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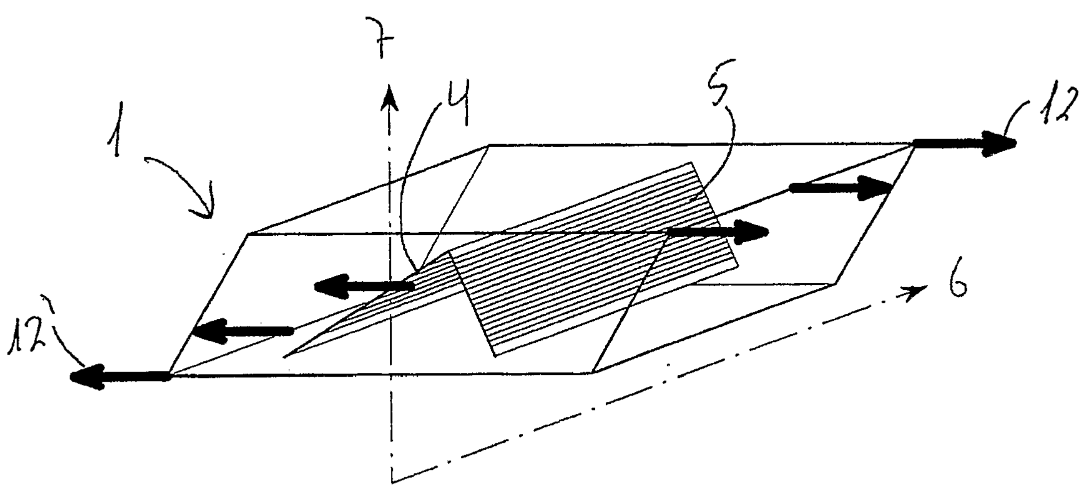
(54) Title: STRUCTURE FOR SHEAR FORCE SENSING



(57) Abstract: This invention relates generally to elastomeric sensors of the type where two electrodes are placed on opposite sides of an elastomeric corrugated core. More specifically, this invention relates to the application of such sensors as a shear force sensor structure. It is a task of this invention to disclose a device, by means of which elastomeric sensors can be used for sensing shear forces.

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Structure for shear force sensing

This invention relates generally to elastomeric sensors of the type where two electrodes are placed on opposite sides of an elastomeric corrugated core. More specifically, this invention relates to the application of such sensors as a shear force sensor structure.

Examples of such sensors exist, where the basic elements often are a strain gauge consisting of resistive elements composing each side of a bridge formation, like a Wheatstone bridge circuit. The resistive elements are characterized by a change in resistance, when forces, like a shear force, are applied thereto. In the application DE 100 40 287 A1 four such strain gauges are placed plane and orthogonal to each other on a sheet, and each consists of two connected bridges placed mutual diagonal on the sheet. The idea to place several strain gauges in such a formation, is to eliminate the influence of parasitic forces and moments on the measurements.

It is the subject of this invention to eliminate the need of strain gauges, and to produce a cheap and easily manufactured shear force sensor, based on the fact that the capacity alters when the distance between the to electrodes and/or the area of the two electrodes of a capacitor are changed.

Elastomeric actuators with a corrugated core, and having anisotropic properties, are known from DE 100 54 247 C2. The actuator described in DE 100 54 247 C2 has an elastomeric corrugated core, onto which an electrode is deposited by for example physical vapor deposition processes. The electrode, evaporated onto opposite sides of the core, onto which an electrode is vaporised. The electrode, vaporised onto opposite sides of the core, will follow the corrugation, and will therefore give the actuator a higher ability of deformation in a direction across the corrugation, than in a direction along the corrugation. Consequently, when an electrical field is applied to two opposite electrodes, forcing the two electrodes towards each other, the thickness of the core will decrease, and convert into an extension only in the direction across the corrugation.

The actuator of DE 100 54 247 C2 will also work as a capacitive sensor, described in PCT/DK02/00861. Mechanical deformation or influence in one direction across the corrugation will be converted into a variation in thickness and the area, and this will change the distance to area ratio, and thus the capacitance, between the two electrodes on opposite sides.

It is an object of this invention to disclose a device, by means of which elastomeric sensors can be used for sensing shear forces. This object could be achieved in that the shear force sensor is made as a structure comprising a base plate, at least one pair of planes positioned around a centre plane, said centre plane raised as a normal to said base plate, each of said pair of planes comprising:

- a first plane inside the structure having defined on it a first and a second endline, said two endlines placed at different vertical distances relative to said base plate and different horizontal distances relative to said centre plane,
- a second plane inside the structure opposing said first plane through said centre plane and having defined on it a first and a second endline, said two endlines placed at different vertical distances relative to said base

plate and different horizontal distances relative to said centre plane,

where the first and second planes do not necessarily have identical profiles, and where the first plane and the second plane are provided with similar elements, each element consisting of an elastomeric core with a compliant electrode on each side. The corrugation of the elastomeric sensors runs along the base plate and the centre plane, deformations across the centre plane being converted into dimension variations in each of the two elements.

In a prefered embodiment of the invention, the shear force sensor consists of multiples of such pairs of first and second planes, where the first plane of a second pair is following in succession of the second plane of a first pair.

Preferably the structure can be formed as a massive elastomeric body, moulded with the two elements inside. This will give the structure a high degree of deformation, depending on the elastomeric material, and thus the shear force sensor could be useful in applications with a low level of forces, but at high relative deformation.

In one specific embodiment the structure could be moulded as only one unit, where only the two elements are forming the first and second plane inside the structure. This will provide a very simple structure, which in production will be easy to handle.

In another specific embodiment of the invention the elastomeric body can be formed by a bottom part and a top part, where the geometry of the bottom and top part forms the first and the second plane. Further specific, the bottom and the top part are separate sub-structures, which are assembled with the two elements between them in a way that provides an interlock of the two sub-structures. Hereby a multi-element structure is provided, and the shear force sensor is formed upon assembly of the sub-structures.

As the structure is a sensor element, it is preferable that the capacitance of each of the elements is detectable. Detection of the capacitance difference could give the sensor signal, depending on the level of shear forces and shear deformation. An advantage obtained through difference sensing, is that influences from temperature variations, influences from force or deformations in other directions than pure shear force, or the like will have same impact on both elements, and therefore have no influence on the difference detection.

In a specific embodiment of the invention, the two elements could be mounted or fixed in a loaded position, when the structure is in an unstressed situation, meaning that an increase as well as a decrease in capacitance is detectable. When an element is in an unloaded position, the capacitance can only be increased through an extension of the element across the direction of the corrugation, as a reduction of the element beyond the no-load position is impossible. This could be overcome by pre-loading each element.

It is preferable that only deformations in said shear force direction is detectable. This could reduce detection errors from forces in other directions than the pure shear forces. Despite this the invention is not to be limited to detecting shear forces alone. The sensor may measure shear force by detecting a change in the capitance difference, or a normal force by detecting a change in the sum of capacitances.

In yet another specific embodiment of the invention, the structure could further comprise an electronic circuit, and yet further the electronic circuit could be connected with each element to perform the force detection. Hereby is achieved that the structure exposes a complete sensor unit, where the output signal corresponds directly to the shear force.

Now having described the invention in general terms, a detailed embodiment of the invention will be described with reference to the drawings, showing:

Fig. 1: An exploded view of a multi-element structure
Fig. 2: The multi-element structure of figure 1 assembled
Fig. 3: The shear force sensor block in a sensing position
Fig. 4: The shear force sensor block in another sensing position
Fig. 5: The shear force sensor made of two blocks.
Fig. 6: Sideview of a second embodiment of the shear force sensor.
Fig. 7: Sideview of a third embodiment of the shear force sensor.

Figure 1 shows a structure, generally indicated as position 1, in an exploded view. The structure comprises a bottom part 2, a top part 3 and elements 4 and 5, each formed as an elastomeric sensor with a corrugated core. Two axes 6 and 7 are indicated on figure 1, by means of which the geometry of the structure is to be explained.

The bottom part 2 has a base plate 8, and on the opposite surface a first plane 9 and a second plane 10 are formed. The two planes 9 and 10 in this embodiment are facing each other through a centre plane, the centre plane being the plane with the axes 6 and 7.

The top part 3 has a bottom surface with a geometry similar to that of the top surface of the bottom part 2, and between the top part 3 and the bottom part 2, the two elements 4 and 5 are placed on the two planes 9 and 10. Putting the elements of figure 1 together will give figure 2 as result.

On each plane is defined a first endline 14 and a second endline 15, where it is seen that the first endline 14 is placed above the second endline 15, and the first endline 14 is placed closer to the normal plane 7 than the second endline 15.

The structure of figure 2 has been explained through an exploded view in figure 1, simply for the explanation. The preferred embodiment is a homogenous structure, moulded in one piece with the two elements 4 and 5 fixed in position before the structure is moulded. This will give the structure of figure 2, with the two elements 4 and 5 inside the structure. Wiring between an electronic circuit and the electrodes on each element of 4 and 5 are not shown in figures 1 and 2, and the electronic circuit itself is not shown either. Applying this is simply a matter of using known techniques, and shall therefore not be subject to further explanation.

The defined endlines 14 and 15 are seen to have different vertical distances to the base plate 26, and different horizontal distances to the center plane defined by the axis 6 and 7.

Figure 3 shows the shear force sensor 1 in a sensing position, where pure shear forces are applied as a couple indicated as positions 12 and 12'. The couple 12 and 12' will increase element 4 and decrease element 5, whereby the capacitance of element 4 is increased and the capacitance of element 5 is reduced. Figure 4 shows another sensing position where a couple 13 and 13' are applied as pure shear force. In figure 4, the element 4 is decreased and element 5 is increased, whereby the capacitance of element 4 is reduced and the capacitance of element 5 is increased.

On figure 5 a shear force sensor is illustrated comprising two pairs of planes of the type shown in figure 1. The view is here from the side and the electrodes are not shown. A first pair 20 consists of the two planes 21 and 22, the second pair 23 consists of the two planes 24 and 25. The pairs are positioned so that the first plane 24 of the second pair 23 follows in succession of the second plane 22 of the first pair 20. Any number of such pairs as 20 and 23 may be used in the shear force sensor.

Figure 6 shows a sideview of a second embodiment of the invention, dimensions not being correct, where the two opposing planes 16 and 17 are facing each other through the center plane, the black parts 18 and 19 being the electrodes (the corrugations not shown). Here the profile takes on a curved shape. The two planes 16 and 17 are shown not to be symmetrical around the normal plane.

Figure 7 shows a sideview of a third embodiment of the invention, where endpoints 30 and 31 of the first plane 33 not are at the same vertical level as the endpoints 34 and 35 of the second plane 36.

Claims

1. Shear force sensor made as a structure comprising a base plate, at least one pair of planes positioned around a centre plane, said centre plane raised as a normal to said base plate, each of said pair of planes comprising:

   - a first plane inside the structure having defined on it a first and a second endline, said two endlines placed at different vertical distances relative to said base plate and different horizontal distances relative to said centre plane,
   - a second plane inside the structure facing said first plane through said centre plane and having defined on it a first and a second endline, said two endlines placed at different vertical distances relative to said base plate and different horizontal distances relative to said centre plane,

   where said first plane and said second plane are supplied with similar elements, each element consisting of an elastomeric core with a compliant electrode on each side.

2. Structure in accordance with claim 1, characterised in that it forms a massive elastomeric body, moulded with said pairs of elements inside.

3. Structure in accordance with claim 2, characterised in that said pairs of elements are forming said first and second plane inside said structure.

4. Structure in accordance with claim 1, characterised in that said body is formed by a bottom part and a top part, and where the geometry of said bottom and top part forms said first and second plane.

5. Structure in accordance with claim 4, characterised in that said bottom and said top part are separate sub-structures, which are assembled with said two elements between them in a way that provides an interlock of the two sub-structures.

6. Structure in accordance with claim 1, characterised in that the capacitance of each of said elements is detectable.

7. Structure in accordance with claim 6, characterised in that shear forces relative to said centre plane induce deformations, which will influence said capacitance.

8. Structure in accordance with claim 7, characterised in that said influence on said capacitance is detectable.

9. Structure in accordance with claim 8, characterised in that an increase as well as a decrease in capacitance is detectable.

10. Structure in accordance with claim 7, characterised in that only deformations in said shear force direction is detectable.

11. Structure in accordance with claim 1, characterised in that it further comprises an electronic circuit.

12. Structure in accordance with claims 11 and 6, characterised in that said electronic circuit is connected with each element to perform said detection.

13. Structure in accordance with claim 7, characterised in that said structure is formed of an elastomeric material with characteristics in accordance with the magnitude of the mechanical stress in the application.

Fig 1

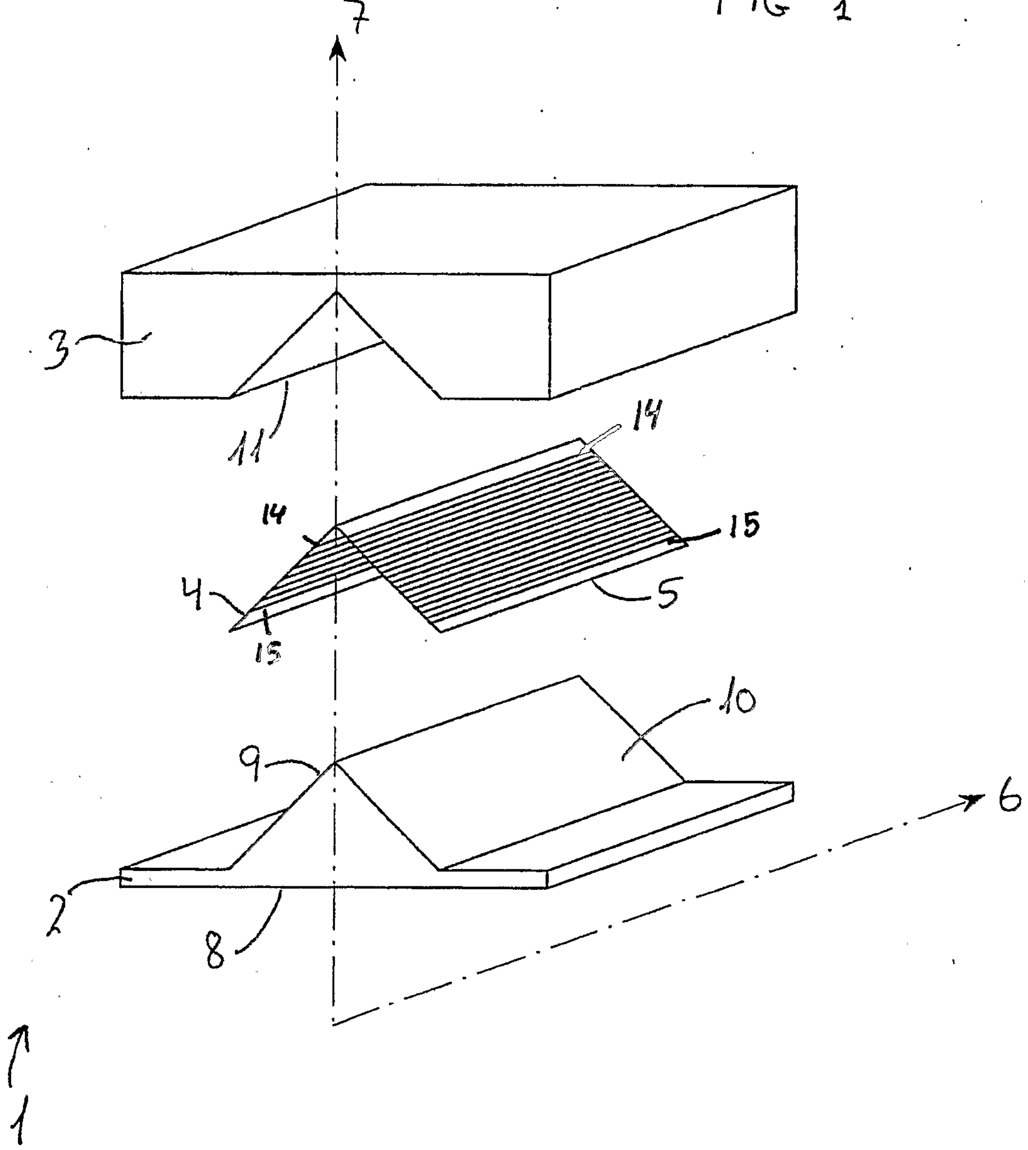


FIG 2.

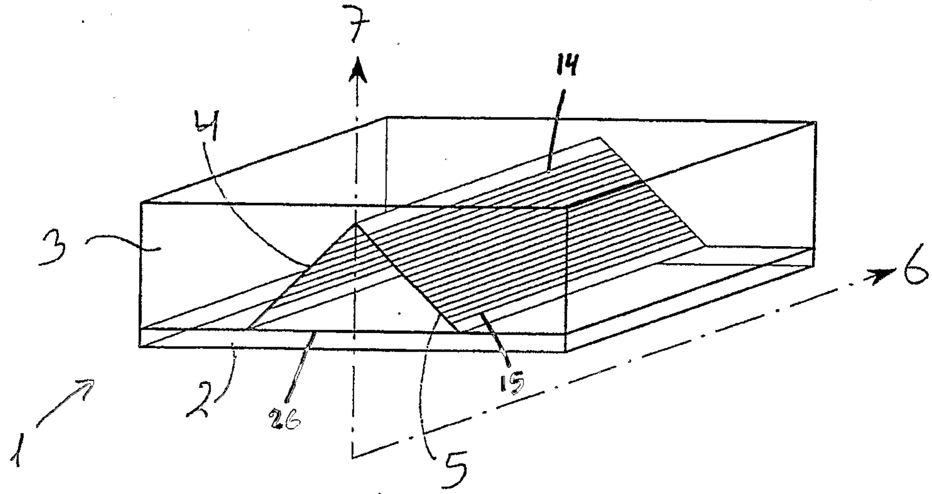


Fig 3

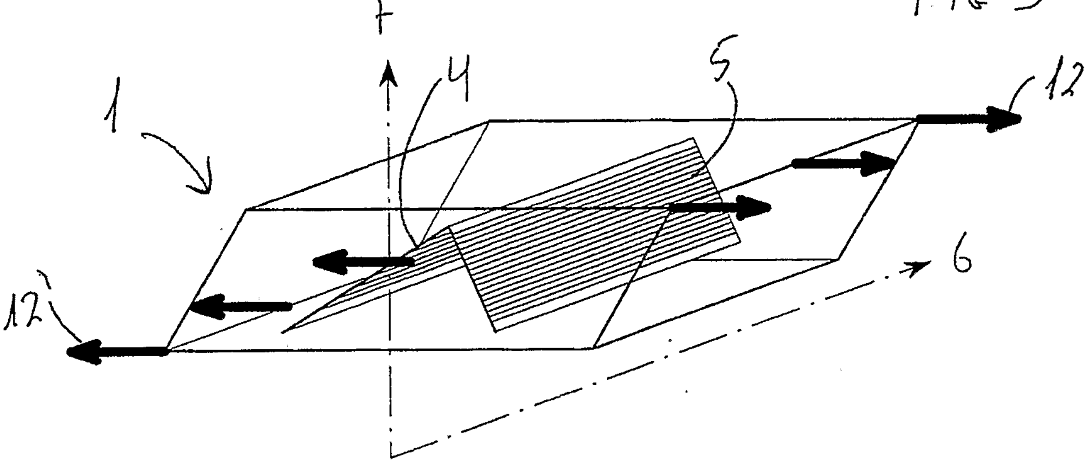


Fig 4

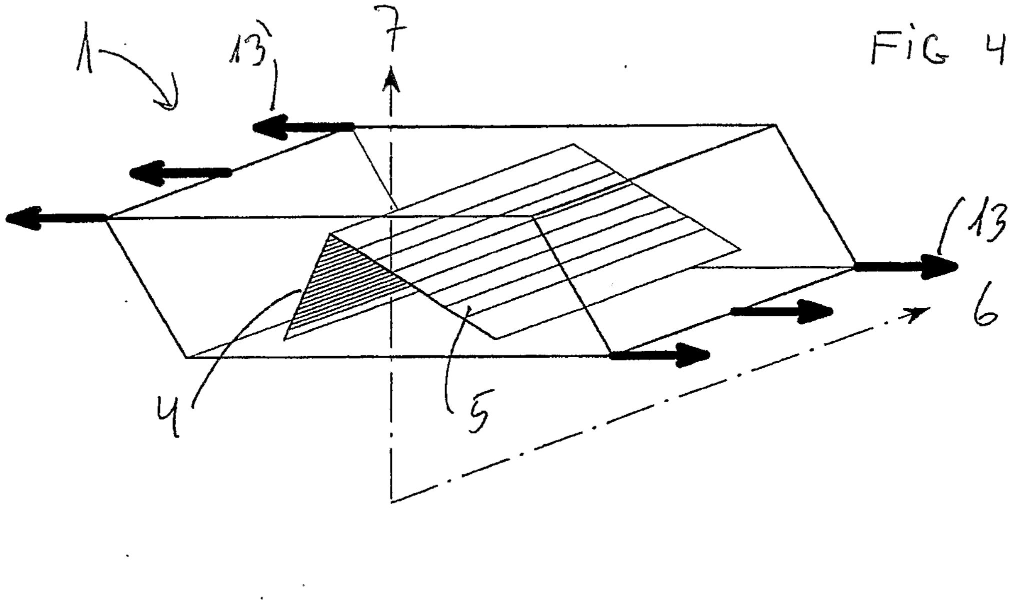


FIG. 5.

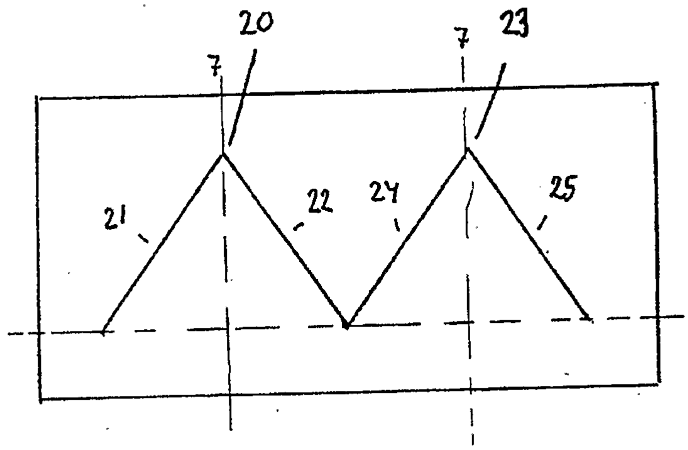


FIG. 6.

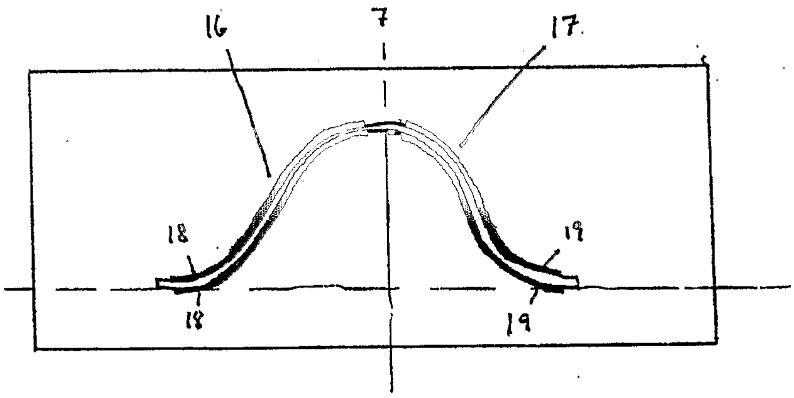
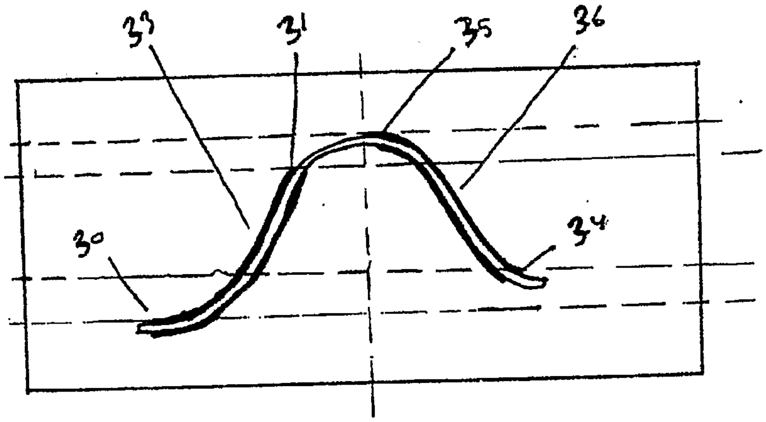


FIG. 7.



INTERNATIONAL SEARCH REPORT

International Application No
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A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01L1/14

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G01L

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

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

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 02/057711 A (MICHELIN RECHERCHE ET TECHNIQUE SA) 25 July 2002 (2002-07-25) abstract page 9, line 13 - line 32 page 10, line 32 -page 11, line 7 figures 1A,1B,2A,2B ---	1
A	EP 0 756 162 A (NIPPON DYNE-A-MAT CORP; HOKUSHIN CORP) 29 January 1997 (1997-01-29) abstract figures 4,22,25 ---	1

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

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
19 May 2004	01/06/2004

Name and mailing address of the ISA	Authorized officer
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INTERNATIONAL SEARCH REPORT

national Application No
PCT/DK2004/000122

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	DE 100 54 247 A (DANFOSS AS) 23 May 2002 (2002-05-23) cited in the application abstract page 3, line 53 figure 2	1

Form PCT/ISA/210 (continuation of second sheet) (January 2004)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/DK2004/000122

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
WO 02057711	A	25-07-2002	CN	1484749	T	24-03-2004
			WO	02057711	A1	25-07-2002
			EP	1352210	A1	15-10-2003
			US	2004004486	A1	08-01-2004
EP 0756162	A	29-01-1997	JP	9043080	A	14-02-1997
			JP	9043081	A	14-02-1997
			CA	2182221	A1	29-01-1997
			CN	1388364	A	01-01-2003
			CN	1148166	A ,B	23-04-1997
			DE	69616198	D1	29-11-2001
			DE	69616198	T2	20-06-2002
			EP	0756162	A2	29-01-1997
			US	5693886	A	02-12-1997
DE 10054247	A	23-05-2002	DE	10054247	A1	23-05-2002
			AU	1383102	A	15-05-2002
			WO	0237660	A1	10-05-2002
			EP	1330867	A1	30-07-2003
			US	2004012301	A1	22-01-2004