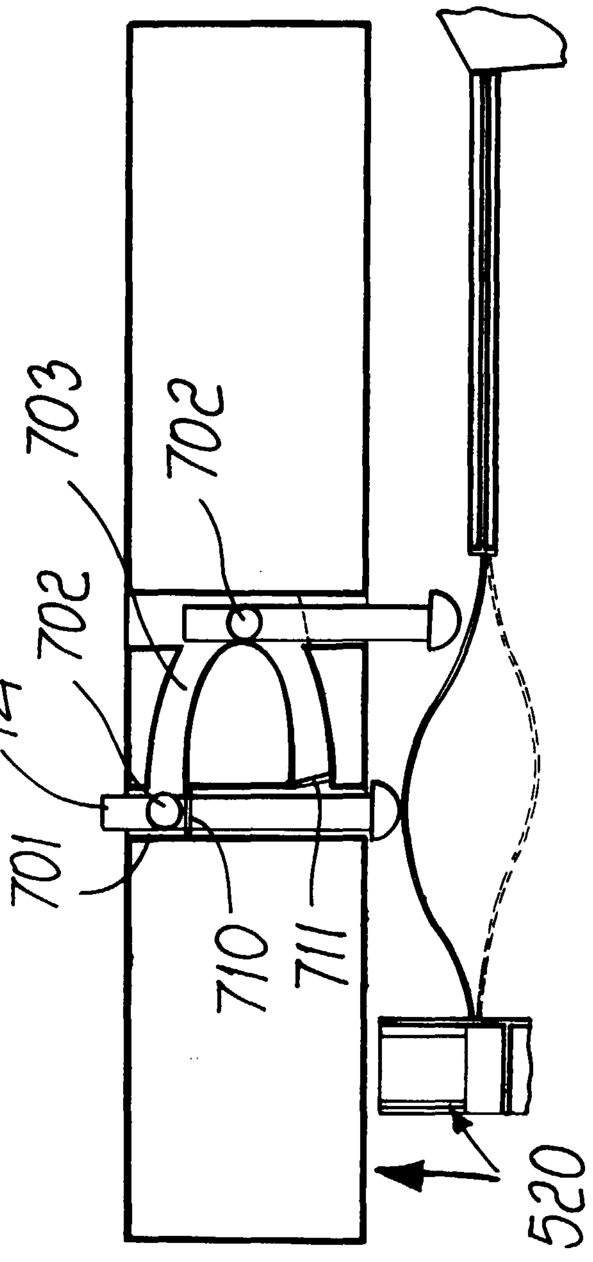

Fig. 12