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(54) Benævnelse: **Mikrosensor, der er i stand til at detektere en afstandsændring eller en cyklus af afstandsændringer mellem to punkter eller områder i en struktur når udsat for belastning**

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The present invention relates to the field of microsensors and more particularly relates to a microsensor able to detect, and preferably also to count, the number of cycles of variations in the distance between two points or regions of a structure subject to a repeated outside action, for example cycles of temperatures or mechanical stresses such as, for example, the number of passages of vehicles over a bridge, generating a known stress level in the structure.

In the field of road infrastructures, for example a bridge, it is important to know the number of vehicles having crossed it in order to determine the structural evolution thereof.

To that end, known is patent FR 2,875,324, which describes a vehicle passage counter primarily including a microphone positioned in an acoustic cavity and connected to means for processing the signals emitted by the microphone. The characteristic signal of a motor vehicle is thus detected by such a device.

Other devices are also known operating using ultrasounds, pressure sensors or image sensors and with which processing means are associated.

These devices have several drawbacks.

The first of them relates to their lifetime: it is limited, at most, to the lifetime of the power supply means, namely batteries, that is to say about one or two years.

The second relates to the impossibility of using them in complete pyrotechnic safety. Indeed, the presence of a difference in potential and therefore an electric current generates a risk of spark formation or short-circuit that may cause a fire or even an explosion in the presence of detonating materials.

The third relates to their sensitivity to the magnetic fields due to, in particular, the generation of currents induced in the electric circuits and the resulting deterioration of the electronic components.

Additionally, these sensors and the associated processing means are large, typically several tens of centimeters, which makes them highly visible and explains why they are subject to acts of vandalism.

The aim of the invention is to resolve these drawbacks by proposing a device for counting the number of stress cycles experienced by a structure that may for example correspond to the number of temperature cycles, of cycles of mechanical stresses in traction, compression and/or bending created, for example, by the passage of moving vehicles on the structure whereof, advantageously, the size does not exceed 5 cm for its largest dimension, and preferably 2 cm, and having a practically unlimited lifetime, able to be used in pyrotechnic safety, not having any sensitivity to electromagnetic fields and which allows error-free counting of this number of cycles or passages.

The provided solution is, according to a first feature, a passive and reversible sensor for deformations, along an OX direction, of a structure outside the sensor, such as during cycles of temperatures or mechanical stresses experienced by this structure, characterised in that the sensor comprises means for detecting and counting the cycles of variations in the distance between two points or regions of a structure, these means comprising a carrier having first and second parts each provided with an anchoring region, these anchoring regions being able to be respectively fixed to either of said two points or regions of the structure and being constituted by studs, notches and/or bores and being of sizes smaller than those of the first and second parts, the counting means being associated with each of said first and second parts of the carrier, the first and second parts of the carrier being connected to each another by at least one elastic member.

Reversible refers to a sensor capable of detecting a cycle of distance variations without becoming damaged, therefore able to detect another cycle.

Passive means refer to means operating without an energy source, unlike the so-called active means used in the aforementioned patent applications and that use an energy source, namely an electrical power source.

According to one particular feature, the studs, notches and/or bores have, along said direction OX, sizes smaller than those of the first and second parts.

According to another feature, this sensor is a microsensor.

According to one advantageous feature, a sensor according to the invention includes at least one of the following features:

the first and second parts of the carrier are connected to one another by a U-shaped third intermediate part,

the detecting and counting means have mechanical counting means that have at least one first toothed wheel.

According to one particular feature, this first toothed wheel is arranged on a first carrier or on a first part of a carrier and at least one driving beam is integral, at one of its ends, with a second carrier or a second part of said carrier and comprises, at its other end, at least one tooth able to mesh with said first toothed wheel.

According to another feature, a microsensor according to the invention comprises a non-return device associated with said first toothed wheel, this device being constituted by a beam integral, at one of its ends, with the first carrier or the first part of the carrier and comprising, at its other end, at least one tooth able to mesh on said first toothed wheel or in strips cooperating with an inner peripheral surface of the first toothed wheel.

According to another feature, the non-return device comprises a tooth able to mesh on said first toothed wheel, this tooth as well as that of the driving beam and those of said toothed wheel each comprising a radial surface and an inclined surface connecting the end of the radial surface of this tooth to the base of the radial surface of the following tooth.

According to a particular feature, a passive microsensor for detecting and counting comprises a carrier, primarily U-shaped, thus comprising a first part and a second part connected by a third part constituting the base of the U, and counting means arranged on the carrier and comprising at least a first toothed wheel arranged on one of the first and second parts and, on the one hand, a beam for driving this toothed wheel that is fastened, at one of its ends, to the other of the first or second parts and comprising, at its other end, a tooth able to constitute a gear with the teeth of the first toothed wheel, and on the other hand, a non-return device for the first toothed wheel and such that bringing the first and second parts closer causes the toothed wheel to be driven by the tooth of the driving beam while moving these two parts way causes the toothed wheel to be held by the non-return device and the tooth of the driving beam to be retracted onto a tooth of the first toothed wheel.

According to another feature, a microsensor according to the invention includes means able to limit the movement of the driving beam, for example made up of stops.

Other advantages and features of the invention will appear in the description of several embodiment variants of the invention and in light of the appended figures, in which:

figure 1 shows a diagram of one of the two main faces of the carrier of a microsensor according to a first embodiment variant of the invention,

figure 2 shows a diagram of the other main face of the carrier of a microsensor as well as counting means according to this embodiment variant,

figure 3 shows a simplified diagram of a sectional view along plane AA' of figure 1,

figure 4 more precisely shows the counting means in this embodiment of the invention,

figure 5 shows the deformations experienced by a sensor according to this embodiment of the invention when the structure, on which it is fastened, experiences a stress,

figure 6 more particularly shows counting means according to a second embodiment of the invention,

figure 7 shows a diagram explaining the operating mode of this second embodiment of the invention,

figure 8 shows a diagram of one of the two main faces of the carrier of a microsensor according to a third embodiment variant of the invention,

figure 9 shows a diagram of the other main face of the carrier of a microsensor as well as counting means according to this embodiment variant,

figure 10 shows a simplified diagram of part of the counting means and a non-return device and in particular comprising a first counting wheel,

figure 11 shows a diagram of the carrier according to figure 2 but without the counting means,

figure 12 shows a diagram of the intermediate part of the driving beam,

figure 13 shows a diagram of a second counting wheel of the counting means,

figure 14 shows a diagram of the numbering means of a first counting wheel in the context of this embodiment variant,

figures 15a and 15b show a diagram of the numbering means of a second counting wheel in the context of this embodiment variant,

figure 16 shows an example of positioning of a microsensor according to this embodiment variant on a structure capable of bending,

figures 17a and 17b show the operating principle of the microsensor according to the invention, figures 18a to 18e show diagrams of different successive positions of the driving and non-return teeth relative to those of the first counting wheel during the detection of the passage of a vehicle over the bent structure,

figure 19 shows a diagram of one of the two main faces of the carrier of a microsensor according to a fourth embodiment variant of the invention,

figure 20 shows the detecting and counting means according to this embodiment variant of the invention,

figure 21 shows the counting means according to this embodiment variant of the invention,

figure 22 shows an embodiment variant of a part of a microsensor according to figure 19.

Figures 1 to 3 show a sensor according to one embodiment and, respectively, the lower face 7, the upper face 8 and a view along section AA' of figure 1.

This sensor 1 comprises a carrier S comprising a frame-shaped first part 2 on which a first stud 6 is fastened that is intended to be fastened on a structure 15 undergoing deformation cycles, in particular in traction, compression or bending, for example due to a mechanical and/or thermal stress.

The carrier S also comprises a second part 3, also called shuttle hereinafter, with a rectangular shape and dimensions smaller than the inside of said frame 2. The first and second parts 2, 3 are secured to one another by four springs 4 arranged in the free space between these two parts 2, 3 and at each of the four corners of the second part 3. This second part 3 also comprises a second stud 5 arranged, in this exemplary embodiment, on the side opposite the upright of the frame 2 that supports the first stud 6 and is also intended to be fastened on said structure 15.

The studs 5 and 6 therefore constitute anchoring regions of the sensor 1 on the structure 15 to be monitored. The inner surface 14 of the frame 2 constitutes a stop for the shuttle 3.

As shown in figures 2 and 3, the second part 3 includes, on its upper surface, a cylindrical hub 10 secured to three strips 12 arranged tangentially to the hub 10 and around which a toothed wheel 11 is placed.

As shown in figure 4, this toothed wheel 11 includes teeth 16 on its outer peripheral surface 17 and an inner peripheral surface 19, preferably rough, intended to cooperate with said strips 12 to form a non-return device for the toothed wheel 11.

At least one driving beam 20, called beam hereinafter, integral with the first part 2 of the carrier S comprises a tooth 21 at its free end 22, this tooth 21 being able to form a gear, of the pawl type, with those of said toothed wheel 11.

In this figure, the direction OX indicates the direction of the relative movements of the first part 2 of the carrier relative to the second part 3 that are able to be counted by the counting means while the arrow indicates the normal direction of rotation of the counting wheel 11. Along this direction, each of the teeth 16 of this first toothed wheel 11 comprises a first radial surface 23 and an inclined surface 24 connecting the upper end 25 of said first radial surface to the base 26 of the radial surface of the following tooth. Along this same direction, the tooth 21 integral with the driving beam 20 includes an inclined surface 27 and a radial surface 28, the latter being located opposite said first radial surface 23 of a tooth 16 of the first counting wheel 11.

Thus, the tooth 21 of the driving beam has a driving face that comes into contact with the tooth of the counting wheel to pull this wheel during a movement in a direction of the driving element and a guide face allowing the sliding, and therefore the retraction, of the driving element on the tooth of the counting wheel during a movement in the direction opposite the previous one of the driving element.

The driving beam has a sufficient elasticity to allow the retraction of a tooth 16 without damage.

As shown in figure 5, when such a sensor is fastened, by both of its studs 5 and 6, on a structure 15 subject to a stress producing a deformation, for example an elongation only in the direction Ox, this deformation of the structure will create a variation of the separation between the studs 5 and 6, therefore of their respective centers. Let A and B be the respective centers of the studs 5 and 6 in their initial or normal position and xA and xB their coordinates along the axis Ox. When the structure 15 is subject to a stress, the separation between the studs varies and the points A and B are found in the extreme positions A' and B', the coordinates then being xA' and xB' while the studs return to their initial position, or slightly different, at the end of the stress or a certain length of time afterwards.

The difference in coordinates between the initial position and the extreme position is given by the following expression: $\Delta x = x A' - x A - (x B' - x B)$

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$\Delta y = 0$ according to the aforementioned hypothesis.

This difference in separation between the studs 5 and 6 causes a variation in position between the first and second parts, respectively 2 and 3. Since the toothed wheel 11 is integral with the second part 3 and the driving beam 20, the tooth 21 of which is meshed on the toothed wheel 11, is integral with the first part 2 of the carrier S, said position variation produces driving of the toothed wheel 11 by the driving beam 20 in the direction of the arrow. Since, in this exemplary embodiment, the relative movement of the tooth 21 of the driving beam 28 with respect to the second part 3 is of the order of magnitude of the pitch of the teeth 16 of the toothed wheel 11, namely, one and a half times greater, the toothed wheel 11 will be rotated by the tooth 21 of the driving beam 20, the respective radial faces 23 and 28 of the tooth n of the toothed wheel 11 and of the tooth 21 of the driving beam 20 being in contact. At the end of the stress, or a certain time afterwards, the studs, and therefore the corresponding carriers, will return to their initial position but the non-return device, made up of the strips 12 and second teeth 18 of the toothed wheel 11, prevents the toothed wheel 11 from rotating in the direction opposite that of the arrow while, due to its elasticity, the inclined face 27 of the tooth 21 of the driving beam slides over that of the tooth n+1 of the toothed wheel 11 with which it is in contact, until it passes the apex 25 of this tooth, the radial face 28 of the tooth 21 of the driving beam then being opposite the radial face 23 of tooth n+1 of the toothed wheel 11.

At the end of this cycle, the studs 5 and 6 have returned to their initial position while the toothed wheel 11 has rotated by one pitch of its teeth 16 in the direction of the arrow.

In summary, moving the studs 5 and 6 away from each other, due to a stress, causes the toothed wheel 11 to be driven by the driving tooth 21 of the driving beam 20 while bringing these two parts closer, at the end of the stress, causes the first toothed wheel

11 to be held by the non-return device 12, 19 and the tooth 21 of the driving beam 20 to be retracted on a tooth 16 of the first toothed wheel 11.

Thus, the detection by the microsensor of a cycle of distance variations is reflected by a rotation of the toothed wheel 11, references associated with this wheel making it possible to determine the number of cycles experienced by the structure from an origin, or between two given times.

Furthermore, it emerges from the preceding that to allow the counting of the number of cycles of deformations experienced by a structure, it is necessary to have a distance L between the studs determined precisely. This is why it is necessary to have small anchoring regions in the detection direction OX of the deformations. This is ensured by the presence of the studs 5 and 6, which allow a thin gluing e in the direction OX and with a greater height h in the direction Y perpendicular to OX, the small thickness of the studs 5 and 6 making it possible to determine said distance L precisely while the height h is sufficient to allow good strength of the gluing of the microsensor on the structure.

To allow a similar result by gluing, the studs can also be replaced by notches or bores.

In the absence of anchoring regions formed by studs, notches or bores, during pressing of the microsensor against the structure, the glue spots would spread out randomly and the length L between the two anchoring regions could assume any value. It would therefore not be possible to anticipate the operation of the microsensor for counting of the cycles of variations in the distance between two points A and B of a structure.

Furthermore, fastening modes other than gluing can be considered, such as the fastening of the microsensor on the structure by screws or by pins. To that end, each of the studs is replaced by at least one bore and preferably two bores positioned such that their diameter d is much smaller than the distance D separating their axis, for example $d/D<0.2$.

It can in particular be considered to fasten the sensor using prestressed pins. To that end, the sensor is prestressed in the plant by an outer frame that can also serve as packaging for the sensor. On the one hand, a bore is made on the carrier, with a diameter slightly smaller than that of the pin, so as to guarantee a tight fit between the pin and the carrier, and on the other hand, a bore on the structure, this time with a diameter slightly larger than that of the pin to allow the placement of the sensor and the take up of play.

After fastening on the structure, with a drilling gauge having an ad hoc center distance, the prestress is released. The “outer” generatrixes of the holes previously drilled in the structure allow a take up of play.

The movements induced by the structure are then transferred in full to the sensor.

Naturally, the sign of the prestress can be reversed if the sign of the stresses induced by the structure is itself reversed.

It can also in particular be considered to fasten the sensor on the structure using screws. This solution involves providing a bore on the carrier, with a diameter slightly larger than that of the screw, to allow its passage, and a tapping on the structure for screwing of the screw.

This fastening mode does not necessarily require prestress. It does, however, require immobilizing the moving parts during the tightening of the screws, since this may cause strain movements by friction. It can therefore be appropriate to use an outer cover to maintain the shape of the sensor. This cover immobilizes the moving parts during the placement.

It emerges from the preceding that the production of studs, notches or a bore as anchoring region makes it possible to determine, with precision, the distance L separating the anchoring regions and therefore to allow the counting of the cycles of variations in the distance between two points A and B of a structure. Knowing the characteristics of the deformation of the structure, and in light of the pitch P of the teeth of the counting wheel, the distance L between the anchoring points is determined such that during the deformation of the structure, the variation in the distance between the anchoring regions 5 and 6 is greater than the pitch P of the teeth of the counting wheel and preferably close or equal to 1.5.P.

From this description, it emerges that on the one hand the distance between the anchoring regions must be determined precisely, and on the other hand that the pitch of the teeth of the first input wheel must be of the order of magnitude of the relative movement of said parts 2 and 3 of the carrier S. The conventional techniques make it possible to produce toothings of several microns, but these can prove insufficient to capture submicronic movements. Yet the relative movements involved in mechanical compression or thermal expansion phenomena can be submicronic.

A principle of subdivision of the pitch is proposed so as to be able to record a relative movement smaller than the pitch of the teeth of the toothed wheel, in the context of a sensor 30 according to a second embodiment of the invention. This principle makes it possible on the one hand to increase the sensitivity of the sensor, since it makes it possible to access greater sensitivity levels than the periodicity of the geometric patterns at which the manufacturing technology makes it possible to arrive and on the other hand the use of less sophisticated techniques to produce the component, therefore resulting in a lower manufacturing cost and better robustness of the sensor. Figures 6 and 7 more particularly show a counting means with a subdivision of the pitch by 5.

As shown in figure 6, a sensor 31 according to this second embodiment of the invention includes a carrier S1 having a first part 32 and a second part 33, the latter having a cylindrical hub 34 secured to three strips 39 arranged tangentially to the hub 34 and around which a toothed wheel 35 is placed.

This toothed wheel 35 includes teeth 36 on its outer peripheral surface 37 and a cylindrical inner peripheral surface 38.

Five driving beams 40, integral with the first part 32 of the carrier S1 and arranged substantially parallel to one another, each comprise a tooth 41 at their free end 42, these teeth 41 being arranged at a distance from one another that is a multiple of the pitch P of the toothing of the wheel plus a fraction of this pitch, namely one fifth of this pitch, such that only one of these teeth constitutes a gear with teeth 36 of said toothed wheel 35. In general, the separation between two successive teeth of the beams 40 will be: E = I 1 . P I 2 . P / m

where

m is the number of beams,

I1 and I2 are integers

P is the pitch of the teeth 36 of the wheel 35 E = I 1 . P + I 2 . P / m

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with

m is the number of beams,

I1 and I2 are natural integers and: I 2 ≠ 0

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I 1 ≠ 0 if 2 I ≤ m Drawings available under “Original document”

And preferably, to allow Vernier indexing, I2≠m.

In this figure, the direction OX’, opposite OX, indicates the direction of the relative movements or displacements of the first part 32 of the carrier with respect to the second part 33 able to be counted by the counting means, while the arrow indicates the normal direction of rotation of the counting wheel 35. Along this direction, each of the teeth 36 of this first toothed wheel 11 comprises a first radial surface 43 and an inclined surface 42 connecting the upper end 44 of said first radial surface to the base 48 of the radial surface 43 of the following tooth. Along this same direction, each of the teeth 41 integral with the driving beam 40 comprises an inclined surface 46 and a radial surface 45, the latter being located, for one of the teeth 41, opposite said first radial surface 43 of a tooth 36 of the first counting wheel 35.

The driving beams 40 have a sufficient elasticity to allow the retraction of their tooth 41 on a tooth 36 of the first counting wheel 35, and without damage.

The inner peripheral surface 38 of the toothed wheel 35 and the end of said strips 39 are intended to cooperate to form an elastic means for accommodating the toothed wheel 35 on the hub 34, the friction force of the end of the strips 39 on the inner peripheral surface 38 of the wheel 35 being, on the one hand, greater than that which can be created by the driving beams when they are oriented in a first direction OX, thus driving a slipping of the teeth 41 of the beams 40 on the wheel 35 and, on the other hand, less than that which can be created by the driving beams when they are in a second direction OX’, opposite said direction OX, then driving a slipping of the inner peripheral surface 38 of the wheel 35 on the ends of the strips 39. The slipping of the wheel on the ends of the strips 39 is authorized by a correct sizing of the elastic means for accommodating the resisting torque relative to the possible shearing of the tooth 41 of the beam 40 or that, 36, of the toothed wheel 35.

Figure 7 shows a diagram of the operation of the counting means constituted by the beams, the toothed wheel 35, the hub 34 and the elastic means for accommodating the resisting torque and for which the second part 33 of the carrier S1 is assumed, in this example, to move relative to the first part 32 of the carrier S1 along the direction OX'.

The different phases are respectively numbered from 1 to 5 and from A to E.

In the phase A, the toothed wheel 35 has moved relative to the stationary beams 40. The beam 3 crosses the tooth shown darkened of the toothed wheel 35, and due to the geometric configuration of the teeth, prevents the return of the tooth, the beams 40 being shown in this first diagram just before crossing the tooth to clearly identify the sequences, instead of showing them after the crossing. The beams 4 and 5 are bent by the toothing. The beams 1 and 2 will also be bent during the next relative movement of the wheel.

The application of the next loading cycle of the phase B causes a second relative movement of the first wheel with respect to the stationary beams. This time, it is the beam 4 that passes another tooth of the toothed wheel 35 and prohibits this wheel from returning to a point of the toothing of the wheel other than that of the phase A.

Likewise, during the phase C, the beam 5 just crossed the toothing of the wheel and prohibits it from returning to a location other than that of the phase B. The same is true for the phases D and E.

During the next phase A, the beam 3 again crosses a tooth of the toothed wheel. This tooth is that which follows the one shown darkened in all of the diagrams. As a result, the five stress cycles are reflected at the first wheel by the meshing of a tooth, illustrating the principle of subdivision of the pitch, therefore the possibility of detecting and recording information with a resolution greater than that inherent to the system.

Such a device makes it possible to detect and count cycles of distance variation of less than 5 µm. By increasing the number of beams, distance variations of less than 1 µm can be detected and counted.

Figures 8 to 18 show diagrams of a third embodiment variant of the invention applied to the counting of the number of vehicle passages over a structure, for example a bridge.

Figures 8 and 9 show both of the two main faces of the sensor according to this third embodiment variant of the invention.

According to this embodiment, a passive microsensor for detecting and counting the number of vehicle passages comprises a carrier 101, primarily U-shaped, thus comprising a first part 102 and a second part 103 connected to one another by a third part 104 constituting the base of the U, and counting means 105 arranged on the carrier and comprising at least a first toothed wheel 106 arranged in said first part 102 of the carrier 101 and, on the one hand, a driving beam 107 for this first toothed wheel 106 fastened, at one, 108, of its ends 108, 109, to said second part 103 and comprising, at its other end 109, a tooth 110, shown in figure 10, and able to constitute a gear 111 with the teeth 112 of the first toothed wheel 106, and on the other hand, a non-return device 113 for the first toothed wheel 106 and such that bringing the first and second parts 102, 103 of the carrier 101 closer causes the toothed wheel 106 to be driven by the driving tooth 110 of the driving beam 107 while moving these two parts away causes the first toothed wheel 106 to be held by the non-return device 113 and the tooth 110 of the driving beam to be retracted on a tooth 112 of the first toothed wheel 106.

As shown in figure 8, the first and second parts comprise first and second anchoring regions, respectively 224 and 225, constituted by bores in each of which a screw can be inserted in order to fasten the microsensor on the structure to be analyzed such as, for example, the parapet of a bridge. The bores 224, 225 have a diameter slightly larger than that of said screws.

In this example embodiment, the first and second anchoring regions 224, 225 are respectively arranged along a first axis Y1 and a second axis Y2 that are parallel to one another and separated by a distance L. In a preferred manner making it possible to minimize the size of the sensor, these anchoring regions are arranged such that the length L is as large as possible and such that the deformation of the structure between the axes Y1 and Y2 is at least equal to P. Indeed, when the microsensor is fastened on a structure subject to a deformation, the variation in the distance between the two anchoring regions 224 and 225, therefore between the axes Y1 and Y2, is proportional to this length L. As a result, for a given pitch P of the teeth of the counting wheel, and in the case of the use of a single driving beam, the deformation of the structure between the axes Y1 and Y2 must be at least equal to P and preferably less than or equal to 1.5.P.

As shown in figure 9, the faces 133, 134 and 135 of the respective parts 102, 103 and 104 of the carrier 101 are planar and arranged in a same plane and intended to be pressed against the structure to be analyzed via said screws.

In this example embodiment, the third part 104 of the carrier itself has an inverted U shape with a thick base 136. This shape makes it possible to have sections at the branches of the U of this beam that are smaller than the base 136, and in the case where a substantial force was exerted at this third part, a break would occur at one of the branches and therefore in a direction parallel to that of the normal movement of the first and second parts, which makes it possible to avoid any relative movement between these parts in the normal direction of the movement and to avoid any offset between the toothed wheel 106 and the tooth 110 of the driving beam 107.

In figure 10, the arrow indicates the normal direction of rotation of the counting wheel 106. In this direction, each of the teeth 112 of this first toothed wheel 106 includes a first radial surface 114 and an inclined surface 115 connecting the upper end 116 of said first radial surface to the base 117 of the radial surface of the following tooth. In this same direction, the tooth 110 integral with the driving beam 109 comprises an inclined surface 118 and a radial surface 119, the latter being located opposite said first radial surface 114 of a tooth 112 of the first counting wheel 106.

This first toothed wheel 106 comprises 512 teeth, that is to say 2<9>.

Figure 11 shows one of the two main faces of the first part 102 of the carrier able to receive a part of the counting means 105. This surface 174 comprises several successive etchings 120, 121, 122, 123 and 124 comprising certain shared parts.

The first etching 120 is arranged in the upper part 125 of the first part and on the side of the first part 102 of the carrier. It is in the shape of a U with a thick base and one of the branches 126 is longer than the other 127.

The second etching 121 has an elongated rectangular shape arranged in the continuation of the first and in the direction of the side opposite the third part 104 of the carrier 101. However, this etching is not complete because a non-return device 113 remains arranged longitudinally over at least half of the length of the etching and fastened to the first part 102 of the carrier 101 by its end located at the transverse side 170 of the etching that is opposite the first etching 120.

The third etching 122 is cylindrical and arranged in the continuation of the second and below, i.e., toward the lower part 128 of the first part 102 of the carrier 101. However, the etching is not complete because a central cylindrical part 129 remains. This etching 122 is intended to receive the first counting wheel 106 and its diameter is slightly larger than that of the latter. Furthermore, the first counting wheel 106 comprises a central bore and the central cylindrical part 129 constitutes an axis for this first toothed wheel 106.

The fourth etching 123 is rectangular and comprises a lower part 31 of the third etching 122 and an upper part 132 of the fifth etching 124.

The fifth etching 124 is cylindrical with a diameter slightly smaller than that of the third etching 122 and arranged tangentially to the latter and in the direction of the lower part 128 of this first part 123 of the carrier. This etching 124 is intended to receive a second toothed counting wheel 130 and is not complete because on the one hand a central cylindrical part remains, intended to serve as rotation axis 155 for the second toothed counting wheel 130, and on the other hand three beams 171, 172 and 173 remain, respectively arranged at $\pi/2$ Rd and able to maintain in position and serve as non-return device for the second toothed wheel 30. The latter includes 16 teeth, that is to say 2<4>.

Figure 10 shows a diagram of the counting means and the non-return device. Thus, the following are shown:

the first toothed wheel 106 arranged on the axis 129,

the driving beam 107 integral with the second part 103 of the carrier 101 and comprising a tooth 110 able to constitute a gear 111 with those 112, of the first toothed wheel 106,

a non-return device 113 for the first toothed wheel 106, constituted by a beam 175 integral, by one of its ends 137, with the first part 102 of the carrier 101 and comprising, at its other end 138, a tooth 139 able to constitute a gear with those, 112, of the first toothed wheel 106. The arrow indicating the normal direction of rotation of the first toothed counting wheel 106, the tooth 139 of the non-return device comprises, along this direction, an inclined surface 140 and a radial surface 141, the radial surface 140 being face-to-face with a radial surface of a tooth 112 of the first toothed wheel 106.

As shown in this figure, the driving beam 107 and that, 75, of the non-return device are prestressed in bending on the toothed wheel 106 due to their positioning. Indeed, the end of the teeth is not tangential to the base of the teeth of the first toothed wheel 106 but tangential to a position located closer to the axis of this wheel. Since these beams cannot go past said base, they are automatically subjected to said prestress exerted by the first toothed wheel 106.

Figure 12 shows a detail of the intermediate part 143 of the driving beam 107 that is located at the first etching 120 of the first part of the carrier 101.

This intermediate part 143 is in the shape of a U whereof the base 144, and the two branches 145, 146, have substantially the same thickness, one, 145, of the branches being longer than the other and intended to penetrate the longest part of the branch 126 of the first etching of the first carrier 101 and which, as can be seen in this figure, includes two stops 147, 148 each facing one of the sides of the longer part 149 of the branch 145 of the driving beam.

The function of these protuberances is to limit the movement of the driving beam toward the first part of the carrier, by a calibrated value substantially corresponding to the value of a pitch and a half of the teeth 112 of the first toothed wheel 106. These protuberances thus constitute travel limiting means for the tooth 110 of the driving beam 107, or in other words, stops.

One can also see that the thickness of the driving beam past this intermediate part is first equivalent to that of this part, then smaller up to its end comprising the driving tooth 110, this smaller thickness being able to guarantee a sufficient elasticity to allow the driving of the toothed wheel 106 by the driving tooth 110 in an outbound direction and the retraction of this driving tooth 110 on those 112 of the first toothed wheel 106 in the return direction.

As shown in figures 9 and 13, a third toothed counting wheel 150 with a diameter smaller than the first toothed wheel 106 is fastened on the latter, these two wheels having the same rotation axis.

As shown in figure 9, said axis Y1 passes through the rotation axes of the first, second and third counting wheels as well as through the axes of the bores of the first anchoring regions. This axis Y1 is perpendicular to the direction X of the deformations of the structure that are able to be detected by the microsensor on which it is fastened.

This third toothed counting wheel 150 comprises a single tooth 151 in the form of a Gothic arch able to constitute a gear with those 152, in the form of a Roman arch, of the second counting wheel 130, these two wheels 130, 150 having the same thickness and being arranged in a same plane. This third toothed wheel 150 is arranged in the fourth etching 123 of the first part 102 of the carrier 101 and comprises a bore with a diameter substantially equal to the axis 155 emerging from the fourth etching. The length of the teeth 152 and 151 of the second and third toothed wheels 130 and 150 is such that when the tooth 51 of the third toothed wheel 150 comes into contact with a tooth 152 of the second toothed wheel 130, this contact persists over a length substantially equal to the pitch of the teeth 152 of the second toothed wheel 130.

Optical reading means of the barcode reader type are associated with the counting means in order to facilitate the reading.

As shown in figure 13, grooves 166 in parallel arcs of circle, in the case at hand no more than four, are associated with the teeth 152 of the second toothed wheel 130 and make it possible to number them in a binary manner, the tooth numbered 1 not comprising any associated groove, tooth number 2 having a groove at a first line 167, tooth number 3 having a groove at the second line 168, tooth no. 4 having a groove at each of the first two lines 167 and 168, etc., to the 16th tooth to which a groove corresponds at each of the four lines 167 to 170.

As shown in figure 14, which shows only a minute part of the first toothed wheel 160 in which the teeth have been considered to be arranged in a same plane, parallel grooves, in the case at hand no more than nine, are associated with the 512 teeth of the first toothed wheel 106 and make it possible to number them in a binary manner, the tooth numbered 1 not comprising any associated groove, tooth number 2 having a groove at a first line 156, tooth number 3 having a groove at the second line 157, tooth no. 4 having a groove in each of the first two lines 156 and 157, etc., up to the 512th tooth, which has a groove at each of the nine lines 156 to 164.

To read the number of vehicle passages between a time t0 and a time t1, an optical reading is done of the numbering of the teeth on each of the first and second toothed wheels 106 and 130 at the moment t0 then at the moment t1, the reader having the same position at these two moments. The image of the first reading at the time t0 is the reference reading that makes it possible to determine which tooth was engaged at the moment of the installation of the device. The second image is used to identify the tooth engaged at the moment t1, chosen by the operator. The identification of the engaged tooth can be done in an automated manner by importing the two images into an image processing software by generating a mask 177 delimiting the reading regions as shown in figures 15a and 15b. Each reading region will be either black if a groove is present and equivalent to 1, or white if there is no groove and then equivalent to 0, which makes it possible to calculate the binary number associated with the tooth. In the proposed example, the number 0000 is read in figure 15a associated with the second toothed wheel, corresponding to 0 in radix 10 and one reads 0001 in figure 15b, corresponding to 1x2<0>+ 0x2<1>+ 0x2<2>+ 0x2<3>= 1 in decimal base. This means that the structure has undergone (1 - 0) x 512 events, to which it is appropriate to add those counted on the first toothed wheel and which are determined in the same way.

All of the elements of this microsensor are made from silicon, which allows it to operate correctly irrespective of its operating temperature, since the expansions or constrictions that result therefrom will be the same in all directions for all of the components.

The operation of the device previously described is as follows:

It is first fastened, as shown in figure 16, for example with glue and by its planar surfaces 133 and 134 of the first and second parts of the carrier 101, on the parapet 181 of a bridge 100 comprising a roadway 180 on which vehicles travel.

This microsensor is positioned on the parapet on either side of a vertical virtual straight line CD. For a given position of the sensor on the parapet, the microsensor will not count the passage of the vehicle as a function of a threshold value corresponding to the mass of the vehicle. It will thus for example be possible to detect, with three identical sensors but positioned in different locations of the parapet, the number of passing vehicles with a mass greater than 500 kg for one, the number of vehicles of more than 3500 kg for the second and all of the vehicles of more than 10,000 kg for the other.

As shown in figures 17a and 17b, when a vehicle passes on the roadway 180 to the right, embodied by dashes, of the line CD, the weight thereof produces bending of the roadway that is passed on to the parapet, where the points A and B located on either side of the line CD move from their neutral position (figure 17a) to their respective extreme positions A' and B' (figure 17b) before returning to their initial position after the vehicle has passed. Therefore, when a vehicle travels on the road to the right of a microsensor according to the invention, it causes, due to its weight, bending of the roadway that results, on to the parapet of the bridge that is integral with it, in bringing the points A and B closer together. Let Ox and Oy be two orthogonal axes, the movement of the point A along the direction Ox is xA'-xA and that of the point B xB'-xB while the respective movements of the points A and B along the direction Oy are yA'-yA and yB'-yB.

In the context of the aforementioned exemplary embodiment, it is the difference in movement of the points A and B along the axis Ox, namely Δx = (xA'-xA) – (xB'-xB) that is involved to actuate the passive counting means, the point A being located on the first part 102 of the carrier 101 and the point B being located on the second part 103 of the carrier 101. Thus, Δx is greater than the pitch of the teeth 112 of the first toothed wheel 106 and preferably less than 2 times this pitch. In all cases, the stops 147, 148 are able to limit the movement of the first part of the carrier 101 relative to the second part by a distance Δx, relative to their neutral position, greater than the pitch of the teeth 112 of the first wheel 106, but less than two times this pitch.

Figures 18a to 18e show the evolution of the position of the driving tooth 110 relative to the teeth 112 of the first toothed wheel 106 for successive moments t0, t1, t2, t3 and t4, t0 and t4 corresponding to the equilibrium position and t2, the position where bringing the first and second parts 102, 103 of the carrier 101 closer is maximal.

In figure 18a, the first and second parts 102, 103 of the carrier 101 are in the neutral position. The radial face of the driving tooth 110 as well as that of the non-return device 113 are each opposite a radial face of a tooth, respectively 200 and 203, of the first toothed wheel 106, the opposite faces not being in contact.

When a vehicle begins to pass over the roadway 180 to the right of the line CD, the first and second parts 102, 103 of the carrier 101 begin to come closer together as shown in figure 18b. The radial face of the driving tooth 110 comes into contact with the radial face of the tooth 200, then pushes it in the direction of the arrow, which causes the first toothed wheel 106 to rotate. In parallel, the end of the non-return tooth of the non-return device 113 slips, due to the elasticity of the beam 175, on the inclined surface of the tooth 202 of the first wheel 106, this slipping occurring until this non-return tooth passes beyond the inclined surface and its radial surface is again located, as shown in figure 18c, opposite the radial surface of the tooth 202.

At this moment, either naturally, or due to the stops 147 148, said approach stops and one can see that the tooth 200 of the toothed wheel has assumed the initial position of the tooth 201, the wheel 106 having therefore rotated by a distance substantially equal to a pitch of the teeth of this wheel 106.

When the vehicle has passed the right side of the line CD, the first and second parts 102, 103 of the carrier 101 begin to move away to return to their neutral position. The inclined face of the driving tooth will come into contact with the inclined face of the tooth 199 and begin to rotate the first toothed wheel 106 in the direction opposite the arrow until the radial face of the non-return tooth 139 comes into contact with the radial face of the tooth 202. At this moment, the non-return device will prevent any additional rotation of the first toothed wheel 106 in the direction opposite that of the arrow. As shown in figure 18d, the end of the driving tooth 110 slips, due to the elasticity of the beam 107 at this level, on the inclined surface of the tooth 199 of the first wheel 106, this slipping occurring until this driving tooth passes beyond the inclined surface and its radial surface is again located, as shown in figure 18e, opposite the radial surface of the tooth 199.

At the end of this cycle, shown in figure 18e, the first and second parts 102, 103 of the carrier have assumed again their original position of figure 18a and only the first toothed wheel 106 is not in its original position, since it has rotated by the value of a pitch of its teeth and therefore of a tooth, this rotation thus making it possible to count each vehicle passage on the roadway and to the right of the line CD.

Figure 19 shows an exemplary embodiment of a sensor intended to be positioned on the lateral surface of the parapet of a bridge and able to detect and count the number of cycles of deformations of the parapet of a bridge that result in a cycle of variation in the distance (separation, then approach or the reverse) between two points A and B of the parapet that are preferably arranged horizontally and at a distance smaller than 3 cm from one another, wherein the distance variations could be for example between 15 and 100 µm. The sensor 300 comprises a first carrier 301 made from the same material as that of the parapet of the bridge, namely aluminum, this feature making it possible to cancel out the effect of the thermal expansions between the parapet and the sensor. This carrier comprises a first part 302 comprising first transverse notches 303 with an axis Y1 perpendicular to its longitudinal axis X, a second U-shaped part 304 comprising second transverse notches 305 with an axis Y2 perpendicular to the longitudinal axis X, and a third part 306 comprising, on the one hand, an intermediate part 307 integral with the first part and separated from the second part by a U-shaped groove 308 and continuing inside the U shape of the second part and on the other hand two U-shaped parts 309, 310 arranged transversely along an axis Y3 perpendicular to the longitudinal axis X of the carrier 301. The function of the two U-shaped parts 309, 310 is to maintain the positioning of the first part relative to the second part before and during the fastening of the sensor on the receiving structure, namely the parapet of the bridge. When the first and second parts of the carrier 301 are fastened on the receiving structure, even a damage of the two U-shaped parts or their removal does not prevent the sensor from working.

The first and second notches are intended to receive glue so as to fasten the carrier 301 on the receiving structure and thus to obtain stationary regions of narrow width and located at predetermined locations and allowing an optimal operation of the sensor.

Two cylindrical studs 311, 312 are each fastened in a bore provided in the second part of the carrier. Their function is to guide the positioning of the plate 314, here made of silicon and with a square shape. This plate comprises an L-shaped opening 315 whereof one of the ends 316 opens toward the middle of a first side 317 of the square while its other end 318 is located at the middle of the second side 319 of the square adjacent to the first side 317 but without opening on this second side, such that a thin width of material 320 remains at this level. Thus, this plate is made up of a first and a second part, respectively 321 and 322, second part whereof the width is substantially equal to that of the intermediate part 307 of the third part 306 and intended to be fastened on the latter.

Each of the first and second parts 321, 322 of the plate comprises an oblong opening 324 arranged with a transverse axis that coincides with the fastening axis Y2 of the second part 304 of the carrier 301 along said axis Y2, as shown in figure 21. These openings are intended to receive glue in order to fasten the plate 314 on the carrier 301, and more specifically to fasten the first part 321 of the plate 314 on the second part 304 of the carrier 301 and the second part 322 of the plate 314 on said intermediate part 307 that is secured to the first part 302 of the carrier 301, and thus to obtain fastening regions of narrow width and located in predetermined locations. Thus, when the plate 314 is positioned on the carrier 301 and then glued, the L-shaped opening 315 is located above said U-shaped groove 308 separating said intermediate part 307 from the second part 304 of the carrier 301. The part 320 is destroyed once the part 314 is glued on the carrier 301. It is used just for maintenance in position before and during the gluing phase.

As shown in figure 20, which shows the detecting and counting means according to this embodiment variant of the invention, a driving beam 329, which comprises a tooth 330 at its first end, has a second end that is integral with the second part 322 of the plate 314 at said first side 317 of the square. It extends parallel to the side of this second part 322 located on the side of said first side 317.

As shown in figure 21, which shows the counting means according to this embodiment variant of the invention, a toothed counting wheel 328, similar to that of figure 10, is mounted on a tubular bearing 331 comprising a shoulder 332 on which the toothed wheel 328 rests, this bearing 331 being able to rotate around a rotation axis 333 secured to the second part of the carrier 301 and such that the toothed wheel 328 forms, with the tooth 330 of the driving beam 329, a gear while the use of a complementary friction pad 335 makes it possible to obtain an assembly forming a pawl, as explained for example in the context of figure 4. The bearing 331 comprises protuberances 334 on its base that are capable of limiting the friction with the carrier 304 during its rotations. Preferably, in the neutral position, the tooth 330 of the driving beam 329 bears against the toothed wheel 328 and is thus prestressed. Such a sensor being intended to detect and count deformations of the structure along the direction X, the pre-stressing of the driving beam 329 makes it possible to offset deformations of the structure along the direction Y2.

With such a sensor, a deformation of the receiving structure in the direction X causes a similar deformation of the carrier of the sensor, therefore a separation (or approach) of the axes Y1 and Y2. This separation (or this approach) causes a relative movement of the first part of the carrier relative to the second part and therefore a movement of the tooth 330 of the driving beam 329 integral with the first part 302 of the carrier 301 relative to the toothed wheel 328, this movement causing the toothed wheel 328 to be driven in the direction indicated by the arrow. During the return of the receiving structure to its initial position, due to the presence of the pad 335 and to the shapes of the teeth of the driving beam 329 and the toothed wheel 328, the tooth 330 of the driving beam 329 retracts that of the toothed wheel, the latter thus remaining in the engaged position at the end of the rotation in the direction of the arrow, hence the analogy with a pawl.

In the case where the material of the carrier is different from that of the receiving structure, the compensation of the temperature can be done by adapting the length of the first part of the carrier and/or of said intermediate part such that the product of the distance separating the two gluing axes Y1, Y2 of the sensor on the receiving structure by the expansion coefficient of the component material of the receiving structure is equal to the product of the distance separating said gluing axis Y1 from the tooth of the driving beam by the thermal expansion coefficient of the carrier of the sensor.

Furthermore, by placing several identical sensors at different heights of the lateral surface of the parapet, it is possible to discriminate the types of vehicle passing over the bridge as a function of their mass. For example, a first sensor positioned lowest can count the passage of all of the vehicles whose mass is greater than 500 kg, a second sensor placed in an intermediate position can count the passage of all of the vehicles of more than 3 tons and a third sensor located even higher will only count the passage of vehicles of more than 10 tons.

Figure 22 shows a second embodiment variant of the plate 314 in which the first and second parts 321, 322 are secured by a U-shaped elastic intermediate element 340, said thin width of material 320 also having been eliminated. This intermediate element 340 makes it possible on the one hand to maintain the positioning of said first and second parts 321, 322 before and during gluing thereof on the respective parts 304 and 307 while its elasticity allows a relative movement of said first and second parts 321, 322 when the structure on which the sensor is fastened is subjected to a stress causing a variation in the distance between the points A and B of the sensor, this movement causing a rotation of the counting wheel via the driving beam 329.

The embodiments previously described have many advantages relative to the state of the art. Indeed, the microsensor is completely passive, and it is the event itself (action of an object able to bend a structure) that provides the necessary energy for activation of the detecting and counting functions.

In the present case, the microsensor is commissioned for a duration that is not limited by the lifetime of the energy source. In light of the very nature of the materials used, in the case at hand silicon, the life expectancy of the sensor is in any case much greater than that of all of the arming systems, including for passive systems stored for very long periods.

In the present case, the inert nature of the counter makes it possible to consider applying it on a system operating in pyrotechnic safety, which procures a considerable advance relative to the current capacities. Furthermore, a microsensor according to the invention is completely insensitive to electromagnetic fields.

Furthermore, the proposed solution is very simple to implement and its operation is very reliable. It is independent of a power source, it is discrete and has a low unit cost.

In addition, when the counting means comprises several beams that are able successively to drive the toothed wheel in a same direction, these beams can be arranged on the same side of the toothed wheel like in figure 6 or, for example, partially on one side and partially on the other without the operation of the device being changed as a result. Furthermore, the teeth of said beams can be placed at the same distance from one another or at different distances while respecting the separating formula E given in the description.

Furthermore, the tooth of the non-return beam as shown in figure 10 can be replaced by a friction pad able to apply a friction force on the toothed counting wheel. It plays a double role. In both cases it is the friction force of the pad on the wheel that allows it to play its role. This friction force is determined by the prestress of the pad beam. It limits on the one hand an excessive rotation due to inertial effects of the counting wheel in the normal direction of rotation. It on the other hand prevents a rotation of the counting wheel in the direction opposite the normal direction during the return of the driving tooth, as long as the friction force of the pad is greater than that of the driving beam on the wheel.

Furthermore, in the case where one wishes to make up for the differences in thermal expansions between the sensor and the structure, it is on the one hand preferable to make the carriers of the sensor from a material whereof the thermal expansion coefficient is close to that of the material of the structure, and on the other hand to compensate this thermal expansion geometrically, via the shape of said first and second parts of the carrier and the positioning of the counting wheel.

Krav

1. Passiv og reversibel sensor af deformationer langs en OX-retning af en struktur (15) uden for sensoren, især under temperaturcyklusser eller mekaniske spændingscyklusser, som denne struktur udsættes for, **kendetegnet ved at** sensoren omfatter midler til at detektere og tælle variationscyklusserne i afstanden mellem to punkter eller områder i en struktur, hvor disse midler omfatter:

- en bærer (S; 101) med første og anden dele (2, 3; 102, 103), som hver besidder et forankringsområde (5, 6), hvor disse forankringsområder er i stand til at blive fastgjorte til et respektivt af det ene og det andet af strukturens (15) nævnte to punkter eller områder, og udgøres af kontaktstykker (5, 6), hak og/eller boringer (224, 225), og har mindre dimensioner end dem for de første og anden dele, tællemidlet er forbundet med hver af bærerens nævnte første og anden dele,
- mekaniske detekterings- og tællemidler besidder mindst ét første tandhjul (11; 106) anbragt på bærerens (S) første del (2) og mindst én drivstang (20; 107), som ved én af dens ender er fast forbundet med nævnte bærers anden del (3; 103), og som ved sin anden ende omfatter mindst en tand (21; 110), der er i stand til at indgribe med nævnte første tandhjul (11),
- en returspærreindretning (12; 113) forbundet med nævnte første tandhjul,

bærerens første og anden dele (2, 3) er forbundne med hinanden med mindst ét elastisk element (4), returspærreindretningen (113), som er forbundet med nævnte første tandhjul (106), omfatter en stang (175), som ved én af dens ender er fast forbundet med bærerens (101) første del (102), og som ved dens anden ende omfatter mindst én tand (139), som er i stand til at indgribe med dem på nævnte første tandhjul (106), denne tand såvel som den (110) på drivstangen og dem (112) på det første tandhjul (106) omfatter hver en flade arrangeret på en radius af dette tandhjul (106) og en flade vinklet i forhold til denne radius.

2. Sensor ifølge krav 1, **kendetegnet ved at** denne sensor er en mikrosensor.

3. Sensor ifølge krav 1, **kendetegnet ved at** bæreren (101) er U-formet.

4. Sensor ifølge krav 3, **kendetegnet ved at** den omfatter en bærer (101), som i det væsentlige er U-formet, og således omfattende en første del (102) og en anden del (103) forbundne med en tredje del (104), som udgør U'ets base, og **ved at** det at bringe

bærerens første og anden dele tættere på hinanden forårsager, at det første tandhjul drives af drivstangens (107) tand, mens det at bringe disse to dele væk fra hinanden forårsager, at det første tandhjul (106) holdes ved hjælp af returspærreindretningen (113), og at drivstangens (107) tand trækkes tilbage på en tand på det første tandhjul (106).

5. Sensor ifølge krav 3, **kendetegnet ved at** alle elementerne deraf er lavet af silicium.

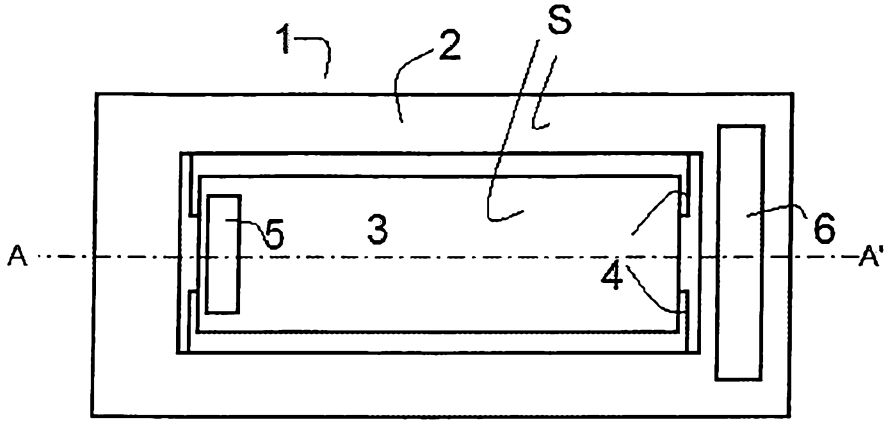


Fig.1

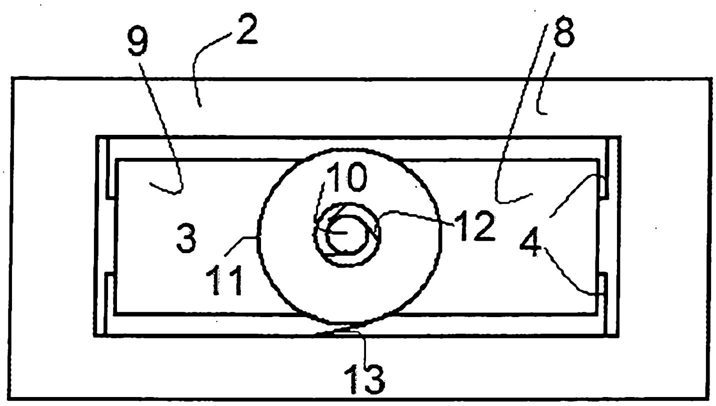


Fig.2

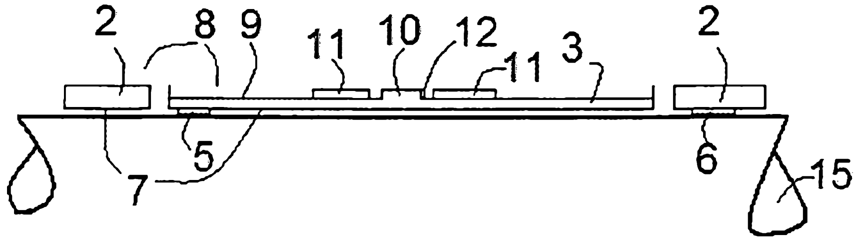


Fig.3

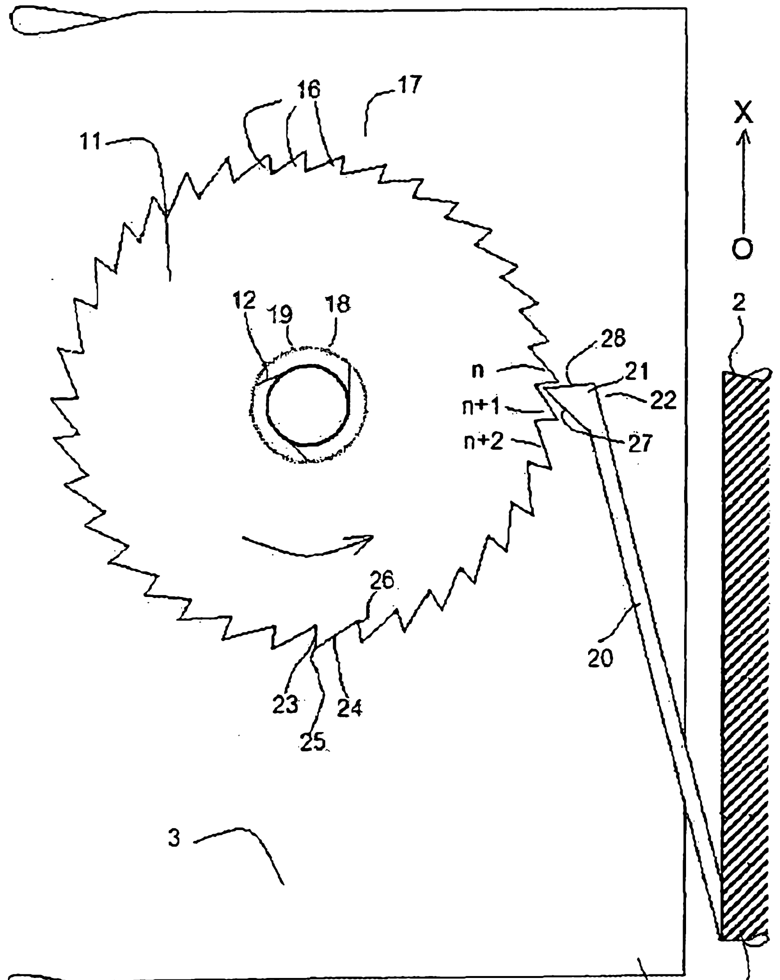


Fig.4

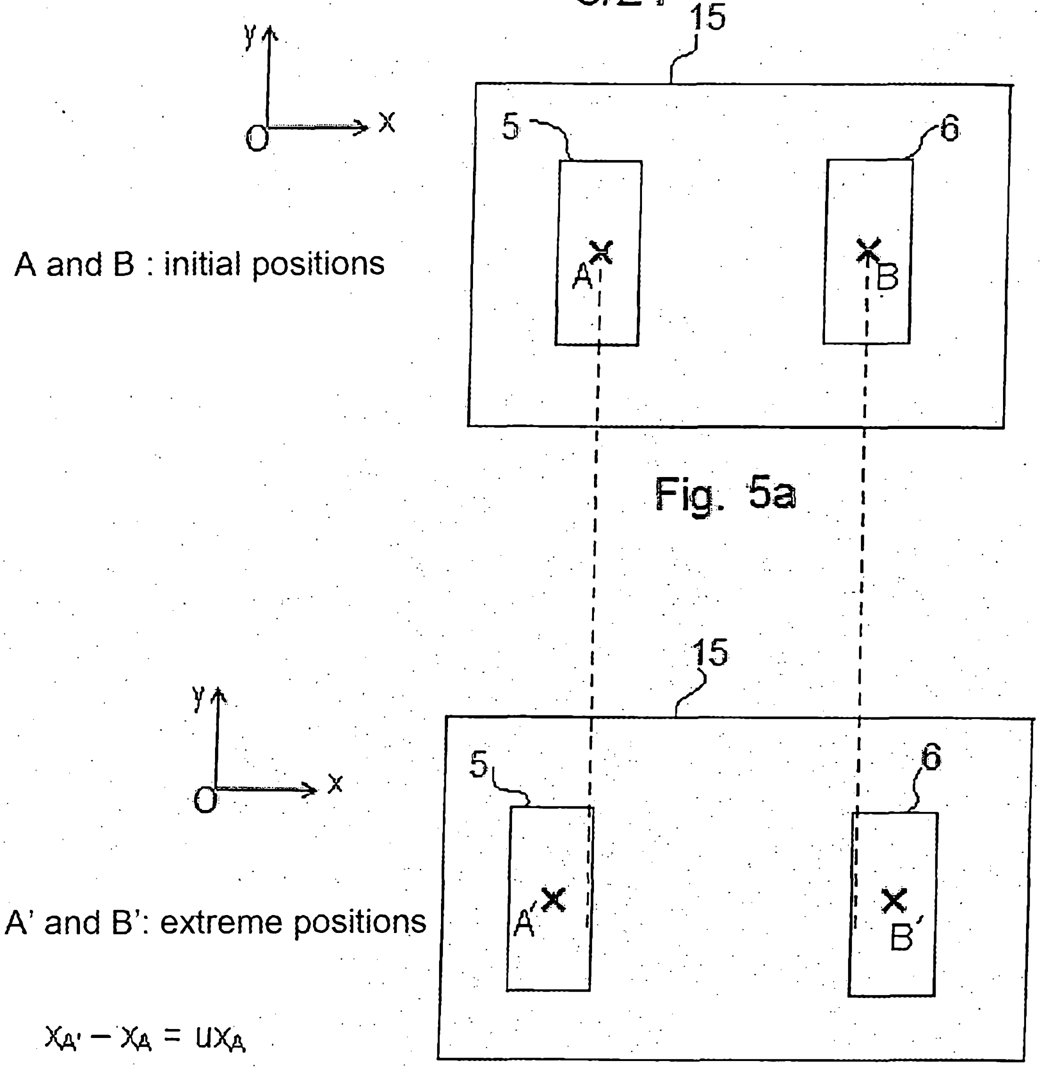


Fig. 5a

$x_{A'} - x_A = ux_A$

$x_{B'} - x_B = ux_B$

$\Delta x = (x_{A'} - x_A) - (x_{B'} - x_B)$

$\Delta y = 0$

Fig. 5b

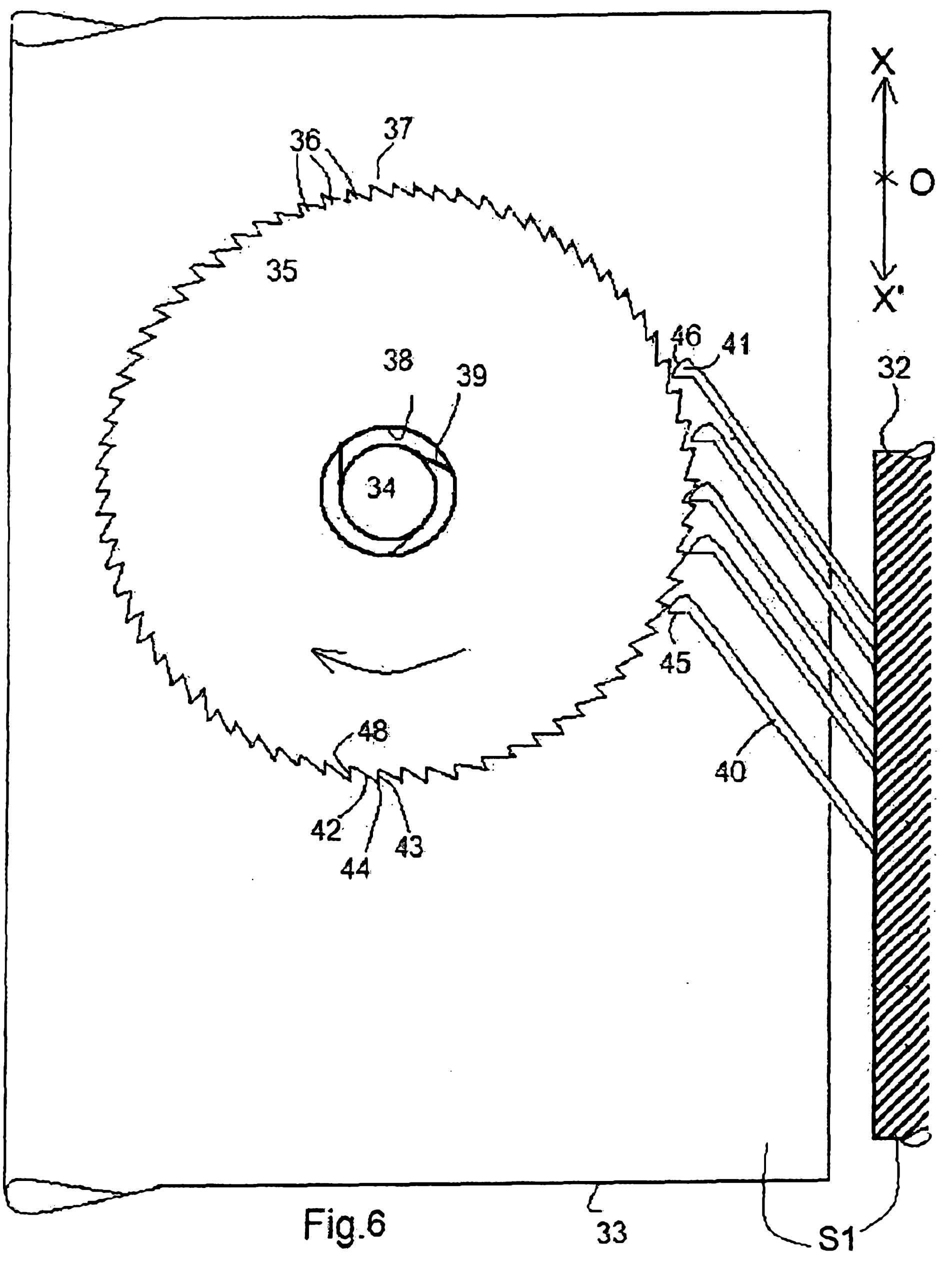


Fig.6

Event sensor without energy source

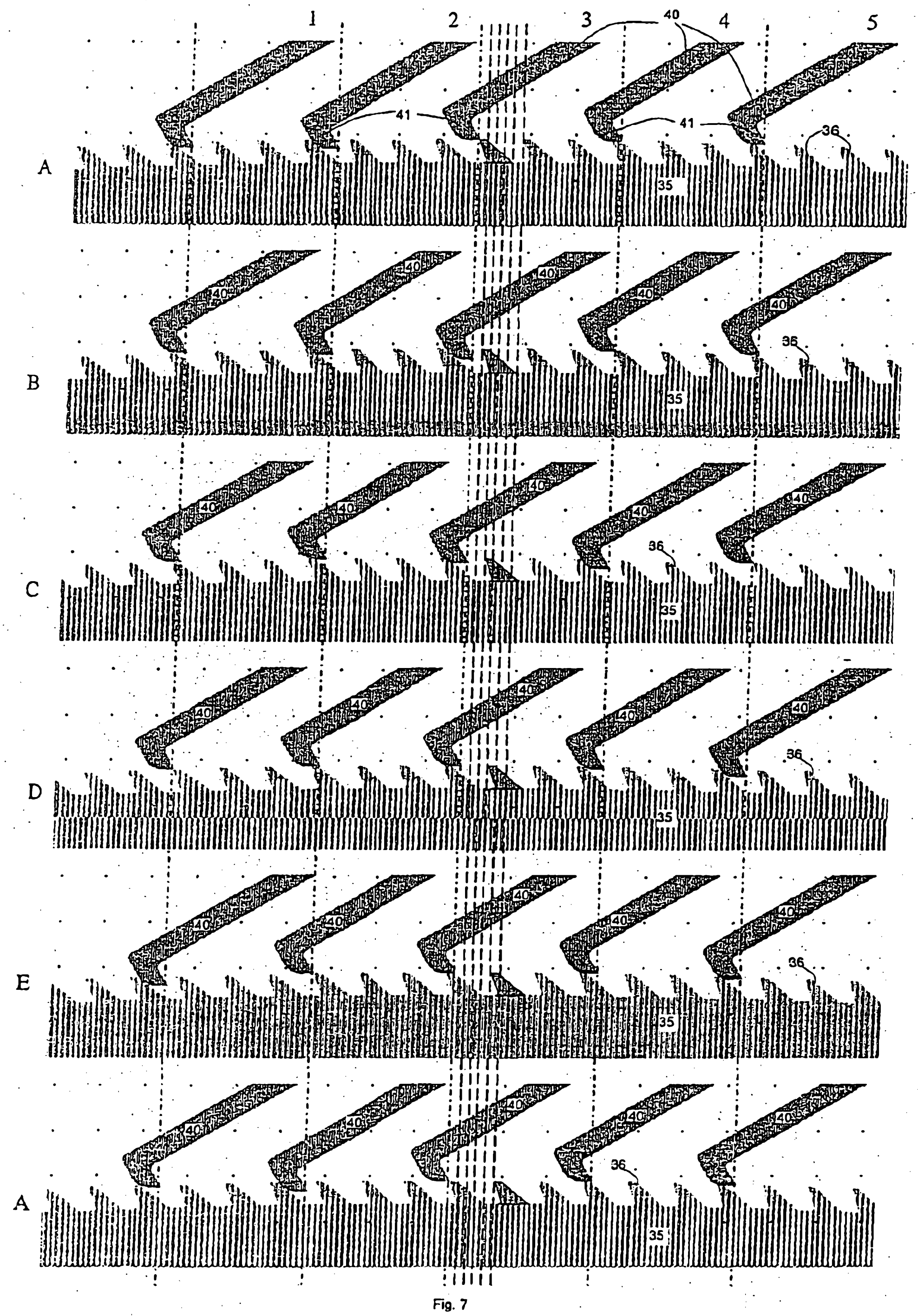


Fig. 7

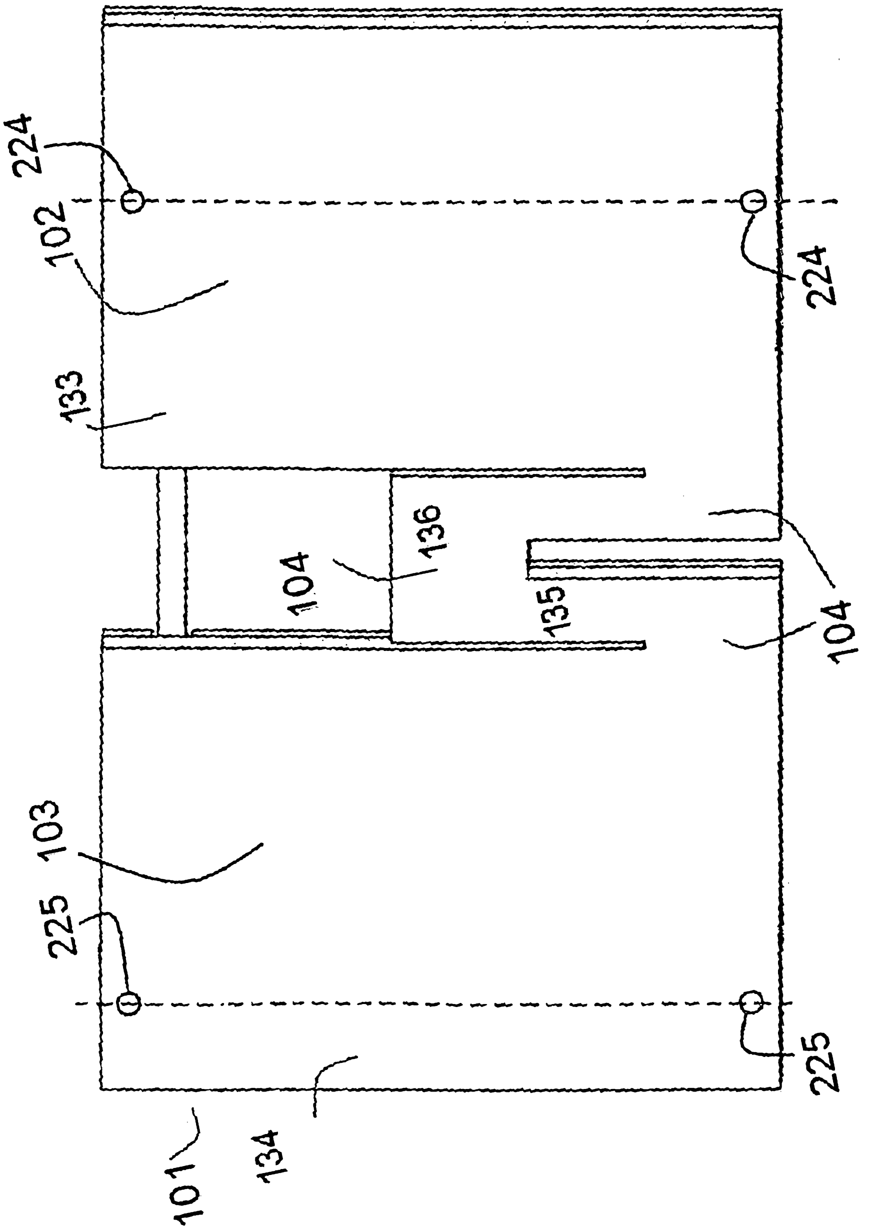


Fig. 8

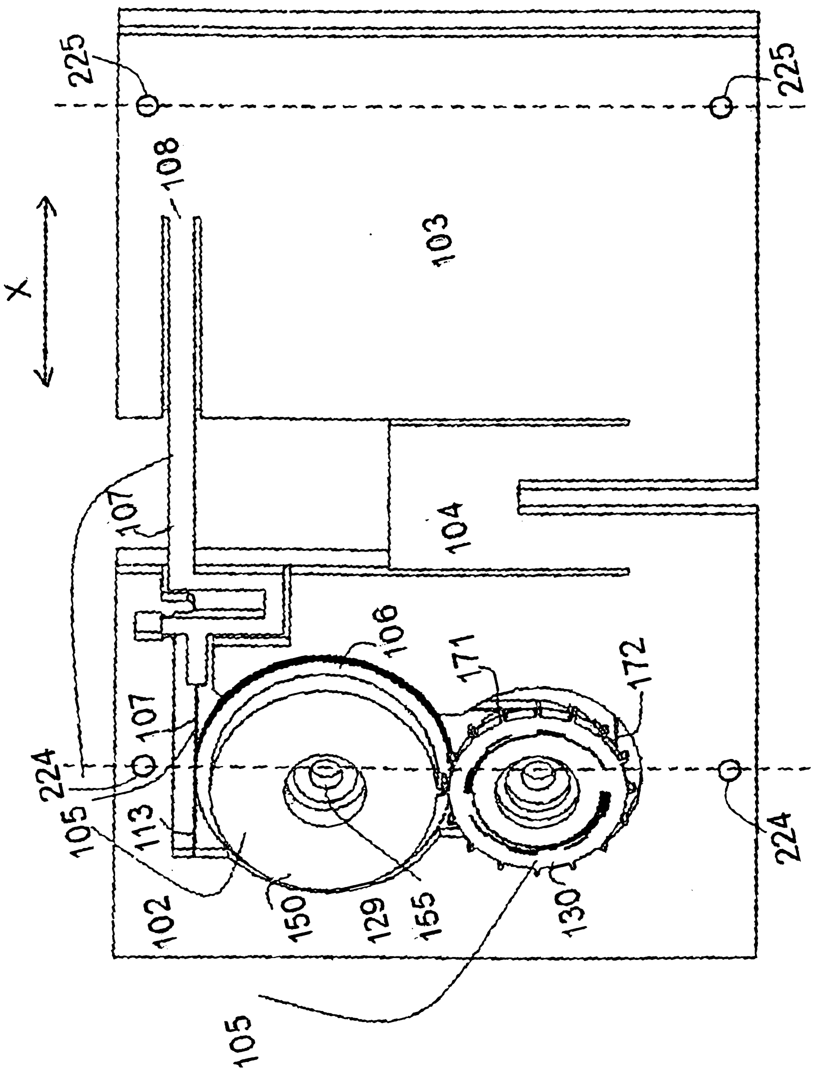

225
225
108
X
103
107
104
106
171
172
107
224
105
113
102
150
129
155
130
224
105

Fig. 9

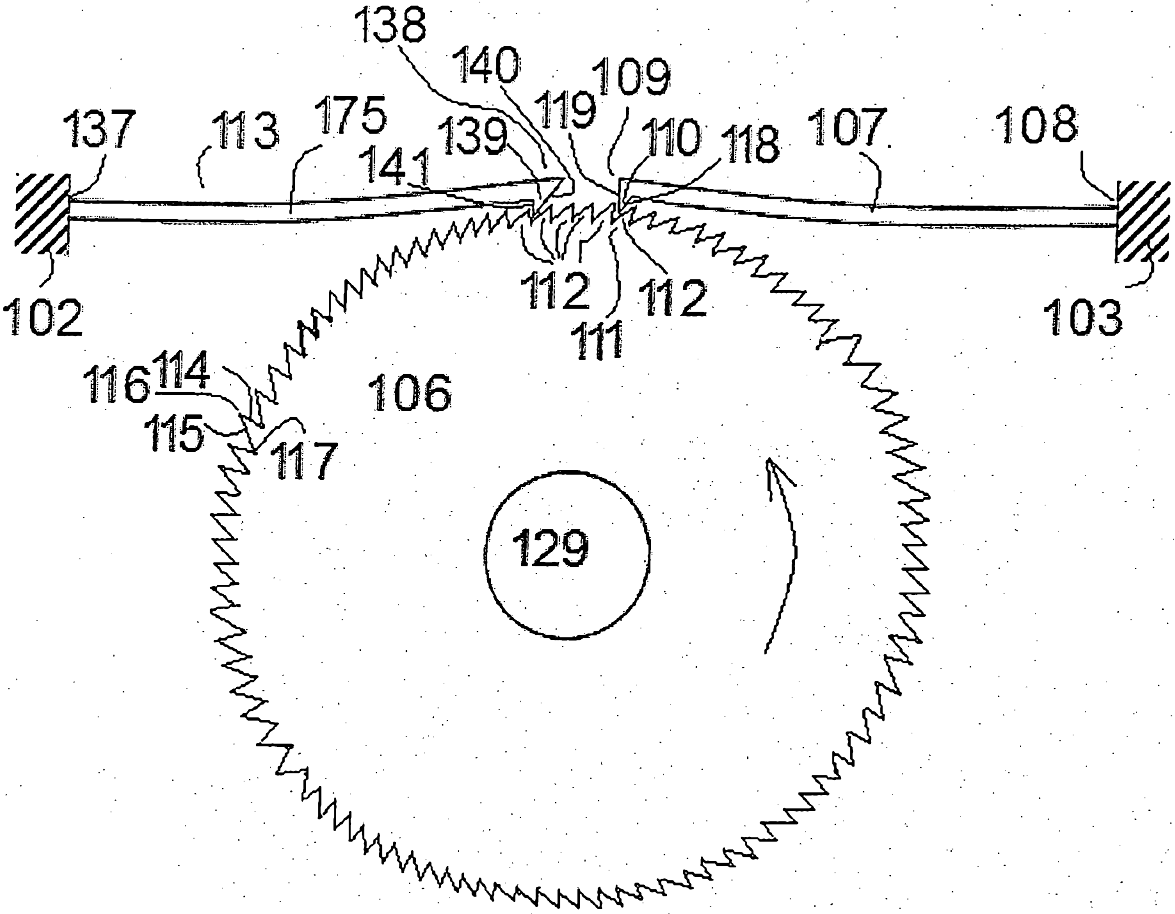

138
140
109
119
137
113
175
139
110
118
107
108
141
102
112
112
103
111
116
114
106
115
117
129

Fig. 10

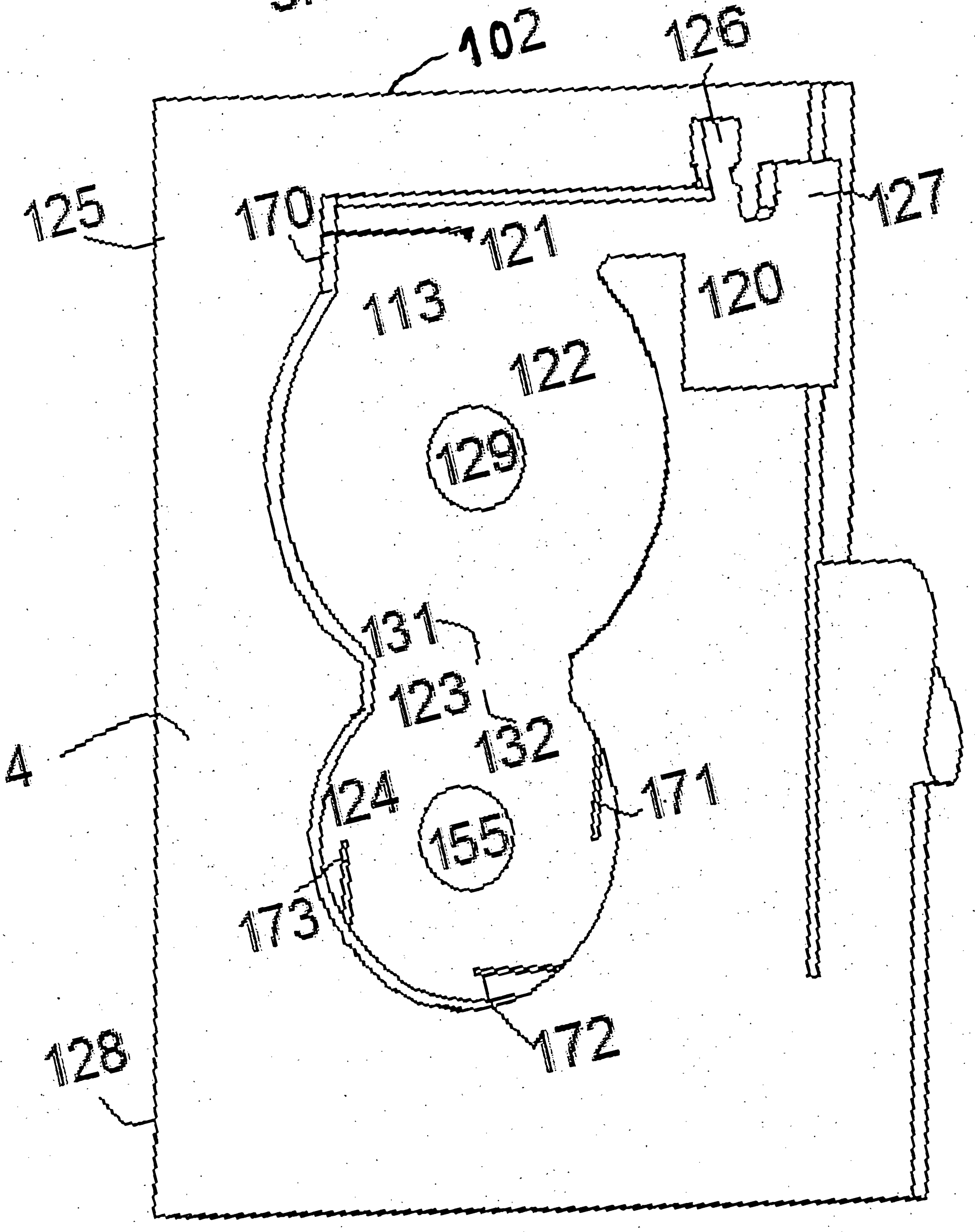

102
126
125
170
121
127
113
120
122
129
131
123
132
174
124
155
171
173
172
128

Fig. 11

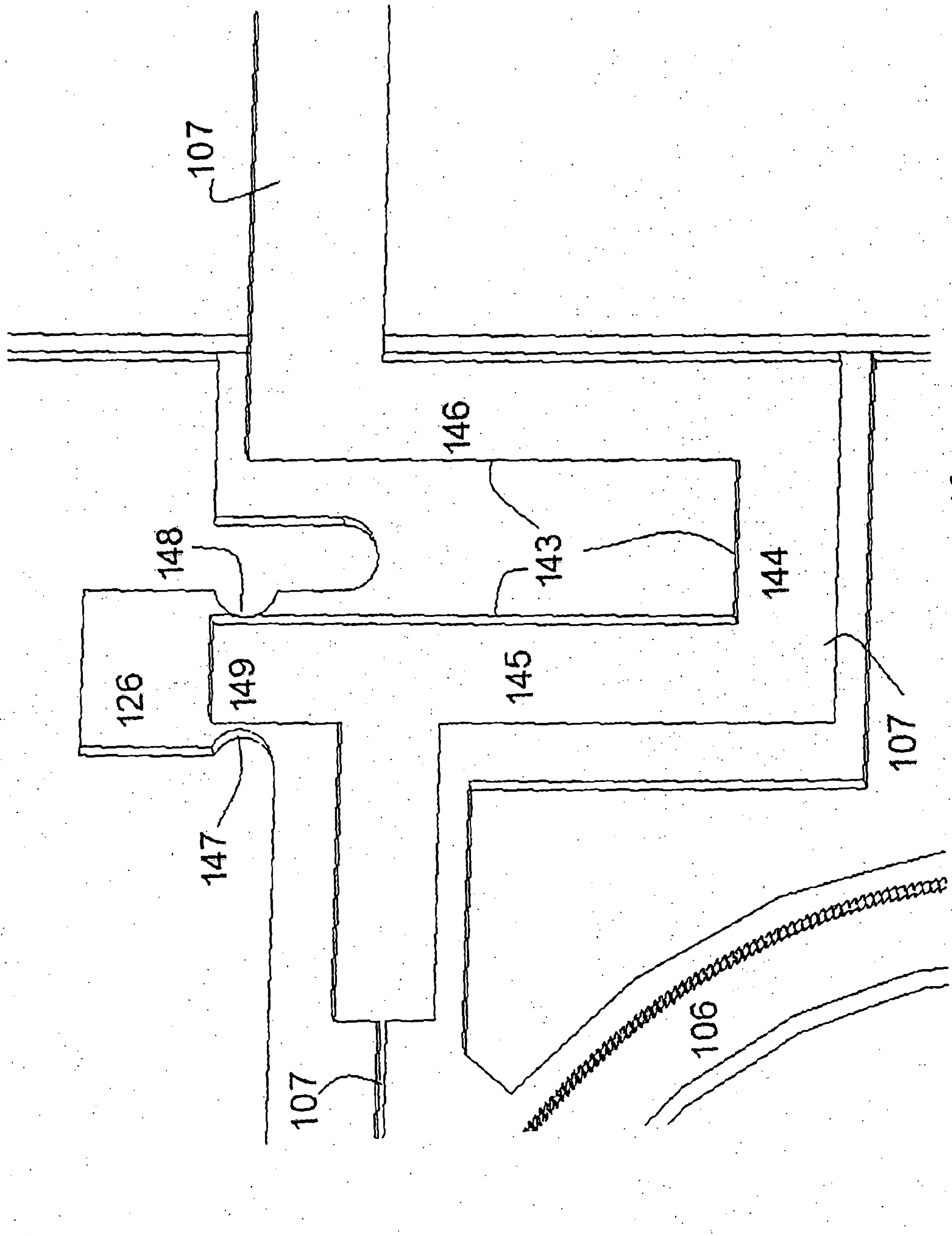


Fig. 12

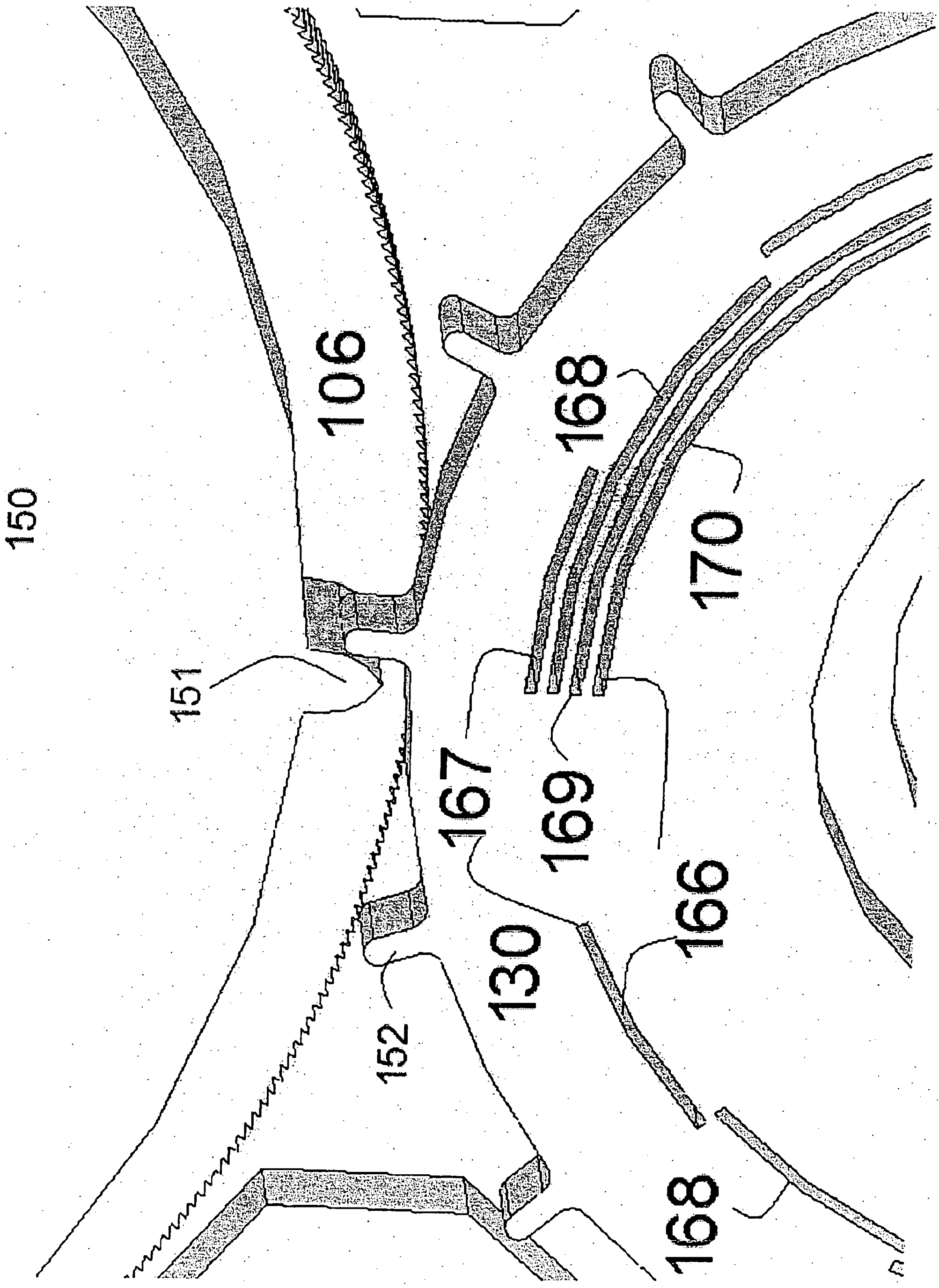


Fig. 13

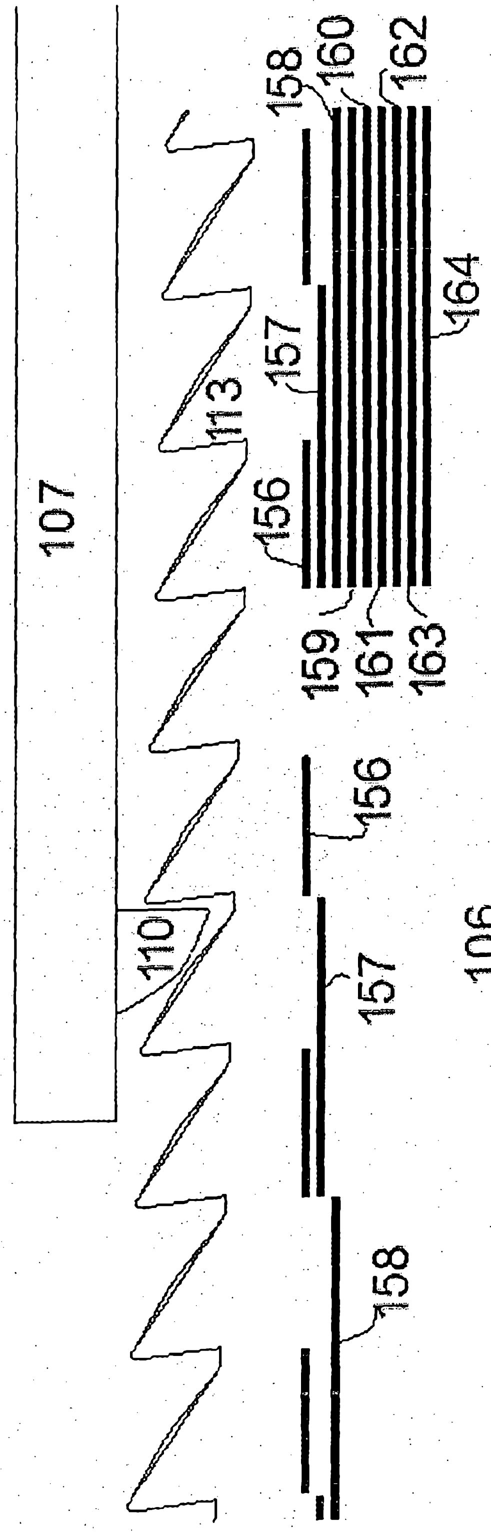


Fig. 14

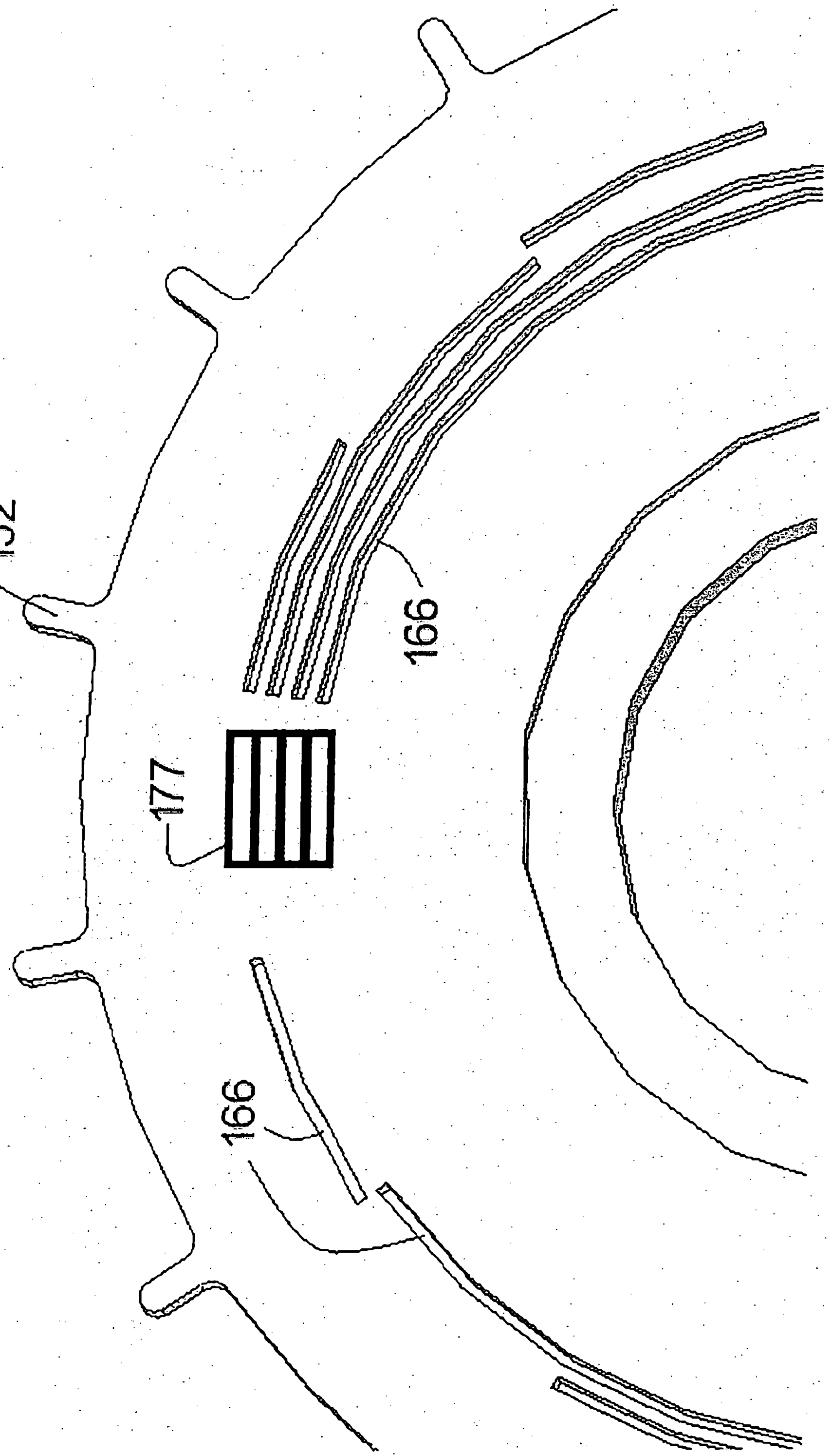


Fig. 15a

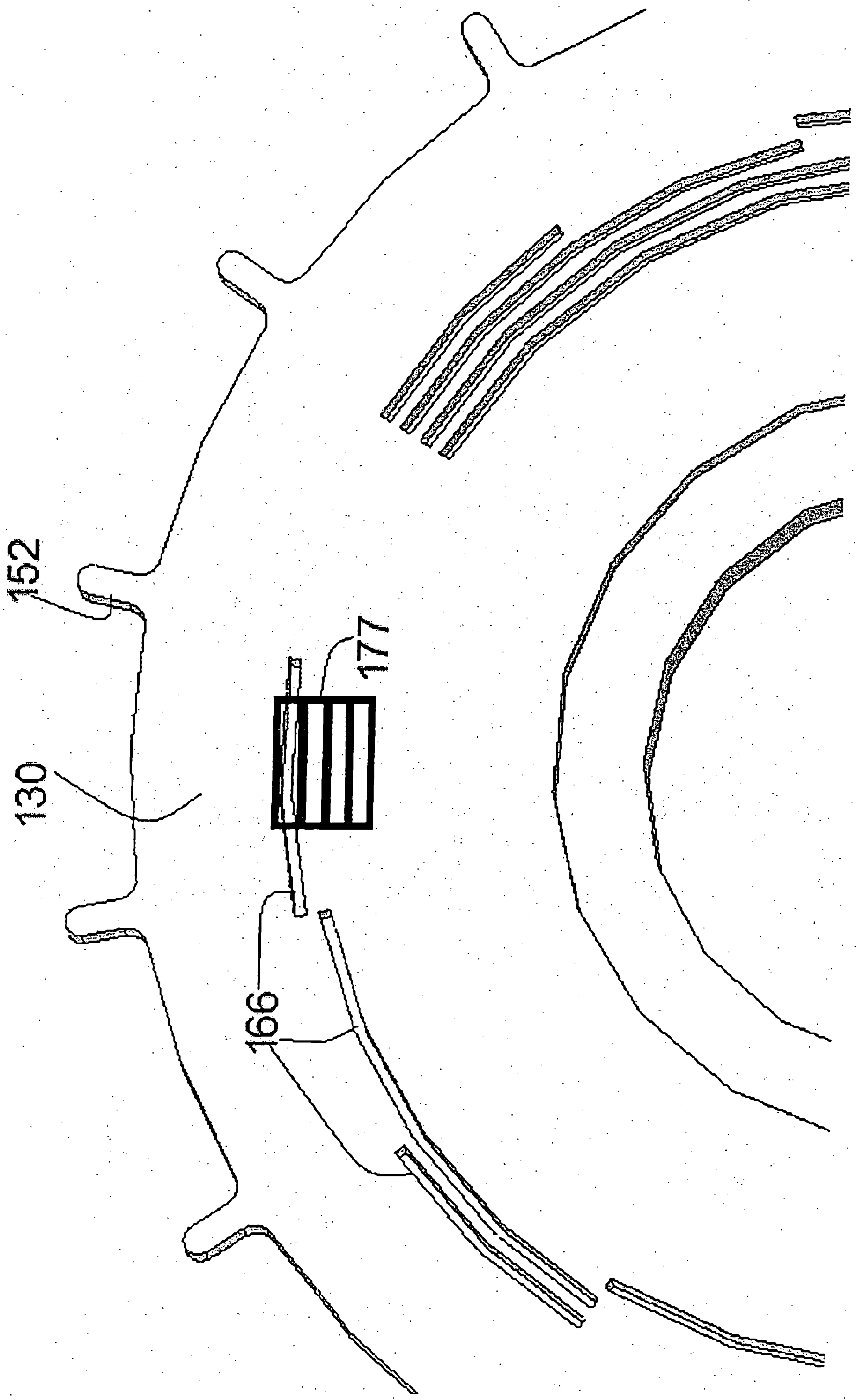


Fig 15b

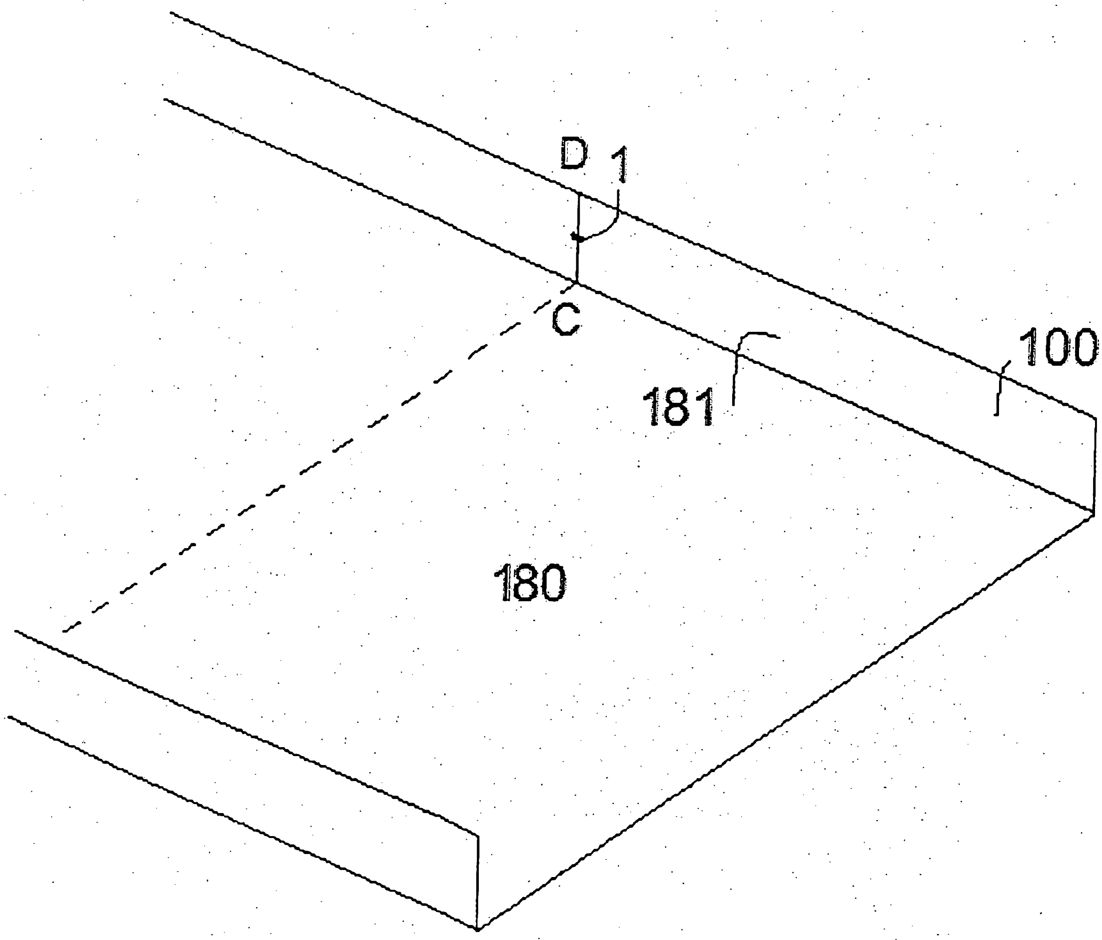


Fig. 16

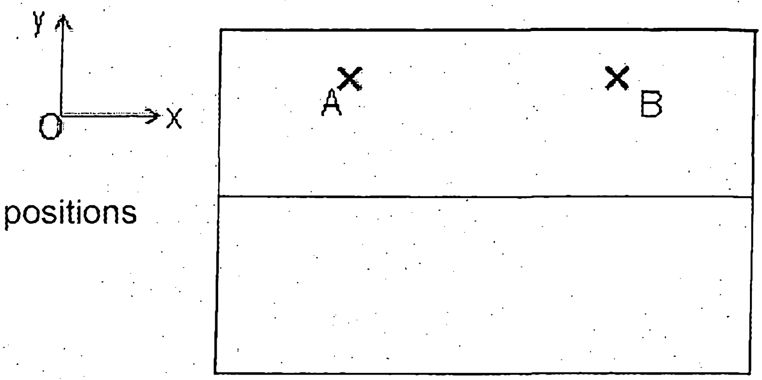
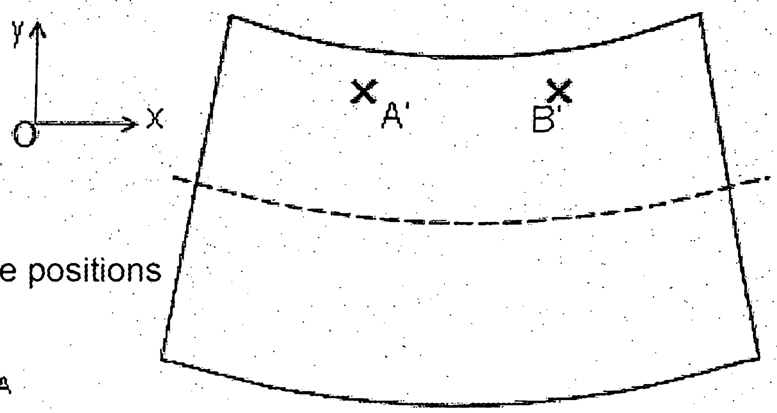


Fig. 17a



$x_{A'} - x_A = ux_A$

$x_{B'} - x_B = ux_B$

$\Delta x = (x_{A'} - x_A) - (x_{B'} - x_B)$

Fig. 17b

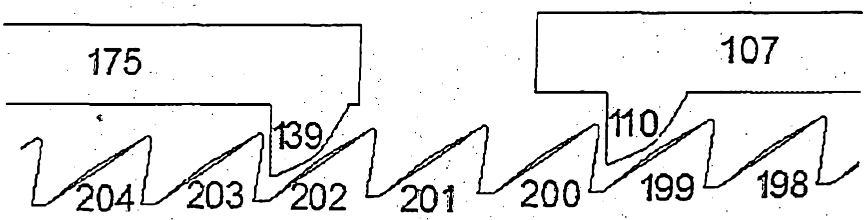


Fig. 18 a

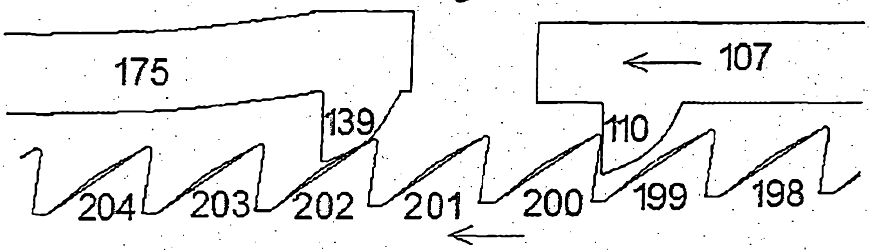


Fig. 18 b

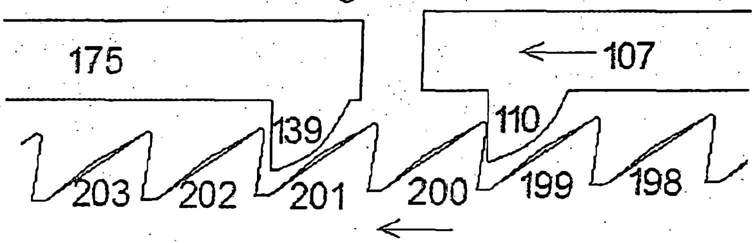


Fig 18c

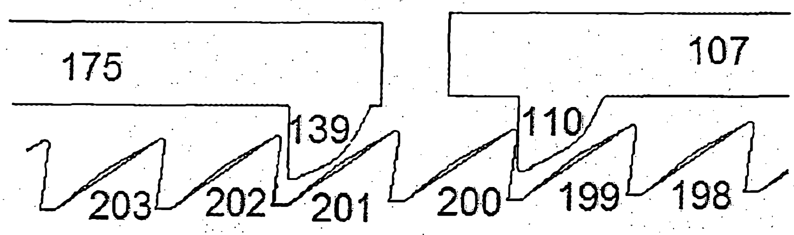


Fig. 18 c

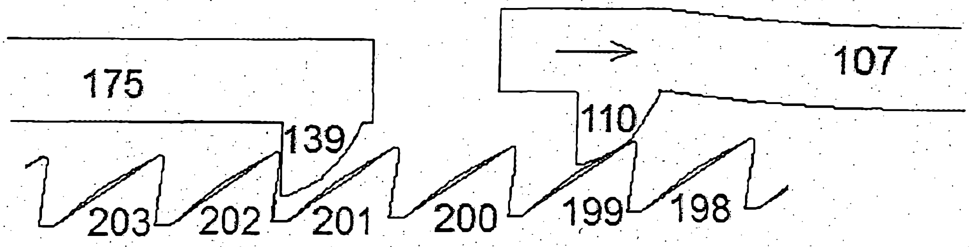


Fig. 18 d

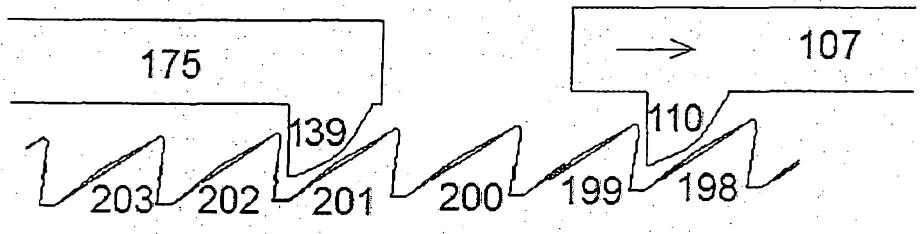


Fig. 18 e

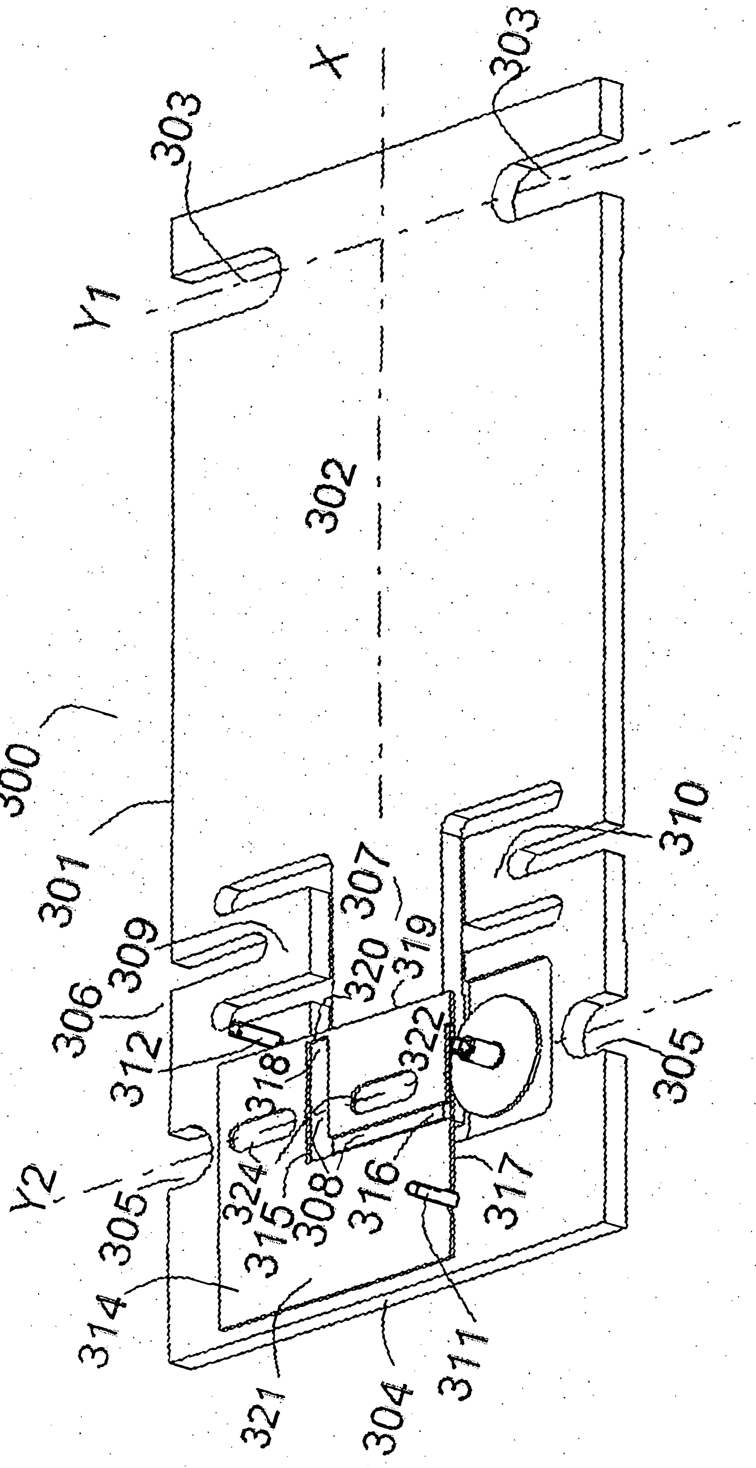

X
303
303
Y1
302
300
301
309
306
312
310
307
320
319
322
318
305
324
315
308
316
317
Y2
305
314
321
311
304

Fig. 19

316

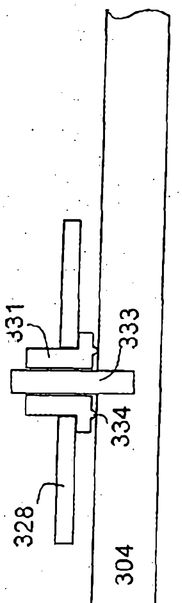

331
333
334
328
304

Fig. 20

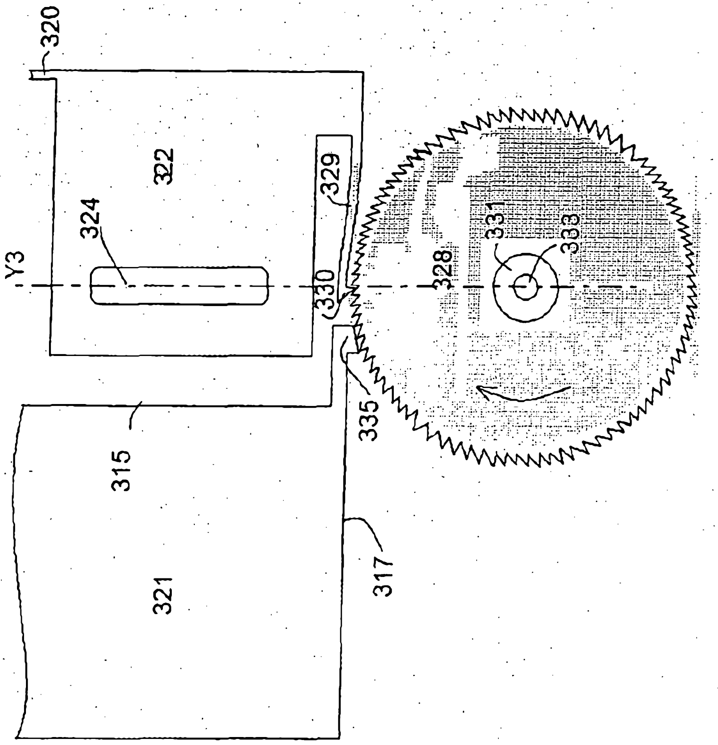

320
322
324
Y3
329
330
328
331
333
335
315
321
317

Fig 21

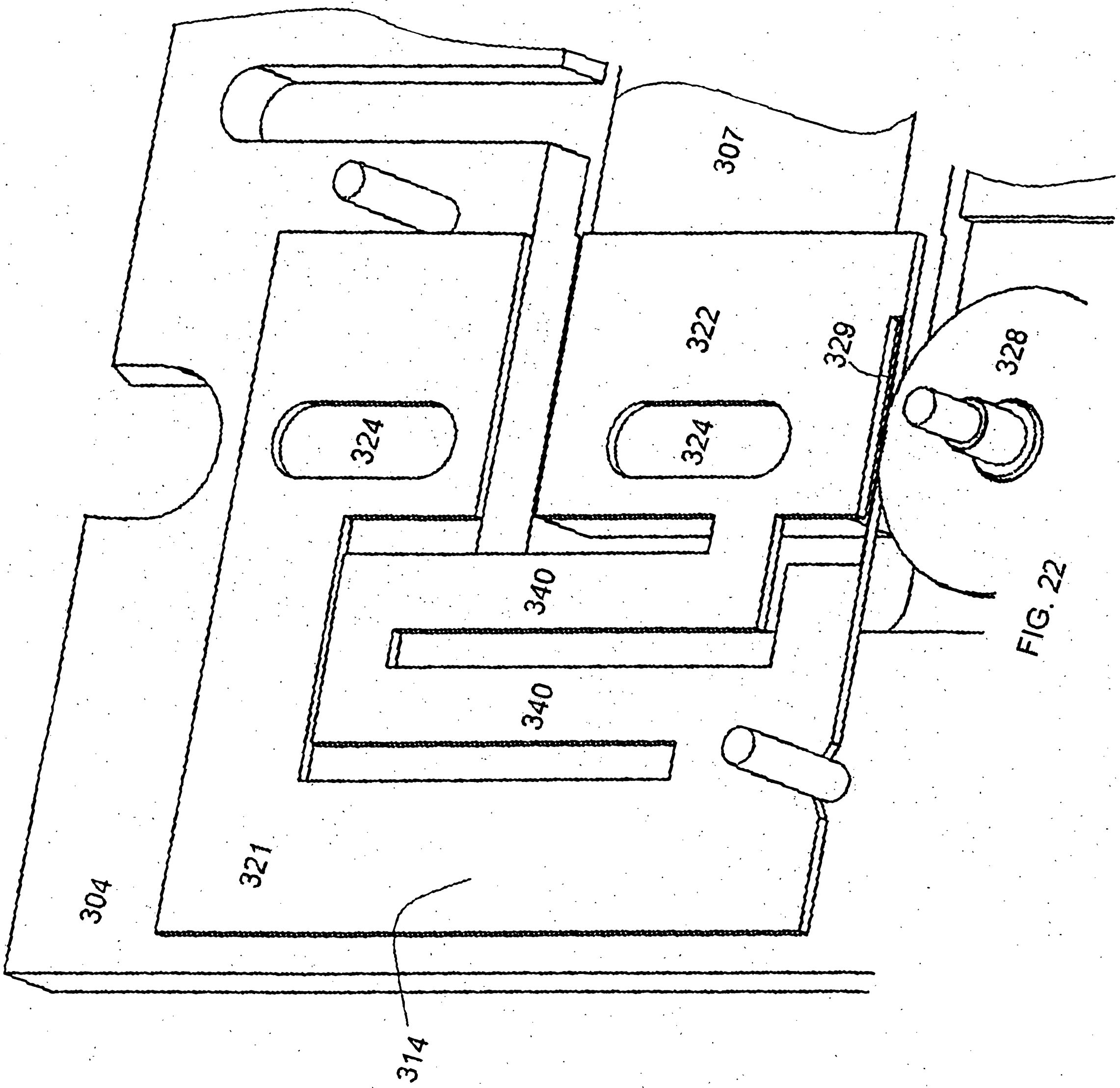


FIG. 22