(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 2 207 190 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
14.07.2010 Bulletin 2010/28

(51) Int Cl.:
H01H 1/00 *(2006.01)* ***H01H 59/00*** *(2006.01)*

(21) Application number: **09000159.5**

(22) Date of filing: **08.01.2009**

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO SE SI SK TR
Designated Extension States:
AL BA RS

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(54) **Resilient device**

(57) A resilient device of length L, variable width w (x) and variable thickness t(x) comprising a first longitudinal section, a second longitudinal section, and a third longitudinal section is provided. The first longitudinal section of length 11 has an area moment of inertia I (0 ≤ x ≤ 11) and a first distal end at x = 0, the second longitudinal section of length 12 has a constant area moment of inertia I (11 < x ≤ 11 + 12) and is attached to the first longitudinal section, the third longitudinal section of length 13 has an area moment of inertia I (11 + 12 < x ≤ 11 + 12 + 13), is attached to the second longitudinal section, and has a second distal end at x = L. The area moment of inertia of the first longitudinal section decreases from x = 0 to x = 11, the area moment of inertia of the third longitudinal section increases from x = 11 + 12 to x = 11 + 12 + 13.

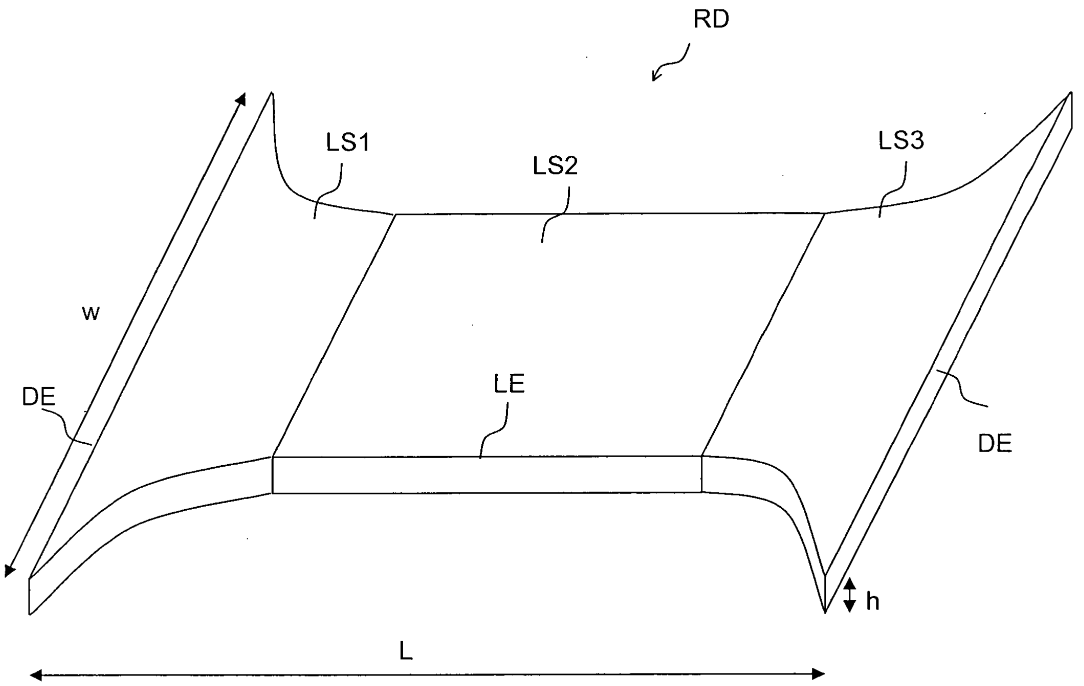

Fig. 1

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Description

Field of the invention

[0001] The present invention relates to perpendicularly moving resilient devices for application e.g. in MEMS devices.

Description of the related art

[0002] Conventional resilient devices (e.g. springs having a fixed cross-section) or spring elements used in MEMS devices can suffer from high stress levels being restricted to small areas of such devices. As a result, these high-stress areas often form the geometrical starting point for later failure.

[0003] Therefore, what is needed is a resilient device with improved geometrical shape to reduce the maximum stress level and that is less prone to failure due to e.g. plastic deformation, fatigue, or mechanical overstraining in general.

Summary of the invention

[0004] The present invention provides a resilient device of length L, variable width w(x) and variable thickness t(x) comprising a first longitudinal section of length l1 having an area moment of inertia I(0 <= x <= l1) and having a first distal end at x = 0, a second longitudinal section of length l2 having a constant area moment of inertia I(l1 < x <= l1 + l2) and being attached to the first longitudinal section, a third longitudinal section of length l3 having an area moment of inertia I(l1 + l2 < x <= l1 + l2 + l3) and being attached to the second longitudinal section and having a second distal end at x = L, where the area moment of inertia of the first longitudinal section decreases monotonically from x = 0 to x = l1, the area moment of inertia of the third longitudinal section increases monotonically from x = l1 + l2 to x = l1 + l2 + l3. Here, x denotes the position along a longitudinal axis of the resilient device and l1 + l2 + l3 equals the total length L of the resilient device, and x, l1, l2, l3, L, w and t are real numbers larger than zero. It has to be clarified that the resilient device is not restricted to a straight structure, but can also follow a curved path i.e. trajectory. Then x refers to the linear position along the trajectory.

[0005] The area moment of inertia I_x of a straight beam following the x-axis is defined as:

$$I_x = \iint y^2 dA$$

where dA denotes an differential elemental area and y denotes the perpendicular distance from the x-axis to the element dA. Each short section of a resilient device following a curved trajectory can locally be approximated as a section of a straight beam. As the tendency to kink for a perpendicularly moving resilient device does not directly depend on the geometrical details of such a device but only to the area moment of inertia I, there are degrees of freedom to design the geometrical details of a resilient device while restricting the area moment of inertia to a desired value.

[0006] Here the wording monotonically decreasing / increasing means that the first or the third longitudinal section may comprise subsections where the respective area moment of inertia is constant.

[0007] In a preferred embodiment the area moment of inertia at least one of the first longitudinal section and the third longitudinal section decreases/increases strictly monotonically within its respective longitudinal section.

[0008] Furthermore combinations of subsection of monotonical and strictly monotonical decrease / increase within each respective section are possible.

[0009] In another preferred embodiment of the present invention, the resilient device's cross-section has at every longitudinal position x a mainly rectangular shape. Then the cross-sectional area is the product of the width w and the thickness t. Such shaped devices make it easy to calculate the ratio of width w and thickness t in order to get the desired area moment of inertia. To be more precise, the area moment of inertia is then:

$$I_x = \frac{w(x)t(x)^3}{12}$$

[0010] In order to further avoid local high-stress areas at the edges of a resilient device, it is preferred that the resilient device comprises chamfered lateral edges.

[0011] It is further preferred to keep the thickness t of the resilient device constant over the whole device. If the shape of the cross section is kept constant the width w of the device is the only adjustable parameter. Having a constant thickness is preferred because it simplifies the manufacturing process, especially in the case of MEMS devices.

[0012] It is further preferred that the area moment of inertia decreases linearly within the first longitudinal section and increases linearly within the third longitudinal section. As the tendency to kink is proportional to the length of the effective lever and reciprocal to the area moment of inertia, such a resilient device's tendency to kink keeps nearly constant over its longitudinal axis at an approximately constant stress level.

[0013] In another preferred embodiment, the resilient device is stiffly connected with one of its distal ends to an anchor element. Such a resilient device can be part of a MEMS device.

[0014] When the resilient device is part of a MEMS device, it is preferred that one of its distal ends is connected to a movable element. The other end can be connected to an anchor element. Whether the resilient device has a constant thickness or not, the width w can vary from 25% to 100% of the maximum width in the first and in the third longitudinal section. In a preferred physical embodiment the width w can vary from 15 to 60 μm in the first and in the third longitudinal section. In another preferred embodiment, the width can vary in the first and in the third section from 20 to 40 μm. The length of the second longitudinal section can be zero. Then the first and the third longitudinal section are attached to each other directly. In another preferred embodiment, the width of the resilient device does not extend below 40% of the maximum width over the whole length of the device.

[0015] The resilient device can comprise metal, especially an aluminum comprising alloy, or an inorganic dielectric or a ceramic or it can comprise a plastic.

[0016] It is especially preferred that such a resilient device used in a MEMS device connects a fixed external anchor element of the MEMS device with a suspension element of a movable element. The movable element can have mainly rectangular or trapezoid shape, can be a membrane of rectangular or trapezoid shape, and can have sharp or chamfered corners or lateral edges.

[0017] In a preferred embodiment, four of such resilient devices are used in a MEMS device comprising a mainly rectangular shaped movable element that is flexibly suspended between two fixed external anchor elements by means of the four resilient devices, wherein, on each of two opposing sides of the movable element, two of the resilient devices are connected with one of their distal ends to a respective one of two sides of a respective one of the anchor elements each. The respective other distal ends of the resilient devices are then connected to respective suspension elements of the movable element. The resilient devices not necessarily follow a straight path. They also can follow an arbitrarily shaped trajectory as long as the area moment of inertia follows the requirements at each point of the trajectory. The resilient device thus can have a curved structure / shape although no lateral stress is applied, i.e. the device is in its stand-by position.

[0018] Another preferred embodiment concerns a MEMS device comprising a trapezoid shaped movable element being flexibly connected to two external anchor elements by means of two resilient devices. Then, on each of two opposing non-parallel sides of the movable element, one of the resilient devices is connected with one of its distal ends to a respective anchor element while the respective other distal end of the respective resilient device is connected to a suspension element of the movable elements.

[0019] Suspension elements of the movable elements can be realized by a special means for mounting a resilient device to a movable element. Apart from that, the wording suspension element can also just refer to a part of the movable element where the resilient device is bound to.

Brief description of the drawings

[0020] The present invention will become fully understood from the detailed description given herein below and the accompanying drawings. In the drawings,

FIG. 1 illustrates a resilient device comprising a first, a second and a third longitudinal section,

FIG. 2 illustrates a top view on a resilient device,

FIG. 3 shows a top view on a resilient device consisting only of the first and the third longitudinal section,

FIG. 4 illustrates a cross-sectional view on a resilient device consisting of the first and the third longitudinal section, each with a non-linear increase or decrease in thickness,

FIG. 5 illustrates a cross-section of a resilient device having chamfered lateral edges,

FIG. 6 illustrates four resilient devices being connected between anchor elements and suspension elements of a movable element,

FIG. 7 illustrates four resilient devices having a curved trajectory and connecting a movable element to anchor elements,

FIG. 8 illustrates an element of a MEMS device having a trapezoid movable element being suspended by two resilient devices.

Detailed description

[0021] FIG. 1 illustrates a resilient device RD of length L having a first longitudinal section LS1, a second longitudinal section LS2 of constant width and thickness, and a third longitudinal section LS3. The beginning of the first longitudinal section LS1 and the end of the third longitudinal section LS3 mark the distal ends DE of the resilient device RD. The width w of the first longitudinal section LS1 decreases strictly monotonically while the width of the third longitudinal section increases strictly monotonically. The thickness t is constant over the total length L.

[0022] FIG. 2 illustrates a top view of a resilient device comprising a first longitudinal section LS1 having length l1 and a second longitudinal section LS2 of constant width w having length l2 and a third longitudinal section LS3 of length l3. The total length of the resilient device L equals the sum l1 + l2 + l3 of the lengths of the first, second and third longitudinal sections. In this embodiment, the width of the first longitudinal section LS1 decreases linearly with increasing position x and the width of the third longitudinal section LS3 increases linearly with increasing position x.

[0023] FIG. 3 illustrates a resilient device comprising only the first longitudinal section LS1 and the third longitudinal section LS3, i.e. the length of the second longitudinal section equals zero. Analog to FIG. 2, the width w decreases linearly in longitudinal section LS1 and increases linearly in longitudinal section LS3. Here, the total length of the resilient device equals the sum of the lengths l1 + l3 of the first LS1 and the third LS3 longitudinal section.

[0024] In the following figures, an assumption is made that the resilient device extends towards the x-direction while the width extends towards the y-direction and the thickness extends towards the z-direction of a Cartesian coordinate system.

[0025] FIG. 4 illustrates a cross-section being parallel to the x-axis of the resilient device comprising a first longitudinal section LS1 and a third longitudinal section LS3 where the thickness t decreases not linearly with increasing x and the thickness t increases not linearly with increasing x in longitudinal section LS3 (thickness).

[0026] FIG. 5 illustrates a cross-sectional view of a resilient device showing a cross-section parallel to the yz-plain having a mainly or rectangular cross-section with chamfered longitudinal edges CLE and having thickness t and width w. The dotted line indicates the strict rectangular shape while the continuously curved line indicates the deviation from the strict rectangular shape i.e. it indicates a shape with chamfered lateral edges. As the deviation may be sufficiently small a person skilled in the art will recognize that the cross section can still be regarded as a rectangular cross section.

[0027] FIG. 6 illustrates a structure that may be part of a MEMS device comprising two anchor elements AE, a movable element ME, that may be a membrane M, four suspension elements SE, two of them mounted to a first side, the other two mounted to the opposite side of the movable element ME. Four resilient devices RD connect suspension SE elements to anchor elements AE. On each of the opposing sites of the movable element ME, two resilient devices RD are connected with one of their distal ends DE to one of the two suspension elements, and with their other distal end (DE) to one common anchor element. As the distal ends of the resilient devices are supposed to be dislocated parallel (or antiparallel) to the z-direction, the movable element can be dislocated towards the positive side of the z-direction or the negative side or can be tilted, i.e. one end of the movable element is moved towards the negative direction of the z-axis and the other end of the movable element is moved towards the positive direction of the z-axis. Analog, the movable element ME can also oscillate with elongations towards the z-direction.

[0028] FIG. 7 illustrates a variation of the structure of FIG. 6 having four resilient devices RD following not a straight path but a curved trajectory TR each. One distal end DE of the resilient device RD is connected to one of two anchor elements AE while the other distal end DE of the resilient device RD is connected to a movable element ME at a suspension element SE. FIG. 7 shows four resilient devices RD. In the figure however, for simplicities sake, notations are only made exemplarily for one resilient device. The suspension element SE can be formed by one distal end DE of the resilient device RD or the point where the distal end DE is mounted to the movable element ME. In this case, the movable element and the resilient device are fabricated as one single piece and/or in one common production step.
Especially when special requirements have to be fulfilled in view of highly stressed connections between the resilient device and the movable element, then special enforcement means can be applied to the connection point between the resilient device and the movable element. This could, for example, be a special variation in thickness of the movable element ME or of the resilient device at the denoted distal end DE.

[0029] FIG. 8 illustrates another embodiment where two resilient devices RD, having a curved trajectory TR, connect non-parallel sides of a trapezoid movable element ME to two anchor elements AE. When comparing FIG. 8 to FIG. 7, it can be seen that in FIG. 8 the resilient devices are directly mounted to an edge of the movable element, while in FIG. 7, the resilient devices are not directly connected to the edge of the movable element leaving a gap GP between the mounting area and the edge of the movable element ME. Any of these two cases can be preferred in any of both structures. The size of the gap GP depends on the modes of translation or torsion respectively of the movable elements. When designing MEMS devices comprising resilient devices connecting movable elements to anchor elements, the size of this gap gives the engineer another degree of freedom. The engineer has the opportunity, for example, to influence the value of a torque resulting at the suspension element, i.e. the area where the resilient device is mounted to the movable element.

[0030] The present invention refers to resilient devices for perpendicular movement having lower maximum stress levels. The basic concept does not depend on details concerning geometric details of the resilient devices. Further, the invention is not restricted by the embodiments or the accompanying figures. Alternative embodiments are also possible without departing from the invention.

List of reference symbols:

[0031]

AE: Anchor element
CLE: Chamfered lateral edge
CS: Cross section
DE: Distal end
GP: Gap
L: length of RD

LE: Lateral edge
LS1: First longitudinal section
LS2: Second longitudinal section
LS3: Third longitudinal section
M: membrane
MD: MEMS device
ME: Movable element
RD: Resilient device
SE: Suspension element
t: thickness of RD
TR: Trajectory
w: width of RD

Claims

1. Resilient device (RD) having a length L, a variable width w(x), and a variable thickness t(x), comprising

- a first longitudinal section (LS1) of length l1 having a area moment of inertia I (0< = x < = l1) and having a first distal end (DE) at x = 0,
- a second longitudinal section (LS2) of length l2 having a constant area moment of inertia I (l1 < x < = l1 + l2) and being attached to the first longitudinal section (LS1),
- a third longitudinal section (LS3) of length l3 having a area moment of inertia I (l1 + l2 < x < = l1 + l2 + l3) and being attached to the second longitudinal section (LS2) and having a second distal end (DE) at x = L, where
- the area moment of inertia of the first longitudinal section (LS1) decreases monotonically from x = 0 to x = l1,
- the area moment of inertia of the third longitudinal section (LS3) increases monotonically from x = l1 + l2 to x = l1 + l2 + l3,
- x denotes positions along a longitudinal axis of the resilient device,
- l1 + l2 + l3 = L and x, l1, l2, l3, L, w and t are real numbers > = 0.

2. Resilient device of claim 1, wherein

- the area moment of inertia of the first longitudinal section (LS1) decreases strictly monotonically from x = 0 to x = l1 or
- the area moment of inertia of the third longitudinal section (LS3) increases strictly monotonically from x = l1 + l2 to x = l1 + l2 + l3.

3. Resilient device of one of claims 1 or 2, wherein at every longitudinal position x the cross section (CS) has a rectangular shape of a cross sectional area a (x) = w(x)*t(x).

4. Resilient device of one of claims 1 to 3, wherein the thickness t(x) is constant over the whole device.

5. Resilient device of one of claims 1 to 4 wherein the area moment of inertia I(x) decreases linearly with increasing x in the first longitudinal section (LS1) and increases linearly in the third longitudinal section (LS3).

6. Resilient device of one of claims 1 to 5, having a distal end (DE) stiffly connected to an anchor element (AE).

7. Resilient device of one of claims 1 to 6, the device being part of a MEMS-device (MD).

8. Resilient device of claim 7, having a distal end (DE) connected to a movable element (ME) of the MEMS-device (MD).

9. Resilient device of one of claims 1 to 8, the width w (x) of which varying from 15 μm to 60 μm in the first (LS1) and third (LS3) longitudinal section.

10. Resilient device of one of claims 1 to 9, wherein the second longitudinal section has a length l2 (LS2) equaling zero.

11. Resilient device of one of claims 1 to 10, whose width w(x) varies between $0.4*w_{max}$ and $1.0*w_{max}$ in the interval 0 < = x < = L wherein w_{max} is the maximum value of width w (x) .

12. Resilient device of one of the claims 1 to 11, whose longitudinal sections (LS1, LS2, LS3) comprise one of a metal, an inorganic dielectric, a ceramic, an Al containing alloy and a plastic.

13. Resilient device of one of claims 1 to 12, for use in a MEMS device (MD), the resilient device (RD) connecting a fixed external anchor element (AE) with a suspension element (SE) of a movable element (ME).

14. MEMS device comprising a rectangular shaped movable element (ME) being flexibly suspended between 2 fixed external anchor elements (AE) by means of 4 resilient devices (RD) as described in claim 13, wherein, on each of two opposing sides of the moveable element (ME), two of the resilient devices (RD) are connected with one of their distal ends (DE) to a respective one of two sides of a respective one of the anchor elements (AE) each, while the respective other distal ends of the resilient devices (RD) are connected to a suspension element (SE) of the movable element (ME) each.

15. MEMS device comprising a trapezoid shaped movable element (ME) being flexibly connected to two external anchor elements (AE) by means of two resilient devices (RD) as described in claim 13, wherein, on each of two opposing non parallel sides of the moveable element (ME), one of the resilient devices (RD) is connected

- with one of its distal ends (DE) to a suspension element (SE) at the respective non parallel side of the movable element (ME) while
- the respective other distal end of the respective resilient device (RD) is connected to a respective one of the anchor elements (AE).

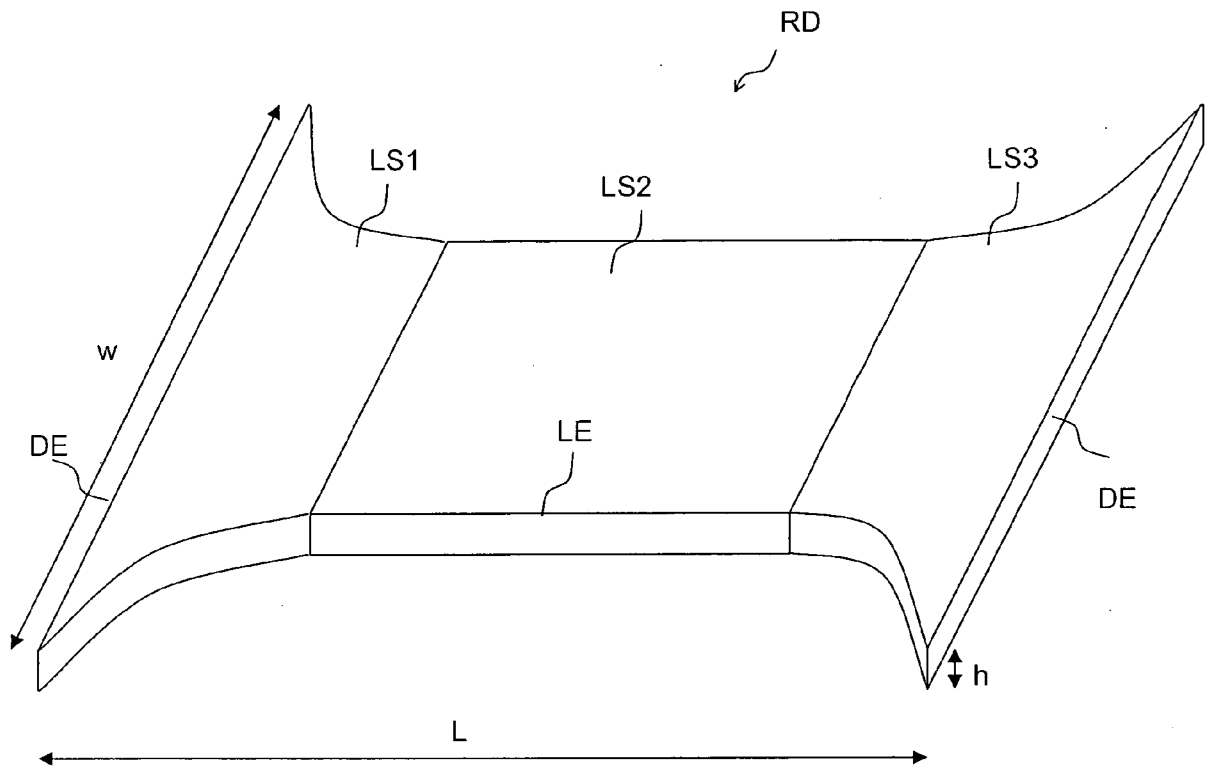

Fig. 1

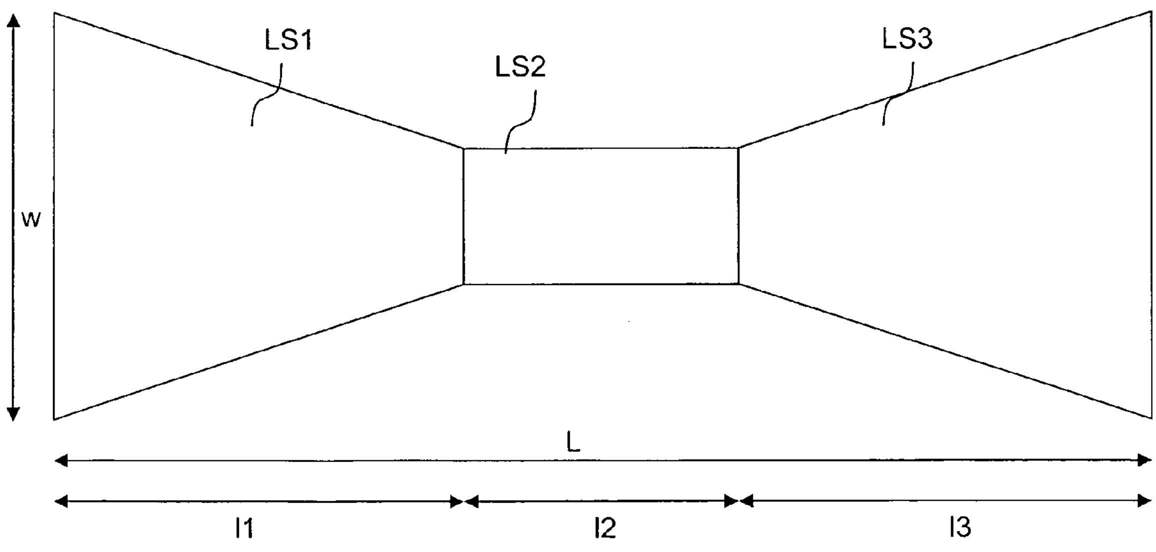

Fig. 2

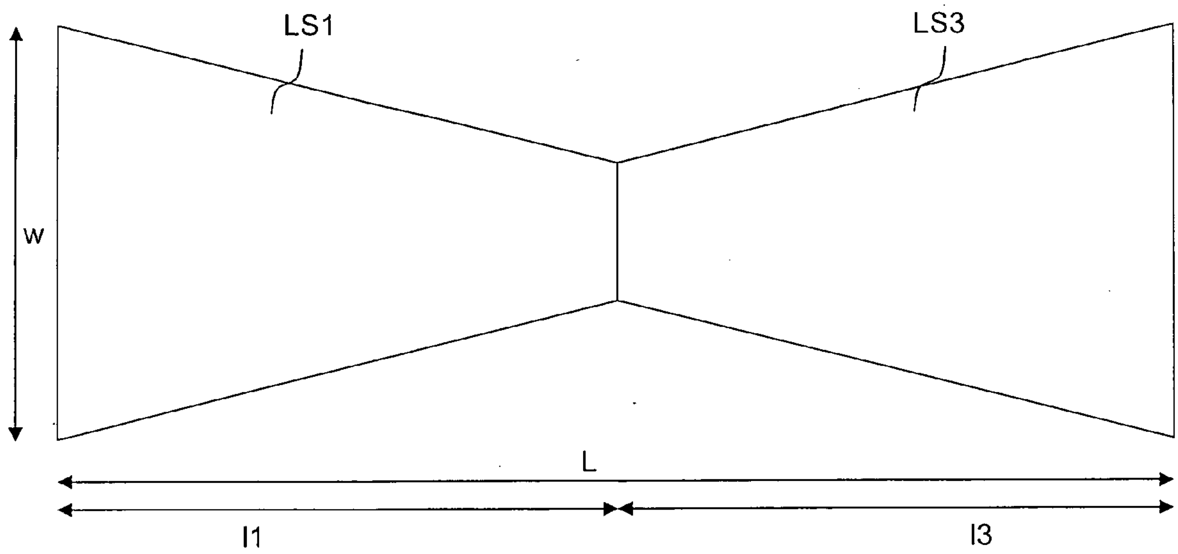

Fig. 3

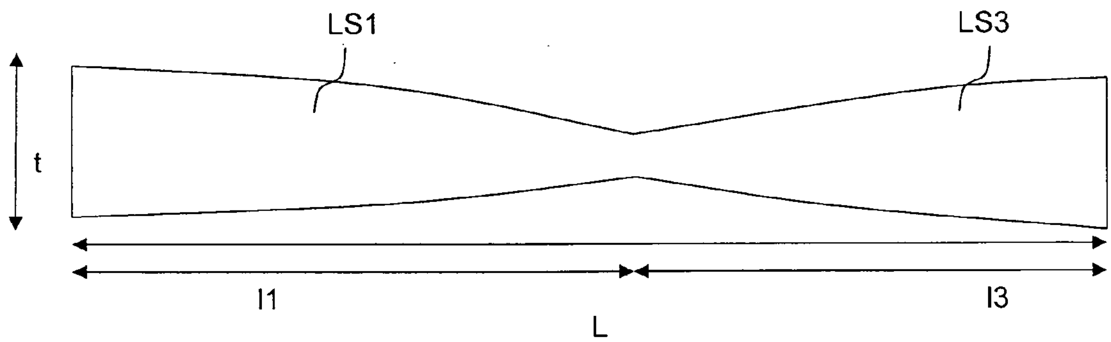

Fig. 4

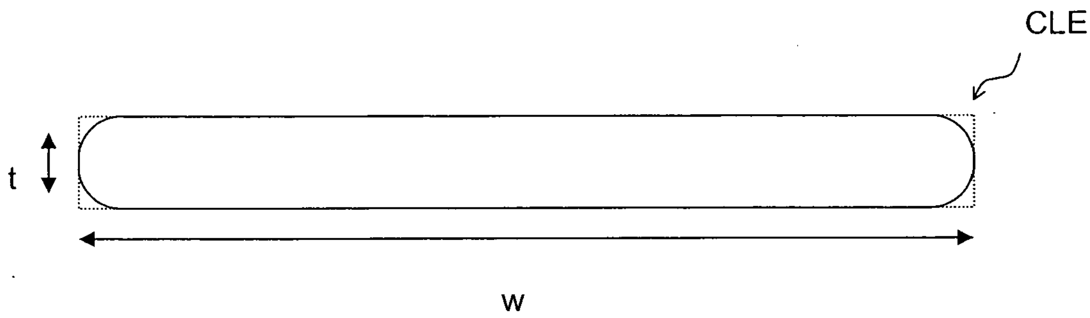

Fig. 5

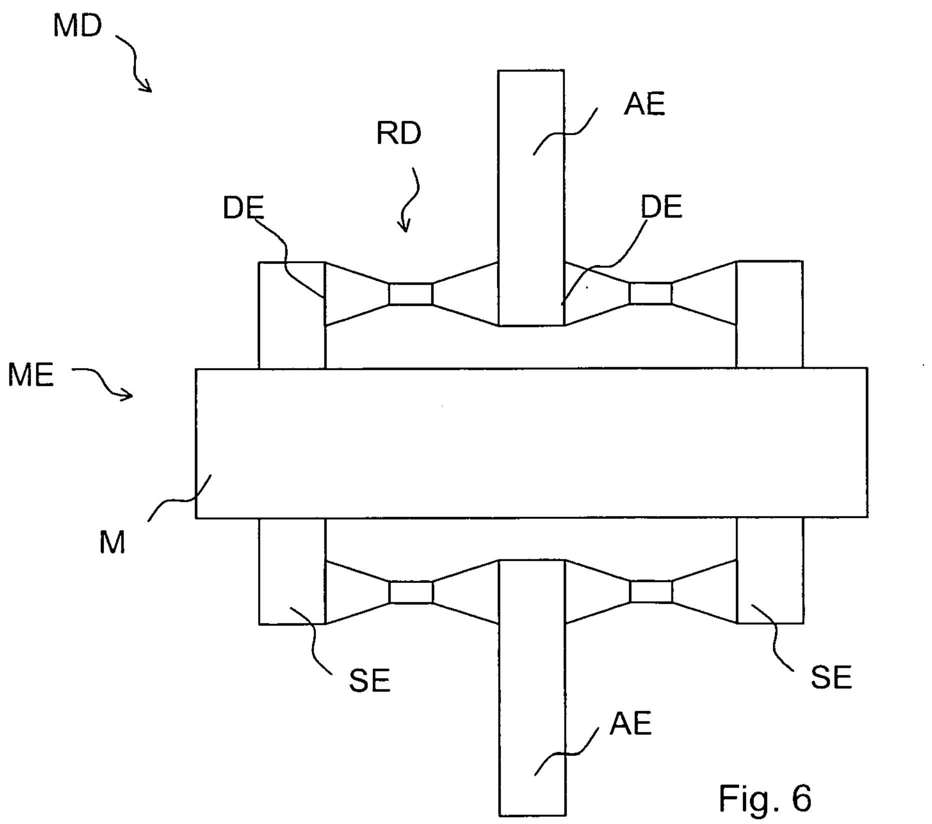

Fig. 6

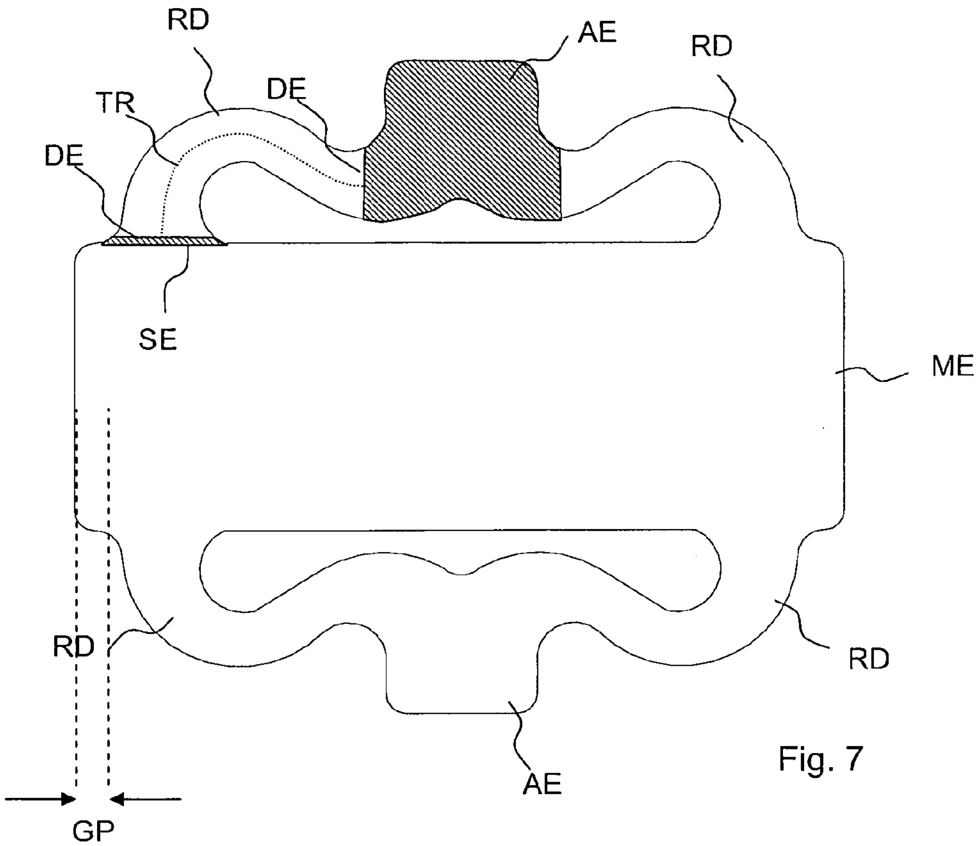

Fig. 7

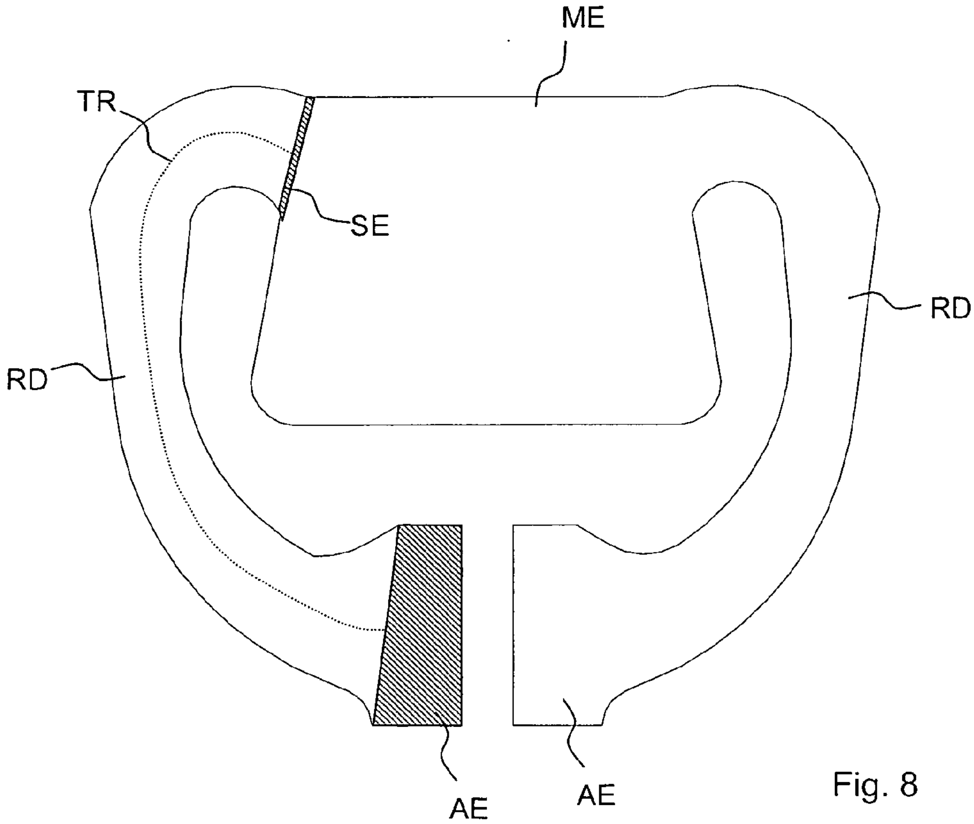

Fig. 8

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EUROPEAN SEARCH REPORT

Application Number
EP 09 00 0159

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 2003/042117 A1 (MA QING [US]) 6 March 2003 (2003-03-06) * paragraphs [0046] - [0049]; figure 5A * -----	1-15	INV. H01H1/00 H01H59/00
A	US 6 360 035 B1 (HURST JERRY E JR [US] ET AL) 19 March 2002 (2002-03-19) * column 24, lines 24-55 * -----	1	

TECHNICAL FIELDS SEARCHED (IPC)
H01H

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	1 July 2009	Findeli, Luc

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01-07-2009

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