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(54) Title: MICRO-ELECTROMECHANICAL SYSTEM

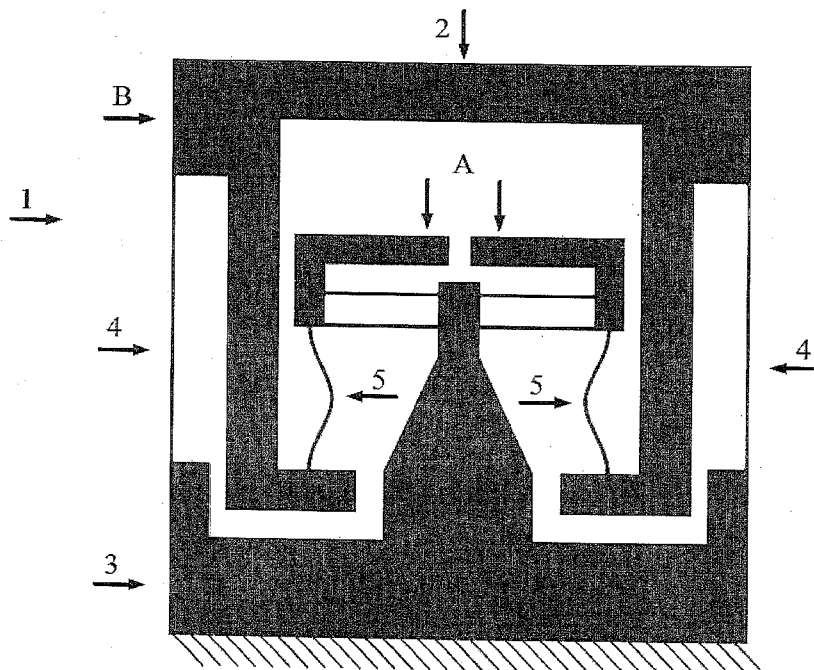


FIG. 1

[Continued on next page]



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(57) Abstract: Micro-electromechanical system (MEMS) comprising a substrate or substrate parts, and a compliant first segment or segments within the substrate or substrate parts with a predefined positive stiffness, wherein the first segment or segments is or are statically balanced. This is embodied by applying a second segment or segments within the substrate or substrate parts that provide a balancing force to the first segment or segments so as to counteract at least in a predefined working range of the first segment or segments the said predefined positive stiffness.

Micro-electromechanical system

The invention relates to a micro-electromechanical system (MEMS) comprising a substrate or substrate parts, and a compliant first segment or segments within the substrate or substrate parts with a positive stiffness.

5 In recent decades, compliant mechanisms have been used extensively rather than professional rigid-body joint mechanisms due to their numerous advantages such as single piece production, absence of Coulomb friction, no need for lubrication, compactness and other advantages. Compliant mechanisms
10 gain some or all of their motion from the relative flexibility (elastic deformation) of it's segments as opposed to jointed rigid-body motions of conventional mechanisms.

When looking at micro-electromechanical systems the application of compliant segments is the rule rather than the
15 exception. Manufacturing of pin-joints which are exceptionally small compared to the entire design of the micro-electromechanical system, is costly and requires significantly small position resolution. Consequently compliant mechanisms play an important role in micromechanical structures, in par-
20 ticular in micro-electromechanical systems. However, the positive stiffness of these mechanisms is an important drawback resulting in insufficient working range of the MEMS, the requirement to apply relatively large actuators and the need to design the MEMS with larger dimensions. Also the energy consumption in
25 such known systems is disadvantageous.

The invention aims to provide a solution for these problems or at least alleviate them to a certain extent, and to this end a micro-electrical mechanical system is proposed in accordance with one or more of the appended claims.

30 At the heart of the invention is the feature that the first segment or segments is or are statically balanced, meaning that in the working range of the MEMS there is virtually zero stiffness and it requires virtually no actuation force to move the MEMS from a first point of equilibrium to a second
35 point of equilibrium. When the MEMS is statically balanced the shortcomings of conventional compliant micro-mechanisms can

thus be overcome. The potential energy that is stored in the MEMS of the invention can thus be kept virtually constant, at least in a part of the working range of the MEMS which is of interest.

5 The static balancing of the micro-electromechanical system of the invention can appropriately be carried out by the feature that a second segment or segments is or are applied within the substrate or substrate parts which is provided with a negative stiffness so as to at least in part provide a balancing force to the first segment or segments, which counter-acts in a predefined working range of the first segment or segments the said positive stiffness of said first segment or segments.

10 It has further been found advantageous that at their extremities where the first and second segments connect to the substrate or substrate parts, said segments are initially cosine shaped when the segments are free from an external load. This provides both lower Von Mises stresses and better distributed force-displacement and efficiency for a larger working range.

15 The inventors have envisaged at the time of conception of this entirely new and inspiring idea two general embodiments of the micro-electromechanical system in which the features of the invention may be embodied.

20 A first embodiment has the feature that it has separate substrate parts that are movable with respect to each other, and that the first segment or segments as well as the second segment or segments connect the separate substrate parts to each other, wherein the first segment or segments and/or the second segment or segments are embodied with a preloading force.

25 A second embodiment has the feature that it has a monolithic substrate within which the first and second segment or segments are embodied as (straight or curved) beams which are provided with an interconnecting link and wherein the distance between the beams as seen in their longitudinal direction differs at the extremities of the beams as compared to their distance in the middle of the beams.

30 The invention will hereinafter be further elucidated

with reference to the drawing of some exemplary embodiments of the micro-electromechanical system of the invention.

In the drawing:

5 -figure 1A shows a first embodiment of the micro-electromechanical system of the invention, and figures 1B and 1C show two variants of the first embodiment; and

-figure 2 shows a second embodiment of the micro-electromechanical system of the invention.

10 Wherever in the figures the same reference numerals are applied, these numerals refer to the same or similar parts.

Making reference now first to figure 1 a micro-electromechanical system 1 is shown in which the balancing forces are applied are perpendicular to the actuation direction of the system 1.

15 The micro-electromechanical system 1 shown in figure 1A has separate substrate parts 2, 3 that are movable with respect to each other. The system 1 further has a first segment or segments 4 as well as a second segment or segments 5 that connect the separate substrate parts 2, 3 to each other. The
20 first and second segments 4, 5 are embodied with a preload so as to arrange that the segments 4, 5 are statically balanced, which results in their having in combination a virtually zero stiffness, and requiring virtually zero actuation force in the working range of the system. For this purpose of static balancing the second segments 5 are applied within the substrate
25 parts 2, 3 with a negative stiffness that provides a balancing force (symbolized by the arrows A) to the first segments 4 so as to counteract at least in a predefined working range of the first segments 4 the positive stiffness of these first segments
30 4. When an actuation force according to arrow B is applied to the system 1, this force can thus be close to zero due to the balancing of the system 1 as just described.

Making reference now to figure 2 a micro-electromechanical system 1 is shown in which the balancing
35 forces are applied parallel to the actuation direction of the system 1.

The micro-electromechanical system 1 shown in figure 2 is embodied with a monolithic substrate 6 within which the first segment 4 and the second segment 5 are embodied as sub-

stantially parallel beams which have an interconnecting link 7 and wherein the distance a, b between the beams as seen in their longitudinal direction differs at the extremities a of the beams 4, 5 as compared to their distance in the middle b of the beams 4, 5.

Also in this embodiment the first and second segments 4, 5 are statically balanced. This is executed by arranging that the second segment 5 has a negative stiffness which provides a balancing force to the first segment 4 so as to counteract at least in a predefined working range of the first segment 4 the positive stiffness of this first segment 4. As a result, it requires a force in the direction of the travel path indicated with arrow C which is virtually zero in order to move the linked first segment 4 and second segment 5.

Both the embodiment in figure 1 as well as the embodiment shown in figure 2 is shown to be provided with the feature that at their extremities where the first and second segments 4, 5 connect to the substrate 6 (see figure 2) or substrate parts 2, 3 (see figure 1), said segments 4, 5 are initially cosine shaped, when said segments are free from external load. As mentioned already above this provides the advantage of both lower Von Mises stresses and better distributed force-displacement and efficiency for a larger working range.

CLAIMS

1. Micro-electromechanical system (MEMS) comprising a substrate (6) or substrate parts (2, 3), and a compliant first segment or segments (4) within the substrate or substrate parts with a positive stiffness, **characterized in that** a second segment or segments (5) is or are applied within the substrate (6) or substrate parts (2, 3) with a negative stiffness, so as to at least in part provide a balancing force to the first segment or segments (4) which counteracts in a predefined working range of the first segment or segments (4) the said positive stiffness of said first segment or segments (4).

2. Micro-electromechanical system (1) according to claim 1, **characterized in that** at their extremities where the first and second segments (4, 5) connect to the substrate (6) or substrate parts (2, 3), said segments (4, 5) are initially cosine shaped when said segments are free from an external load.

3. Micro-electromechanical system (1) according to any one of claims 1-2, **characterized in that** it has separate substrate parts (2, 3) that are movable with respect to each other, and that the first segment or segments (4) as well as the second segment or segments (5) connect the separate substrate parts (2, 3) to each other, wherein the first and/or second segment or segments (4, 5) are embodied with a preload.

4. Micro-electromechanical system (1) according to any one of claims 1-2, **characterized in that** it has a monolithic substrate (6) within which the first and second segment or segments (4, 5) are embodied as beams which are provided with an interconnecting link (7) and wherein the distance (a, b) between the beams as seen in their longitudinal direction (a) differs at the extremities (a) of the beams (4, 5) as compared to their distance in the middle (b) of the beams (4, 5).

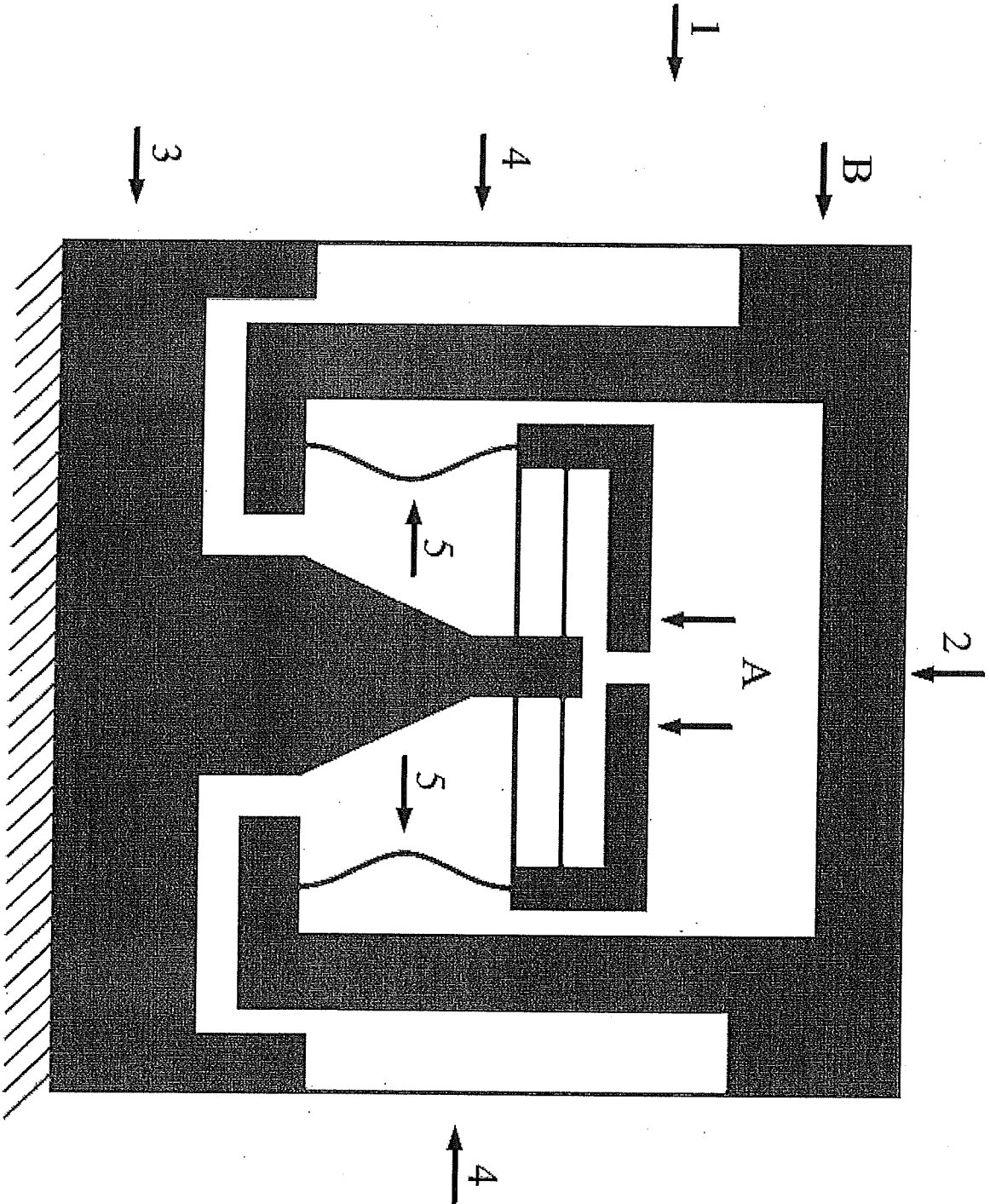


FIG. 1

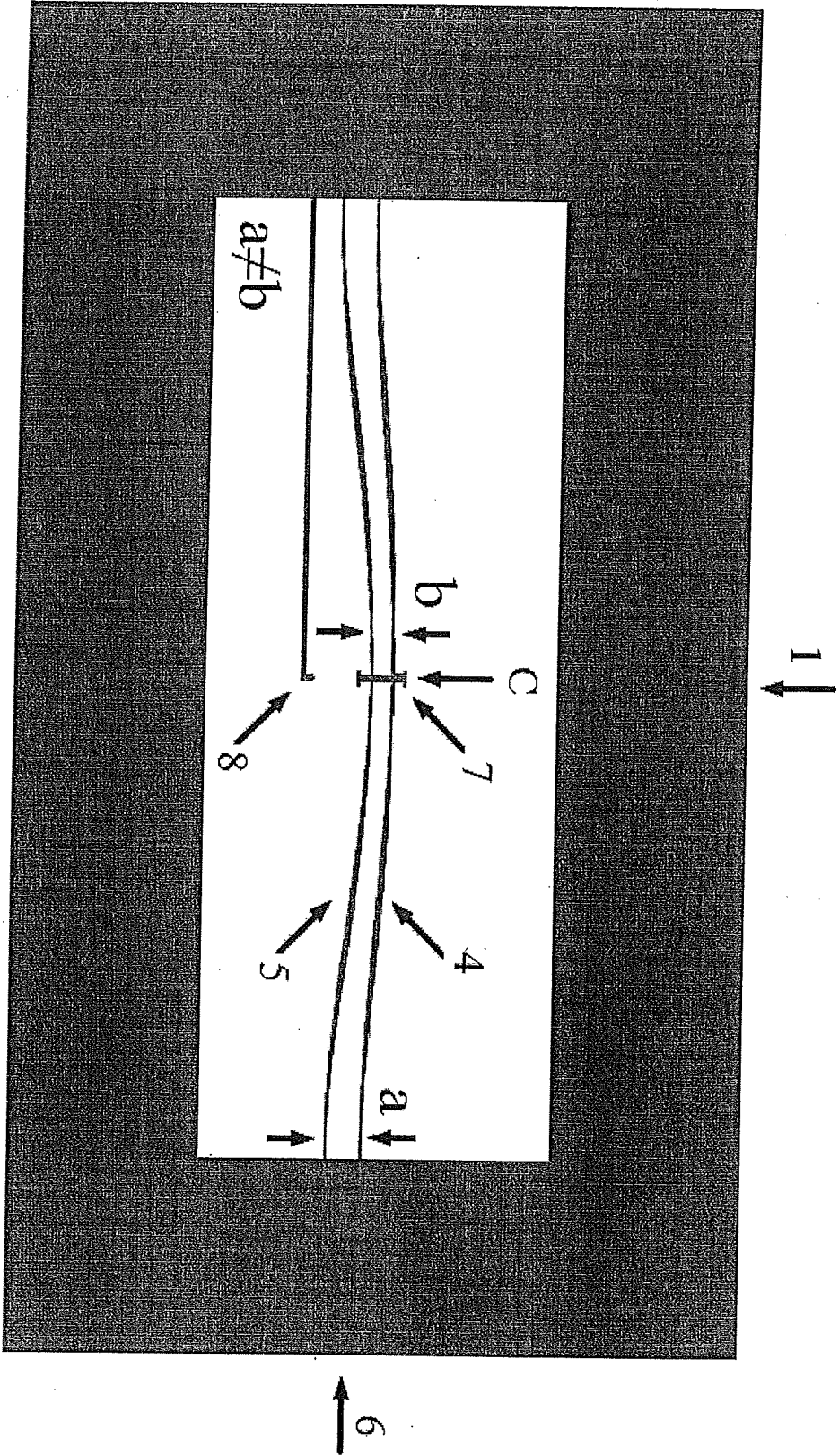


FIG. 2