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(54) TWO DEGREE OF FREEDOM OSCILLATOR SYSTEM

(57) Oscillator system (1) comprising:
- a substantially planar frame (3);
- a first sub-oscillator (5), a second sub-oscillator (7), a third sub-oscillator (9), and a fourth sub-oscillator (11), each sub-oscillator (5, 7, 9, 11) comprising a substantially rigid support (5a, 7a, 9a, 11a) carrying at least one inertial mass (5f, 5g, 7f, 7g, 9f, 9g, 11f, 11g) and being joined to said frame (3) by means of a respective flexure pivot (5b, 7b, 9b, 11b) defining a corresponding axis of rotation (5c, 7c, 9c, 11c), wherein:
- the first sub-oscillator (5) is coupled to the second sub-oscillator (7) by means of a first coupler link (17), these sub-oscillators (5, 7) and said first coupler link (17) being arranged such that these sub-oscillators (5, 7) are constrained to rotate synchronously in opposite directions of rotation as said first coupler link (17) translates along a first axis of translation (17t);
- the third sub-oscillator (9) is coupled to the fourth sub-oscillator (11) by means of a second coupler link (19), these sub-oscillators (9, 11) and said second coupler link (19) being arranged such that these sub-oscillators (9, 11) are constrained to rotate synchronously in opposite directions of rotation as said second coupler link (19) translates along a second axis of translation (19t) which is substantially orthogonal to said first axis of translation (17t);
- said oscillator system (1) further comprises a driving block (25) arranged to be driven in a circular or oval pathway by means of a crank, said driving block (25) being coupled to said first coupler link (17) by means of a third coupler link (21) and to said second coupler link (19) by means of a fourth coupler link (27);
and wherein said frame (3), said substantially rigid supports (5a, 7a, 9a, 11a), said flexure pivots (5b, 7b, 9b, 11b) and said coupler links (17, 19, 21, 27) are coplanar.

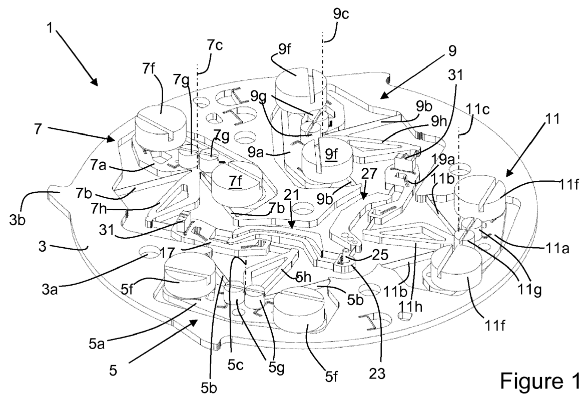

Figure 1

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Description

Technical Field

[0001] The present invention relates to the technical field of horological oscillators. More particularly, it relates to a two degree of freedom mechanical oscillator.

State of the art

[0002] Coupled horological oscillators are known in the documents EP2491463, CH700747 and FR322419. In each of these documents, the oscillator comprises two balance wheels which are coupled to each other by means of teeth. These teeth are either provided on the periphery of the balances, or on gear wheels concentric with each balance, such that the balances turn synchronously in opposite directions. A restoring force is provided by a hairspring associated with each balance, and an escapement is arranged to interact with one or both balances.

[0003] The aim of these arrangements is to improve the isochronism of the oscillator, and to minimize the influence of gravity and shocks thereupon.

[0004] However, the use of teeth to couple the balances in rotation results in non-negligible friction losses. Plus, the use of a conventional escapement in these arrangements is associated with a significant loss of energy in the gear train of the movement in which the oscillator is integrated. In essence, the stop-and-go discretization of time introduces energy losses such as audible ticking and significant accelerations of the movement's gear wheels. In order to overcome this issue, moves have been made to develop oscillators that operate without a conventional escapement, by exploiting multiple degree-of-freedom oscillators. Examples of such are described in EP2894521, EP3095010. These documents contain a definitive discussion of the conditions required for isochronism to be present in an oscillator, which thus need not be repeated at length here and are hereby incorporated by reference in their entirety.

[0005] However, these oscillators are sensitive to the direction of the gravity vector, i.e. to their orientation in space. Plus, they are also sensitive to angular and linear shocks, and as a result are unsuitable for use in a wristwatch or other portable timepiece.

[0006] More recently, document US 2017/269551 discloses a coupled oscillator comprising two rectilinearly-moving inertial bodies coupled together such that they translate linearly in opposite directions along respective axes of displacement, these axes being parallel to each other and defined by the flexure systems which support and guide the bodies. The coupler link which transmits force from one body to the other has an "S" shape, and passes between the two bodies. During oscillation, this coupler pivots about its midpoint at the centre of the mechanism. This arrangement is highly sensitive to angular shocks in the plane of the system, which will affect the movement of the inertial bodies, thereby increasing or decreasing the amplitude of the half-oscillation affected, depending on whether the direction of the shock acts with or against it.

[0007] US 9 465 363 discloses a two degree of freedom oscillator comprising four balances mounted on flexure pivots so as to oscillate around respective axes of rotation. These balances are coupled by means long flexible blades which are attached to lever arms fixed to each balance, the blades being joined at a midpoint by a rigid ring. By driving this ring in a circular or oval trajectory by means of a crank, the four balances are caused to oscillate and to regulate the rotation of the crank. However, the arrangement of coupler links does not permit each opposed pair of sub-oscillators to oscillate independently, which results in a sub-optimal isochronism.

[0008] An aim of the present invention is hence to be able to at least partially overcome these drawbacks.

Disclosure of the invention

[0009] More specifically, and according to a first aspect, the invention relates to an oscillator system comprising:

- a substantially planar frame, serving to support the various other elements of the system;
- a first sub-oscillator, a second sub-oscillator, a third sub-oscillator and a fourth sub-oscillator, each sub-oscillator respectively comprising a substantially rigid support carrying at least one inertial mass defining the majority of the inertia of the corresponding sub-oscillator. Each rigid support is furthermore joined to said frame by means of a respective flexure pivot comprising one or more flexure elements defining a corresponding axis of rotation.

[0010] The first sub-oscillator is coupled to the second sub-oscillator by means of a first coupler link, the third and fourth sub-oscillators and said first coupler link being arranged such that the first and second sub-oscillators are constrained to rotate synchronously in opposite directions of rotation as said first coupler link translates along a first axis of translation. Likewise, the third sub-oscillator is coupled to the fourth sub-oscillator by means of a second coupler link, the third and fourth sub-oscillators and said second coupler link being arranged such that the third and fourth sub-oscillators are constrained to rotate synchronously in opposite directions of rotation as said second coupler link translates along a second axis of translation which is substantially orthogonal to said first axis of translation.

[0011] The oscillator system further comprises a driving block arranged to be driven in a circular or oval pathway by means of a crank, said driving block being coupled to said first coupler link by means of a third coupler link and to said second coupler link by means of a fourth coupler link and hence to permit the above-mentioned translations of the first and second coupler links.

[0012] According to this aspect of the invention, said frame, said substantially rigid supports, said flexure pivots and said coupler links are coplanar, and as such lie in the same plane.

[0013] As a result, the oscillator system is insensitive to the direction of the gravity vector, and to linear and rotational shocks, due to the disposition of the four sub-oscillators, and is extremely compact considered perpendicular to said plane. Furthermore, the majority of the system (namely the frame, supports, flexure pivots, coupler links and driving block) can be manufactured in one piece, e.g. by micromachining from a plate of material such as silicon, metal, ceramic, glass, glass-ceramic or similar.

[0014] Advantageously, said frame, said substantially rigid supports, said flexure pivots and said coupler links can have a substantially uniform thickness considered orthogonal to the plane of the oscillator system, and can be integrally formed as a single piece.

[0015] According to a second aspect of the invention, the oscillator system comprises:

- a substantially planar frame serving to support the various other elements of the system;
- a first sub-oscillator, a second sub-oscillator, a third sub-oscillator and a fourth sub-oscillator, each sub-oscillator respectively comprising a substantially rigid support carrying at least two inertial masses, defining the majority of the inertia of the corresponding sub-oscillator. Each rigid support is furthermore joined to said frame by means of a respective flexure pivot defining a corresponding axis of rotation.

[0016] The first sub-oscillator is coupled to the second sub-oscillator by means of a first coupler link, the first and second sub-oscillators and said first coupler link being arranged such that the first and second sub-oscillators are constrained to rotate synchronously in opposite directions of rotation as said first coupler link translates along a first axis of translation. Likewise, the third sub-oscillator is coupled to the fourth sub-oscillator by means of a second coupler link, the third and fourth sub-oscillators and said second coupler link being arranged such that the third and fourth sub-oscillators are constrained to rotate synchronously in opposite directions of rotation as said second coupler link translates along a second axis of translation which is substantially orthogonal to said first axis of translation.

[0017] The oscillator system further comprises a driving block arranged to be driven in a circular or oval pathway by means of a crank, said driving block being coupled to said first coupler link by means of a third coupler link and to said second coupler link by means of a fourth coupler link, in order to permit the above-mentioned translations of the first and second coupler links.

[0018] According to this aspect of the invention, each of said inertial masses are mounted on the corresponding substantially rigid support by means of a respective pin defining an axis of rotation which is offset from, and hence does not pass through, the centre of mass of said inertial mass.

[0019] As a result, the oscillator system is insensitive to the direction of the gravity vector and to linear and rotational shocks, due to the disposition of the four sub-oscillators. Furthermore, since the axis of rotation of each of the inertial masses does not pass through its respective centre of mass, by rotating the masses with respect to the corresponding support, the inertia of each sub-oscillator can be tuned so as to adjust its resonant frequency very easily.

[0020] Advantageously, each of the aforementioned pins is rotationally-integrated with its respective inertial mass and is friction fitted into a corresponding opening provided in the corresponding substantially rigid support. This opening can, for example, comprise at least one elastic sidewall or elastic tongues, in order to reduce the stresses in the material of the support and to optimise the friction fit.

[0021] Advantageously, each substantially rigid support can carry at least four of said inertial masses, enabling the inertia and the position of the centre of mass of the sub-oscillators to be more precisely adjusted. These masses may be divided into a first pair of said inertial masses and a second pair of inertial masses, the first pair being arranged closer to the axis of rotation of said support and having a lower mass than said second pair. This configuration is optimal for adjusting the inertia, the position of the centre of mass of each sub-oscillator, and hence the isochronism of the system.

[0022] According to a third aspect of the invention, the oscillator system comprises:

- a substantially planar frame serving to support the various other elements of the system;
- a first sub-oscillator, a second sub-oscillator, a third sub-oscillator and a fourth sub-oscillator, each sub-oscillator comprising a substantially rigid support carrying at least one inertial mass defining the majority of the inertia of the corresponding sub-oscillator. Furthermore, each sub-oscillator is joined to said frame by means of a respective flexure pivot defining a corresponding axis of rotation.

[0023] The first sub-oscillator is coupled to the second sub-oscillator by means of a first coupler link, the third and fourth sub-oscillators and said first coupler link being arranged such that the first and second sub-oscillators are constrained to rotate synchronously in opposite directions of rotation as said first coupler link translates along a first axis of translation. Likewise, the third sub-oscillator is coupled to the fourth sub-oscillator by means of a second coupler link, the third and fourth sub-oscillators and said second coupler link being arranged such that the third and fourth sub-oscillators are constrained to rotate synchronously in opposite directions of rotation as said second coupler link translates along a second axis of translation which is substantially orthogonal to said first axis of translation.

[0024] The oscillator system further comprises a driving block arranged to be driven in a circular or oval pathway by means of a crank, said driving block being coupled to said first coupler link by means of a third coupler link and to said second coupler link by means of a fourth coupler link and hence to permit the above-mentioned translations of the first and second coupler links.

[0025] According to this aspect of the invention, at least one of said first coupler link and said second coupler link supports a reflector arranged to reflect a laser beam.

[0026] This reflector enables laser measurements of the displacements of the coupler links, on the basis of which the frequencies of oscillation of the sub-oscillators can be determined and the system tuned accordingly by modifying the inertia of the various sub-oscillators and/or the stiffness of the flexure pivots.

[0027] Advantageously, at least a part of a reflecting surface of said reflector is situated in a plane substantially orthogonal to the axis of displacement of said coupler link.

[0028] Advantageously, said reflector is friction fitted into an opening provided in said coupler link, said opening preferably comprising an elastic structure in contact with said reflector. The reflectors can thus simply be fitted into and held in the coupler links without requiring welding, gluing or similar.

[0029] According to a fourth aspect of the invention, the oscillator system comprises:

- a substantially planar frame, serving to support the various other elements of the system;
- a first sub-oscillator, a second sub-oscillator, a third sub-oscillator and a fourth sub-oscillator, each sub-oscillator comprising a substantially rigid support carrying at least one inertial mass defining the majority of the inertia of the corresponding sub-oscillator. Each rigid support is furthermore joined to said frame by means of a respective flexure pivot comprising one or more flexure elements defining a corresponding axis of rotation.

[0030] The first sub-oscillator is coupled to the second sub-oscillator by means of a first coupler link, the third and fourth sub-oscillators and said first coupler link being arranged such that the first and second sub-oscillators are constrained to rotate synchronously in opposite directions of rotation as said first coupler link translates along a first axis of translation. Likewise, the third sub-oscillator is coupled to the fourth sub-oscillator by means of a second coupler link, the third and fourth sub-oscillators and said second coupler link being arranged such that the third and fourth sub-oscillators are constrained to rotate synchronously in opposite directions of rotation as said second coupler link translates along a second axis of translation which is substantially orthogonal to said first axis of translation.

[0031] The oscillator system further comprises a driving block arranged to be driven in a circular or oval pathway by means of a crank, said driving block being coupled to said first coupler link by means of a third coupler link and to said second coupler link by means of a fourth coupler link and hence to permit the above-mentioned translations of the first and second coupler links.

[0032] According to this aspect of the invention, at least said flexure pivots are made of monocrystalline silicon, each of said respective flexure pivots comprising one flexure extending substantially along a [010] crystal direction of said silicon and one flexure extending substantially along a [100] crystal direction of said silicon. These flexures can be, for instance, blade flexures, or equivalent flexures based on a pair of cols situated either side of a rigid bar, such as that illustrated in Figure 5.5 of the publication "The Art of Flexure Mechanism Design", Florent Cosandier, Simon Henein, Murielle Richard and Lennart Rubbert, EPFL Press, 2017.

[0033] As a result, the Young's modulus of the flexures is minimised, enabling the flexures to have the maximum size (and hence maximum strength) for a given stiffness. This also permits a slightly lower resonant frequency than would otherwise be possible.

[0034] Advantageously, said frame and/or said substantially rigid supports are of monobloc, i.e. one-piece, construction with said flexure pivots. Ideally, said frame, said flexure pivots, said supports, said driving block and said coupler links are monobloc with one another. These elements can hence be micromachined from a plate of material as mentioned above, minimising the number of assembly steps.

[0035] According to a fifth aspect of the invention, the oscillator system comprises:

- a substantially planar frame, serving to support the various other elements of the system;
- a first sub-oscillator, a second sub-oscillator, a third sub-oscillator and a fourth sub-oscillator, each sub-oscillator comprising a substantially rigid support carrying at least one inertial mass defining the majority of the inertia of the corresponding sub-oscillator. Each rigid support is furthermore joined to said frame by means of a respective flexure pivot comprising one or more flexure elements defining a corresponding axis of rotation.

[0036] The first sub-oscillator is coupled to the second sub-oscillator by means of a first coupler link, the third and fourth sub-oscillators and said first coupler link being arranged such that the first and second sub-oscillators are constrained to rotate synchronously in opposite directions of rotation as said first coupler link translates along a first axis of translation. Likewise, the third sub-oscillator is coupled to the fourth sub-oscillator by means of a second coupler link, the third and fourth sub-oscillators and said second coupler link being arranged such that the third and fourth sub-oscillators are constrained to rotate synchronously in opposite directions of rotation as said second coupler link translates along a second axis of translation which is substantially orthogonal to said first axis of translation.

[0037] The oscillator system further comprises a driving block arranged to be driven in a circular or oval pathway by means of a crank, said driving block being coupled to said first coupler link by means of a third coupler link defining at least one respective pivot point between the third coupler link and the first coupler link, and to said second coupler link by means of a fourth coupler link defining at least one respective pivot point between the fourth coupler link and the second coupler link.

[0038] According to this aspect of the invention, each of said third and fourth coupler links comprises at least one rigid body arranged such that its centre of mass lies substantially on the corresponding pivot point.

[0039] Since the centre of mass of each of said rigid bodies lies on the respective pivot point as defined above, the forces engendered during displacement of each coupler link cannot exert a moment around either the centre of mass or said pivot point.

[0040] To this end, each of said rigid bodies typically extends beyond the respective pivot point of the corresponding coupler link and crosses the corresponding axis of translation in order to be able to bring the centre of mass to the desired point.

[0041] The following advantageous features apply equally to each aspect of the invention.

[0042] Advantageously, each of said flexure pivots can be a remote centre compliance flexure pivot.

[0043] Advantageously, each of said flexure pivots can comprise two rectilinear blade flexures arranged at substantially 90° with respect to each other.

[0044] Advantageously, each of said coupler links comprises at least one substantially rigid body extending between a corresponding pair of flexures, each of said flexures defining a pivot point with respect to the adjacent element to which the coupler link is attached.

[0045] Advantageously, at least one of said third and fourth coupler links comprises a pair of substantially rigid bodies each extending between a respective pair of flexures, each of said flexures defining a pivot point, said flexures and said substantially rigid bodies being arranged such that an axis joining the respective pivot points of one of said substantially rigid bodies is parallel to an axis joining the respective pivot points of the other of said substantially rigid bodies. As a result, parasitic small rotations of the driving block can be minimised or even eliminated entirely.

[0046] Advantageously, each of said sub-oscillators comprises a substantially rigid lever extending from the respective substantially rigid support to the respective coupler link.

[0047] Advantageously, said first sub-oscillator is a mirror image of said fourth sub-oscillator and said second sub-oscillator is a mirror image of said third sub-oscillator considered with respect to a plane orthogonal that of the frame and intersecting on the one hand a point equidistant between the respective axes of rotation of the first and fourth sub-oscillators, and on the other hand a point equidistant between the respective axes of rotation of the second and third sub-oscillators. This symmetry minimises the effect of the direction of the gravity vector and of rotational or linear shocks as much as possible.

[0048] The various oscillator systems as defined above can be incorporated into a timepiece movement, which can itself be incorporated into a timepiece.

Brief description of the drawings

[0049] Further details of the invention will appear more clearly upon reading the description below, in connection with the following figures, in which:

- Figure 1 is an isometric view of an oscillator system according to the invention;
- Figure 2 is a plan view of the oscillator system of figure 1;
- Figure 3 is a plan view similar to that of figure 2, the inertial masses having been removed;
- Figure 4 is an isometric exploded view of part of the first sub-oscillator of the oscillator system of figure 1;
- Figure 5 is a schematic view of the third and fourth coupler links and their interaction with the driving block, the first and the second coupler links;
- Figure 6 is a plan view similar to that of figure 3, focussing on the coupler links;
- Figure 7 is an isometric view of a further variant of an oscillator system according to the invention;
- Figure 7a is an exploded view of the oscillator system of figure 7;
- Figure 8 is a partial isometric view of a further variant of an oscillator system according to the invention, illustrating variations in the shapes of certain elements;
- Figure 9 is a partial isometric view illustrating a reflector provided on the first coupler link;
- Figure 10 is a schematic view similar to that of figure 5, in which the rigid bodies of the third and fourth coupler links extend so as to bring their centre of masses to their pivot points with respect to the first and fourth coupler links respectively;
- Figure 11 is a graph of the Young's Modulus of monocrystalline silicon in function of the angle with respect to the crystal directions;
- Figure 12 is a view similar to that of figure 3 upon which the silicon crystal directions have been represented; and
- Figure 13 represents schematically a crank arrangement for driving the oscillator system of the invention.

Embodiments of the invention

[0050] In the present specification, the term "substantially rigid" and "rigid" are used synonymously to signify that an element does not undergo deformations which influence the functioning of the system, at least in the directions specified. "Substantially flexible" and "flexible" or "substantially elastic" and "elastic" imply that, during functioning of the system, deformations of the element under consideration take place as intended, the element being substantially rigid in other directions in which deformations are not intended. It is noted that an element described as "substantially rigid" or "rigid" without mention of a direction hence undergoes no function-influencing deformation in any direction. Furthermore, it should be borne in mind that in some situation, parasitic displacements of certain elements in rotation and/or in translation according to axes other than those of a desired, specified displacement are unavoidable. However, these are trivial (less than 2% of the desired displacement) and can be ignored.

[0051] Figures 1 and 2 illustrate a first embodiment of an oscillator system 1 according to the invention.

[0052] This oscillator system 1 as illustrated is constructed such that all of the supporting and elastic elements are constructed in a single plane, for instance by micromachining from a single sheet of a suitable material such as silicon, alumina (ruby, sapphire, corundum etc.), synthetic diamond, glass, ceramics, glass ceramics, amorphous metals or similar. In the case of crystalline materials being used, this can be monocrystalline, polycrystalline or nanocrystalline. This micro machining can be carried out e.g. by electric discharge machining (EDM), masking followed by wet (chemical) or dry (e.g. ion) etching, and so on. Alternatively, additive manufacture can be used, e.g. 3D printing of various types such as selective laser sintering, the well-known LIGA process, laser cutting, water jet cutting, photolithography and so on, as appropriate for the material chosen. However, multi-piece constructions are also feasible, even if not preferred.

[0053] Oscillator system 1 comprises a substantially planar frame 3 defining a plane. This frame 3 is substantially rigid and is arranged to be attached to a framework component of a timepiece e.g. by means of screws, welding, soldering, clamping, gluing or similar. To this end, in the illustrated embodiment frame 3 comprises a plurality of through-holes 3a (of which only one has been indicated to avoid overloading the figures with redundant reference signs), and a plurality of lugs 3b (of which only one has been indicated for the same reasons) extending outwardly from the periphery of the support 3 in its plane, which are artefacts of manufacture, serving to attach the frame 3 to the wafer from which it is formed. In order to precisely position the frame 3 in its plane, one or more holes 3d with a V-shaped sidewall is provided, together with one or more holes 3e with a flat sidewall, indicated on figure 2 only. The aforementioned sidewalls provide contact points for pins (not illustrated) extending from the underlying framework. Positioning by means of the V-shaped hole 3d and one of the holes 3e with a flat sidewall provides an isostatic in-plane positioning of the oscillator system 1 with respect to the underlying framework. In order to take up any play, one or more further holes 3f are provided, each having an elastic sidewall 3g formed e.g. as a blade. This elastic sidewall 3g interacts with a further pin or similar provided on the framework so as to force the aforementioned sidewalls of the holes 3d and 3e into positive contact with their respective pins. Other arrangements are of course possible.

[0054] Oscillator system 1 further comprises four individual sub-oscillators 5, 7, 9, 11, each comprising a substantially rigid support 5a, 7a, 9a, 11a arranged to carry one or more inertial masses 13, 15. The supports 5a, 7a, 9a, 11a are joined to the frame 3 by means of a respective flexure pivot 5b, 7b, 9b, 11b arranged to support the respective support 5a, 7a, 9a, 11a such that it can pivot about its respective virtual axis of rotation 5c, 7c, 9c, 11c (see figure 3) defined by the flexure pivots 5b, 7b, 9b, 11b. These axes of rotation 5c, 7c, 9c, 11c are parallel to each other, and perpendicular to the plane of the frame 3. Furthermore, these flexure pivots 5b, 7b, 9b, 11b also apply a restoring force to their respective supports 5a, 7a, 9a, 11a. This restoring force, together with the combined inertia of the respective support 5a, 7a, 9a, 11a and the one or more inertial masses 5f, 7f, 9f, 11f, 5g, 7g, 9g, 11g fixed thereto, substantially determines the natural resonant frequency of each respective sub-oscillator 5, 7, 9, 11.

[0055] The sub-oscillators will now be described in reference to first sub-oscillator 5, the other sub-oscillators 7, 9 and 11 comprising the same components with the same reference sign suffixes a, b, c etc. It is hence not necessary to describe each sub-oscillator 5, 7, 9, 11 individually since they are substantially functionally identical in respect of all aspects aside from their orientations with respect to the frame 3 and the exact shape of certain elements. Indeed, the exact shape and orientation of certain elements such as the supports is inconsequential insofar as the same functionality is reproduced.

[0056] First support 5a is of broadly elongated shape, and is connected to the frame 3 by means of a flexure pivot comprising a pair of rectilinear flexures 5b arranged at an angle of substantially 90° with respect to each other, when in an unstressed state. These flexures 5b are substantially flexible in the plane of the support 3 and are substantially rigid in a direction perpendicular to said plane, and are arranged to form a Remote Centre Compliance (RCC) flexure pivot defining a virtual axis of rotation 5c at substantially the intersection of the longitudinal axes of the individual flexures 5b. In the illustrated embodiment, these flexures 5b are simple blade flexures, but can also each be replaced a functional equivalent such as a substantially rigid beam situated between a pair of blade flexures or cols, or similar. On this point, the general knowledge of the skilled person includes the books "Conception des Guidages Flexibles", Prof. Simon Henein, PPUR, 2003, particularly chapter 6 thereof, and also the updated version "The Art of Flexure Mechanism Design", Florent Cosandier, Simon Henein, Murielle Richard and Lennart Rubbert, EPFL Press, 2017, particularly figure 5.5 thereof. The skilled person is hence aware of a large number of equivalent flexure pivots. Also, if desired, these flexures 5b can be curved or comprise bends if desired, since it is not essential that they be straight so long as their function is not compromised.

[0057] Support 5a comprises a first pair of openings 5i (see figure 3) disposed at equal distances from the axis of rotation 5c, these openings being arranged to receive a pin (see figure 4) which is integral with a respective inertial mass 5f. These inertial masses typically represent the overwhelming majority (at least 75%, preferably at least 90%) of the inertia of the sub-oscillator which, together with the elastic coefficient of the flexures 5b, define its resonant frequency. In the illustrated embodiment, the pin is eccentric with respect to the centre of mass of the inertial masses 5f, the position of the centre of mass being indicated by chain lines passing therethrough, perpendicular to the plane of the frame 3. Hence, by adjusting the angular position of each of the masses 5f with respect to the support 5a, for instance by means of a screwdriver cooperating with the clearly visible slot or any other convenient arrangement, the inertia and the position of the centre of mass of the sub-oscillator 5 can be adjusted in order to optimise the frequency and equilibrium of the sub-oscillator 5.

[0058] A second, similar pair of openings 5j is provided, each being closer to the axis of rotation 5c than the corresponding first opening 5i. These openings 5j each likewise receive the pin of a further inertial mass 5g, whose centre of mass is likewise eccentric with respect to its pin. These further inertial masses 5g are of lower mass than the first masses 5f. The four openings 5i, 5j are here arranged substantially in a straight line, although this does not have to be the case as is clearly visible on the second and third sub-oscillators 5, 9, in which the pairs of openings 7i, 7j; 9i, 9j are not similarly aligned. These further inertial masses 5g help to tune the inertia and the position of the centre of mass of the sub-oscillator 5, and as such can be adjusted in order to modify the isochronism. Alternatively, one or more adjustable or non-adjustable masses can be used instead of the illustrated arrangement.

[0059] Although the various openings 5i, 5j can simply be circular or polygonal through-holes into which the pins of the masses 5f, 5g are friction-fitted, in the illustrated embodiment one sidewall 5k of each opening 5i, 5h is flexible (see figure 4). This flexibility is created by forming a slot behind the sidewall, which reduces the stresses in the material of the support 5a while providing enough retaining force to hold the various masses 5f, 5g in place. This applies equally to all of the other sub-oscillators 7, 9, 11, as can clearly be seen on figures 1-3. Other flexible arrangements with the same functionality are known to the skilled person, such as flexible tongues and so on.

[0060] The support 5a also comprises a lever 5h extending laterally therefrom. This lever 5h can be of any desired shape, and may comprise an opening to reduce its mass, as in the case illustrated.

[0061] This lever 5h is attached to a first coupler link 17, which serves to couple its distal extremity to the distal extremity of lever 7h of second sub-oscillator 7, and thereby to form a first coupled oscillator. The levers 5h, 7h, 9h, 11h all have the same effective length considered from the corresponding axis of rotation 5c, 7c, 9c, 11c respectively.

[0062] The first coupler link 17 comprises a substantially rigid body 17a provided with a flexure pivot 17b at each end thereof. In the illustrated embodiment, these flexure pivots 17b are simple blades, but they can also be formed by cols or similar structures which are functionally similar to pinned pivots. The flexure pivots 17b define pivot points (i.e. axes of articulation) that permit the rigid body 17a of the first coupler 17 to articulate with respect to the levers 5h, 7h. By these means, the coupler link 17 transmits force exclusively in along a direction joining these points of articulation, with substantially no force being applied orthogonal to this direction. Indeed, these points of articulation define an axis of translation 17t (see figure 3) along which the coupler link 17 translates (ignoring parasitic rotations of the coupler link 17 since these are trivial; technically it is the centre point of the coupler link situated equidistant from its pivot points which strictly is displaced rectilinearly along this axis, but for small oscillations of the sub-oscillators [see below] the entire coupler link 17 can be considered as translating linearly).

[0063] The two sub-oscillators 5, 7 are arranged such that they have substantially the same resonant frequency, and are situated either side of the first coupler link 17 such that they rotate synchronously in opposite directions at substantially the same amplitude. In the illustrated embodiment, each elastic element 5b extends parallel to one of the elastic elements 7b, in an unstressed state. As a result, when the first coupler link 17 is displaced along the axis 17t, this displacement is converted into a rotation of each sub-oscillator 5, 7 via the respective levers 5h, 7h.

[0064] Fourth sub-oscillator 11 is a mirror image of first sub-oscillator 5, considered with respect to plane P (see figure 3) which is orthogonal to the plane of the system 1 and intersects a first point equidistant between the respective axes of rotation 5c, 11c of the first and fourth sub-oscillators 5, 11, and also intersects a second point equidistant between the respective axes of rotation 7c, 9c of the second and third sub-oscillators 7, 9. In the illustrated embodiment, the result of this is that, when all the flexures 5b, 7b, 9b, 11b are unstressed, one elastic element 5b, 11b of each sub-oscillator 5, 11 is coplanar, the other elastic element 5b, 11b of each sub-oscillator being situated in parallel planes, themselves parallel to plane P.

[0065] Likewise, third sub-oscillator 9 is a mirror image of second sub-oscillator 7, arranged similarly with respect to plane P, mutatis mutandis.

[0066] However, although this structural symmetry is advantageous for minimising the influence of the direction of the gravity vector and shocks as far as possible since these will influence the various sub-oscillators in an equal and opposite fashion and hence cancel out, it is not strictly essential provided that each sub-oscillator is functionally equivalent in respect of its elastic and inertial properties.

[0067] In respect of third and fourth sub-oscillators 9, 11, the distal extremity of lever 9h of sub-oscillator 9 is coupled to the distal extremity of lever 11h by a second coupler link 19, which is substantially functionally the same as first coupler link 17, and, in its unstressed state, extends functionally perpendicular thereto, such that it substantially translates along its axis of translation 19t (in a manner analogous to first coupler link 17), which is orthogonal to the axis of translation 17t of first coupler link 17. As a result, third 9 and fourth 11 sub-oscillators are coupled and hence form a second coupled oscillator.

[0068] First and second coupler links 17, 19 are themselves linked to a driving block 23 by a third coupler link 21 and a fourth coupler link 27 respectively, illustrated schematically at larger scale and in a different orientation on figure 5, and at a larger scale in the present construction in figure 6. Driving block 23, which may be of any convenient shape such as cuboid, cylindrical or similar, supports a driving pin 25 extending out of the plane of the framework and arranged to be driven in a substantially circular or oval movement by a crank, as is known in the context of EP3095010, EP3339969, and many other crank-driven oscillators. As a non-limiting alternative construction, the crank may for instance comprise a pin which is loosely fitted into an opening in the driving block 23. Other constructions are of course possible.

[0069] Third coupler link 21 joins the driving block 23 to the rigid body 17a of the first coupler link 17 by means of a pair of functionally-parallel flexure systems 21a, 21b, each comprising a substantially rigid body 21d situated between two flexures 21c, one of which is attached to the first coupler link 17a, the other being attached to the driving block 25. "Functionally-parallel" in this context means that the flexure systems 21a, 21b act parallel to each other, irrespective of their exact shape. For instance, in figure 6 the horizontal chain lines illustrate the directions of action of these flexures for small displacements (i.e. displacements related to angular displacements of the corresponding sub-oscillators for which the small angle approximation holds, i.e. approximately +/- 0.2 radians), passing through their respective pivot points as defined by the midpoints of each of the blade flexures 21c extending either side of their respective rigid bodies 21d. In figure 5, these flexures are illustrated schematically as being physically entirely parallel, although in figure 6, the rigid bodies 21d are bent so as to pass around parts of the first coupler link's rigid body 17a and the extremity of the lever 5h. However, the direction of force transmission remains defined by the positions of the blade flexures 21c and the exact shape taken by the rigid bodies 21d is immaterial.

[0070] The use of two parallel flexures for third coupler link 21 eliminates a degree of freedom of rotation of the drive block 23, preventing it from rotating parasitically about the longitudinal axis of pin 25.

[0071] Fourth coupler link 27 comprises a single flexure system comprising a yet further rigid body 27a fixed to the second coupler link's rigid body 19a by a blade flexure 27b, and to the drive block 23 by a further blade flexure 27b. Fourth coupler link 27 is functionally orthogonal to third coupler link 21, and to each of the flexure systems 21a, 21b which define it. In an unstressed state, the effective direction of action of the fourth coupler link (as indicated by the vertical chain line) for small displacements is perpendicular to the effective direction of action of the third flexure system (represented by the horizontal dashed line situated equidistant to the two horizontal chain lines representing the directions of action of the individual flexure systems 21a, 21b), these effective directions of action intersecting the axis of the driving pin 25 when the system is unstressed. In the illustrated embodiment, the direction of action of the third coupler link for small displacements from the unstressed state is substantially congruent with the axis of translation 17t of the first coupler link 17, and that of the fourth coupler link is likewise substantially congruent with the axis of translation 19t of the second coupler link 19. However, this congruence does not strictly have to be present, but a different arrangement is suboptimal since it will create off-axis forces during oscillation, thereby causing an isochronism defect.

[0072] Alternatively, the fourth coupler link 27 may comprise a pair of flexure systems, and the third coupler link 21 may comprise a single flexure system, both coupler links 21, 27 may comprise single flexure systems, or both may comprise double flexure systems. Furthermore, in any of these permutations, the blade flexures 21c, 27b may be replaced with cols or similar, functionally-equivalent flexures, as is generally known.

[0073] It should be noted that the third and fourth coupler links 21, 27 may be attached to the respective rigid bodies 17a, 19a of the first and second coupler links 17, 19 at any convenient point, however it is advantageous that the direction of action of each pair of coupler links 17, 21 and 19, 27 respectively is substantially coaxial when the various flexures are in an unstressed state, as can be clearly seen on figure 6. This ensures that undesired rotations are not generated during operation. Furthermore, the exact shape of the coupler links 17, 19, 21, 27 can be chosen at will given the constraints of the available space and the position of the other elements.

[0074] As can be seen from the geometry, if the pin 25 is moved to the left or right on figure 6, first coupler link 17 will be displaced in the same direction, causing first and second sub-oscillators 5, 7 to rotate in opposite directions. Fourth coupler link 27 can simply tilt in the plane of the frame without substantially applying any force to the second coupler link 19, with the result that the third and fourth sub-oscillators 9, 11 do not move.

[0075] If, on the other hand, the pin 25 is moved up or down on figure 6, second coupler link 19 will be displaced in the same direction, causing third and fourth sub-oscillators 9, 11 to rotate in opposite directions. Each flexure system 21a of third coupler link 21 can likewise simply tilt without substantially applying any force to the first coupler link 17, with the result that first and second sub-oscillators 5, 7 do not move.

[0076] When, on the other hand, pin 25 is driven by means of a crank (see figure 13 and the description thereof below) in a circular or oval pathway, the vertical component of its motion excites the second and third sub-oscillators 9, 11, and the horizontal component of its motion excites the first and second sub-oscillators 5, 7. As a result, all four sub-oscillators 5, 7, 9, 11 oscillate, the oscillations of each pair of sub-oscillators 5, 7 and 9, 11 respectively oscillating independently of the other pair 9, 11 and 5, 7 respectively.

[0077] These oscillations regulate the angular velocity of the crank, thereby providing a timebase for the operation of the movement in (not illustrated) in which the oscillator system 1 is integrated.

[0078] Figures 7 and 8 illustrate a further variant of an oscillator system 1 according to the invention, which differs from that of figures 1-6 in the following particulars. In order to avoid over-charging the figures, only the elements explicitly referred to in the foregoing are provided with reference signs; the other elements are substantially unchanged.

[0079] The primary difference of this further variant is that the inertial masses 5f, 7f, 9f, 11f are each unitary, and are not adjustable. Each of these masses is simply attached to its respective rigid body 5a, 7a, 9a, 11a by a pair of pins 29, these pins 29 being arranged to provide sufficient spacing in the thickness of the system such that the inertial masses 5f, 7f, 9f, 11f do not enter into contact with the frame 3. Other arrangements, such as welding, gluing, screws and so on are also possible. As a result, the form of each rigid body 5a, 7a, 9a, 11a is simplified, and the holes provided therein to receive the pins 29 can either be simple circular holes, or can be provided with a flexible sidewall as in the embodiment of figures 1-6. Other forms of inertial bodies, such as conventional balances and similar, are also possible.

[0080] Furthermore, the exact geometric shape of the rigid bodies of coupler links 17, 19, 21, 27 is slightly different, although the various directions of action of the various coupler links remain substantially unchanged.

[0081] Figure 8 illustrates a yet further example of different forms for the various coupler links 17, 19, 21, 27, these being provided with lightening holes in the respective rigid bodies 17a, 19a, 21a, 27a. Furthermore, third coupler link 21 only comprises a single flexure system, and is a mirror reflection of fourth coupler link 21 along the plane P described above. Since the exact forms of the rigid bodies 17a, 19a, 21a, 27a is immaterial, it is not necessary to describe them in detail.

[0082] As can be seen on figures 1, 2, 7, 8 and 9, in order to help to measure the frequency of oscillation of each pair of sub-oscillators 5, 7 and 9, 11, each of the first and second coupler links 17, 19 comprises a reflector 31 (e.g. a mirror) supported by its respective rigid body 17a, 18a, this reflector 31 extending out of the plane of the frame 3. In the illustrated embodiment, these reflectors 31 are held in by flexible clips 17c defining a sidewall of an opening 17d formed in the rigid bodies 17a, 19a of the coupler links 17, 19, or may be force-fitted, glued or welded into simple openings provided therein. Alternatively, instead of flexible clips, the opening may comprise elastic tongues in contact with the reflector 31.

[0083] A laser beam L can be directed to impinge on the reflector 31 in a direction substantially orthogonal to its reflecting plane 31a, in order to measure its displacement optically, e.g. by means of laser optical triangulation or laser Doppler velocimetry. This reflecting plane 31a is typically arranged orthogonal to the axis of displacement 17f of the rigid body 17a, and the laser beam L is parallel to said axis 17f, although other arrangements exploiting measurements of deflection of the beam L by a reflector oriented obliquely with respect to the beam L are also possible.

[0084] By measuring the displacements of the coupler links 17, 19 by means of the laser beam L, the oscillations of each pair of sub-oscillators 5, 7; 9, 11 can be measured, and any required adjustments made. These adjustments can be, for instance, rotating eccentric masses 5a, 5f, 7a, 7f, 9a, 9f of the first embodiment, removal of material from non-adjustable masses 5f of the second variant, removal of material from elastic elements 5b, 7b, 9b, 11b, addition of material by means of inkjet printing or similar to rigid bodies 5a, 7a, 9a, 11a or to masses 5a, 5f, 8a, 7f, 9a, 9f, removal of material from the flexure pivots 5b, 7b, 9b, 10b, or other adjustments

[0085] Figure 10 illustrates schematically a further aspect of the invention. In analogy to figure 5, the rigid bodies 21d and 27a of the third and fourth coupler links 21, 27 respectively are arranged such that their respective centres of mass are as close to the pivot points defined by blade flexures 21c and 27b which join said rigid bodies to the rigid bodies 17a, 19a of first and second coupler links 17, 19 respectively. These pivot points are situated at the midpoint of the blade flexures 21c, 27b in question, as indicated by the circles on figure 10.

[0086] In order to achieve this, each rigid body 21d, 27a is formed such that it extends beyond the corresponding blade flexure 21c, 27b and wraps around such that its centre of mass lies at the desired point. In so doing, each rigid body 21d, 27a extends beyond its respective pivot point 21c, 27b and crosses the line of action of the corresponding flexure system considered when at rest (illustrated by means of dashed lines). Depending on the construction, this may involve the rigid bodies 21a, 27a comprising parallel limbs extending on either side of the plane of the system 1 so as to avoid coming into contact with the rigid bodies 17a, 19a during oscillation. Alternatively, entirely in-plane constructions are possible, the shapes of the various elements being adapted such that they do not contact each other during operation.

[0087] By arranging the centres of mass of the rigid bodies 21d, 27a in this manner, the influence of the direction of the gravity vector on the stiffness of the third and fourth coupler links 21, 27 is reduced or even eliminated, thereby further improving the isochronism of the oscillator system 1.

[0088] It should be noted that the co-planarity of the third and fourth coupler links 21, 27 with the first and second coupler links 17, 19 is only part of the first aspect of the invention. In respect of the other aspects of the invention, the disposition of the third and fourth coupler links 21, 27 is not relevant, and these may hence be arranged in a different plane. For instance, they may be constructed separately and attached to the first and second coupler links 17, 19 by any appropriate means.

[0089] Figures 11 and 12 illustrate another aspect of the present invention. Figure 11 is a graph of the variation of Young's Modulus E in function of the angle φ that the vector of applied force makes with respect to the [110] crystallographic direction of monocrystalline silicon.

[0090] As can be seen from the graph, Young's Modulus is a minimum along the [010] and [100] crystal directions.

[0091] In consequence, one of the rectilinear blade flexures 5b, 7b, 9b, 11b of each sub-oscillator is aligned parallel to the [010] direction (indicated with a_1 suffix in the reference signs), and the other is aligned parallel to the [100] direction (indicated with a_2 suffix in the reference signs). This minimises the stiffness of the rectilinear flexures 5b, 7b, 9b, 11b for given physical dimensions, enabling a good compromise between structural integrity and frequency, this latter being lower than it would otherwise be for flexures of the same dimensions but with different crystallographic orientations. This can sometimes have advantages for instance in respect of reducing energy consumption or in optimising the design of the gear train driving the crank.

[0092] As mentioned above and repeated here for completeness, blade flexures of flexure pivots 5b 7b, 9b, 11b can be replaced with equivalent flexures based on a pair of cols situated either side of a rigid bar, such as that illustrated in Figure 5.5 of the publication *"The Art of Flexure Mechanism Design"* mentioned above. In this case, an axis joining the mid-point of each col of a respective flexure is aligned with the [100] or [010] direction, as appropriate.

[0093] Figure 13 illustrates schematically and partially a timepiece movement 101 comprising an oscillator system 1, of which only pin 25, driving block 23 and the coupler links 21 and 27 have been illustrated. The movement 101 comprises a source of energy M such as a driving spring, electric motor or similar, which drives a gearwheel 103, to which is rigidly attached a bar 105 comprising a slot 107. Bar 105 is typically arranged along a radius of the gearwheel 103 and extends beyond the outer periphery of the gearwheel 103. Other arrangements are of course possible. Driving pin 25 as described above is located slidingly in the slot 107, and as the source of energy M, (which causes torque to be applied to the rotating crank) causes the gearwheel 103 to rotate about its own axis 103a and the crank to cause the driving pin 23 to translate in orbital motion about the axis 103a of the gearwheel 103, thereby to drive the four sub-oscillators 5, 7, 9, 11.

[0094] Although the various aspects of the invention have been described with respect to certain embodiments, variations thereto are possible without departing from the scope of the claims as defined in the appended claims.

Claims

1. Oscillator system (1) comprising:

- a substantially planar frame (3);
- a first sub-oscillator (5), a second sub-oscillator (7), a third sub-oscillator (9), and a fourth sub-oscillator (11), each sub-oscillator (5, 7, 9, 11) comprising a substantially rigid support (5a, 7a, 9a, 11a) carrying at least one inertial mass (5f, 5g, 7f, 7g, 9f, 9g, 11f, 11g) and being joined to said frame (3) by means of a respective flexure pivot (5b, 7b, 9b, 11b) defining a corresponding axis of rotation (5c, 7c, 9c, 11c),

wherein:

- the first sub-oscillator (5) is coupled to the second sub-oscillator (7) by means of a first coupler link (17), these sub-oscillators (5, 7) and said first coupler link (17) being arranged such that these sub-oscillators (5, 7) are constrained to rotate synchronously in opposite directions of rotation as said first coupler link (17) translates along a first axis of translation (17t);
- the third sub-oscillator (9) is coupled to the fourth sub-oscillator (11) by means of a second coupler link (19), these sub-oscillators (9, 11) and said second coupler link (19) being arranged such that these sub-oscillators (9, 11) are constrained to rotate synchronously in opposite directions of rotation as said second coupler link (19) translates along a second axis of translation (19t) which is substantially orthogonal to said first axis of translation (17t);
- said oscillator system (1) further comprises a driving block (25) arranged to be driven in a circular or oval pathway by means of a crank, said driving block (25) being coupled to said first coupler link (17) by means of a third coupler link (21) and to said second coupler link (19) by means of a fourth coupler link (27); and wherein said

frame (3), said substantially rigid supports (5a, 7a, 9a, 11a), said flexure pivots (5b, 7b, 9b, 11b) and said coupler links (17, 19, 21, 27) are coplanar.

2. Oscillator system (1) according to claim 1, wherein said frame (3), said substantially rigid supports (5a, 7a, 9a, 11a), said flexure pivots (5b, 7b, 9b, 11b) and said coupler links (17, 19, 21, 27) have a substantially uniform thickness considered orthogonal to the plane of the oscillator system (1).

3. Oscillator system (1) according to any preceding claim, wherein said frame (3), said substantially rigid supports (5a, 7a, 9a, 11a), said flexure pivots (5b, 7b, 9b, 11b) and said coupler links (17, 19, 21, 27) are integrally formed as a single piece.

4. Oscillator system (1) comprising:

- a substantially planar frame (3);
- a first sub-oscillator (5), a second sub-oscillator (7), a third sub-oscillator (9) and a fourth sub-oscillator (11), each sub-oscillator (5, 7, 9, 11) comprising a substantially rigid support (5a, 7a, 9a, 11a) carrying at least two inertial masses (5f, 5g, 7f, 7g, 9f, 9g) and being joined to said frame (3) by means of a respective flexure pivot (5b, 7b, 9b, 11b) defining a corresponding axis of rotation (5c, 7c, 9c, 11c);

wherein:

- the first sub-oscillator (5) is coupled to the second sub-oscillator (7) by means of a first coupler link (17), these sub-oscillators (5, 7) and said first coupler link (17) being arranged such that these sub-oscillators (5, 7) are constrained to rotate synchronously in opposite directions of rotation as said first coupler link (17) translates along a first axis of translation (17t);
- the third sub-oscillator (9) is coupled to the fourth sub-oscillator (11) by means of a second coupler link (19), these sub-oscillators (9, 11) and said second coupler link (19) being arranged such that these sub-oscillators (9, 11) are constrained to rotate synchronously in opposite directions of rotation as said second coupler link (19) translates along a second axis of translation (19t) which is substantially orthogonal to said first axis of translation (17t);
- the oscillator system (1) further comprises a driving block (25) arranged to be driven in a circular or oval pathway by means of a crank, said driving block (25) being coupled to said first coupler link (25) by means of a third coupler link (21) and to said second coupler link (19) by means of a fourth coupler link (27), and wherein each of said inertial masses (5f, 5g, 7f, 7g, 9f, 9g, 11f, 11g) are mounted on the corresponding substantially rigid support (5, 7, 9, 11) by means of a respective pin defining an axis of rotation offset with respect to the centre of mass of said inertial mass (5f, 5g, 7f, 7g, 9f, 9g, 11f, 11g).

5. Oscillator system (1) according to the preceding claim, wherein each of said pins is rotationally-integrated with the respective inertial mass (5f, 5g, 7f, 7g, 9f, 9g, 11f, 11g) and is friction fitted into a corresponding opening (5i, 5j, 7i, 7j, 9i, 9j, 11i, 11j) provided in the corresponding substantially rigid support (5a, 7a, 9a, 11a).

6. Oscillator system (1) according to the preceding claim, wherein each of said openings (5i, 5j, 7i, 7j, 9i, 9j, 11i, 11j) comprises at least one elastic sidewall.

7. Oscillator system (1) according to one of claims 4-6, wherein each substantially rigid support (5a, 7a, 9a, 11a) carries at least four of said inertial masses (5f, 5g, 7f, 7g, 9f, 9g, 11f, 11g).

8. Oscillator system (1) according to the preceding claim, wherein, each of said substantially rigid supports (5a, 7a, 9a, 11a) carries a first pair of said inertial masses (5g, 7g, 9g, 11g) and a second pair of inertial masses (5f, 7f, 9f, 11f), said first pair of inertial masses (5g, 7g, 9g, 11g) being arranged closer to the axis of rotation of said support and having a lower mass than said second pair of inertial masses (5f, 7f, 9f, 11f).

9. Oscillator system (1) comprising:

- a substantially planar frame (3);
- a first sub-oscillator (5), a second sub-oscillator (7), a third sub-oscillator (9) and a fourth sub-oscillator (11), each sub-oscillator (5, 7, 9, 11) comprising a substantially rigid support (5a, 7a, 9a, 11a) carrying at least one inertial mass (5f, 5g, 7f, 7g, 9f, 9g, 11f, 11g) and being joined to said frame (3) by means of a respective flexure pivot (5b, 7b, 9b, 11b) defining a corresponding axis of rotation (5c, 7c, 9c, 11c);

wherein:

- the first sub-oscillator (5) is coupled to the second sub-oscillator (7) by means of a first coupler link (17), these sub-oscillators (5, 7) and said first coupler link (17) being arranged such that these sub-oscillators (5, 7) are constrained to rotate synchronously in opposite directions of rotation as said first coupler link (17) translates along a first axis of translation (17t);
- the third sub-oscillator (9) is coupled to the

fourth sub-oscillator (11) by means of a second coupler link (19), these sub-oscillators (9, 11) and said second coupler link (19) being arranged such that these sub-oscillators (9, 11) are constrained to rotate synchronously in opposite directions of rotation as said second coupler link (19) translates along a second axis of translation (19t) which is substantially orthogonal to said first axis of translation (17t);
- the oscillator system (1) further comprises a driving block (25) arranged to be driven in a circular or oval pathway by means of a crank, said driving block (25) being coupled to said first coupler link (17) by means of a third coupler link (21) and to said second coupler link (19) by means of a fourth coupler link (27), and wherein at least one of said first coupler link (17) and said second coupler link (19) supports a reflector (31) arranged to reflect a laser beam.

10. Oscillator system (1) according to the preceding claim, wherein at least a part of a reflecting surface of said reflector (31) is situated in a plane substantially orthogonal to the axis of displacement (17t, 19t) of said coupler link (17, 19).

11. Oscillator system (1) according to one of claims 9 or 10, wherein said reflector (31) is friction fitted into an opening (17d) provided in said coupler link (17, 19), said opening (17d) preferably comprising an elastic structure in contact with said reflector (31).

12. Oscillator system (1) comprising:

- a substantially planar frame (3);
- a first sub-oscillator (5), a second sub-oscillator (7), a third sub-oscillator (9) and a fourth sub-oscillator (11), each sub-oscillator (5, 7, 9, 11) comprising a substantially rigid support (5a, 7a, 9a, 11a) carrying at least one inertial mass (5f, 5g, 7f, 7g, 9f, 9g, 11f, 11g) and being joined to said frame (3) by means of a respective flexure pivot (5b, 7b, 9b, 11b) defining a corresponding axis of rotation (5c, 7c, 9c, 11c);

wherein:

- the first sub-oscillator (5) is coupled to the second sub-oscillator (7) by means of a first coupler link (17), these sub-oscillators (5, 7) and said first coupler link (17) being arranged such that these sub-oscillators (5, 7) are constrained to rotate synchronously in opposite directions of rotation as said first coupler link (17) translates along a first axis of translation (17t);
- the third sub-oscillator (9) is coupled to the fourth sub-oscillator (11) by means of a second coupler link (19), these sub-oscillators (9, 11) and said second coupler link (19) being arranged such that these sub-oscillators (9, 11) are constrained to rotate synchronously in opposite directions of rotation as said second coupler link (19) translates along a second axis of translation (19t) which is substantially orthogonal to said first axis of translation (17t);
- the oscillator system (1) further comprises a driving block (25) arranged to be driven in a circular or oval pathway by means of a crank, said driving block (25) being coupled to said first coupler link (17) by means of a third coupler link (21) and to said second coupler link (19) by means of a fourth coupler link (27), and wherein at least said flexure pivots (5b, 7b, 9b, 11b) are made of monocrystalline silicon, each of said respective flexure pivots (5b, 7b, 9b, 11b) comprising one flexure ($5b_1$, $7b_1$, $9b_1$, $11b_1$) extending substantially along a [010] crystal direction of said silicon and one flexure ($5b_2$, $7b_2$, $9b_2$, $11b_2$) extending substantially along a [100] crystal direction of said silicon.

13. Oscillator system (1) according to the preceding claim, wherein at least one of said frame (3) and said substantially rigid supports (5a, 7a, 9a, 11a) are of monobloc construction with said flexure pivots (5b, 7b, 9b, 11b).

14. Oscillator system (1) according to the preceding claim, wherein said frame (3), said flexure pivots (5b, 7b, 9b, 11b), said substantially rigid supports (5a, 7a, 9a, 11a), said driving block (25) and said coupler links (17, 19, 21, 27) are monobloc.

15. Oscillator system (1) comprising:

- a substantially planar frame (3);
- a first sub-oscillator (5), a second sub-oscillator (7), a third sub-oscillator (9) and a fourth sub-oscillator (11), each sub-oscillator (5, 7, 9, 11) comprising a substantially rigid support (5a, 7a, 9a, 11a) arranged to support at least one inertial mass (5f, 5g, 7f, 7g, 9f, 9g, 11f, 11g) and being joined to said frame (3) by means of a respective flexure pivot (5b, 7b, 9b, 11b) defining a corresponding axis of rotation (5c, 7c, 9c, 11c);

wherein:

- the first sub-oscillator (5) is coupled to the second sub-oscillator (7) by means of a first coupler link (17), these sub-oscillators (5, 7) and said first coupler link (17) being arranged such that these sub-oscillators (5, 7) are constrained to rotate synchronously in opposite directions of rotation as said first coupler link (17) translates along a first axis of translation (17t);

- the third sub-oscillator (9) is coupled to the fourth sub-oscillator (11) by means of a second coupler link (19), these sub-oscillators (9, 11) and said second coupler link (19) being arranged such that these sub-oscillators (9, 11) are constrained to rotate synchronously in opposite directions of rotation as said second coupler link (19) translates along a second axis of translation (19t) which is substantially orthogonal to said first axis of translation (17t);
- the oscillator system (1) further comprises a driving block (25) arranged to be driven in a circular or oval pathway by means of a crank, said driving block (25) being coupled to said first coupler link (17) by means of a third coupler link (21) defining at least one respective pivot point (21c) between the third coupler link (21) and the first coupler link (17), and to said second coupler (19) link by means of a fourth coupler link (27) defining at least one respective pivot point (27b) between the fourth coupler link (27) and the second coupler link (19), and wherein each of said third and fourth coupler links (21, 27) comprises at least one rigid body (21d, 27a) arranged such that its respective centre of mass lies substantially on said respective pivot point (21c, 27b).

16. Oscillator system (1) according to the preceding claim, wherein each of said rigid bodies (21d, 27a) extends beyond the respective pivot point (21c, 27b) of the corresponding coupler link (21, 27) and crosses the corresponding line of action of the flexure system to which each rigid body (21d, 27a) belongs.

17. Oscillator system (1) according to any preceding claim, wherein each of said flexure pivots (5b, 7b, 9b, 11b) is a remote centre compliance flexure pivot.

18. Oscillator system (1) according to any preceding claim, wherein each of said flexure pivots (5b, 7b, 9b, 11b) comprises two rectilinear blade flexures arranged at substantially 90° with respect to each other.

19. Oscillator system (1) according to any preceding claim, wherein each of said coupler links (17, 19, 21, 27) comprises at least one substantially rigid body (17a, 19a, 21d, 27a) extending between corresponding a pair of flexures (17b, 19b, 21c, 27b) each of said flexures (17b, 19b, 21c, 27b) defining a pivot point.

20. Oscillator system (1) according to the preceding claim, wherein at least one of said third and fourth coupler links (21, 27) comprises a pair of substantially rigid bodies (21d) each extending between a respective pair of flexures (21c), each of said flexures (21c) defining a pivot point, said flexures (21c) and said substantially rigid bodies (21d) being arranged such that an axis joining the respective pivot points of one of said substantially rigid bodies (21d) is parallel to an axis joining the respective pivot points of the other of said substantially rigid bodies (21d).

21. Oscillator system (1) according to the preceding claim, wherein each of said sub-oscillators (5, 7, 9, 11) comprises a substantially rigid lever (5h, 7h, 9h, 11h) extending from the respective substantially rigid support (5a, 7a, 9a, 11a) to the respective coupler link (17, 19).

22. Oscillator system (1) according to any preceding claim, wherein said first sub-oscillator (5) is a mirror image of said fourth sub-oscillator (11) and said second sub-oscillator (5) is a mirror image of said third sub-oscillator (9), considered with respect to a plane (P) orthogonal to the plane of the frame (3) and intersecting on the one hand a point equidistant between the respective axes of rotation (5c, 11c) of the first and fourth sub-oscillators (5, 11), and on the other hand a point equidistant between the respective axes of rotation (7c, 9c) of the second and third sub-oscillators (7, 9).

23. Timepiece movement (101) comprising an oscillator system (1) according to any preceding claim.

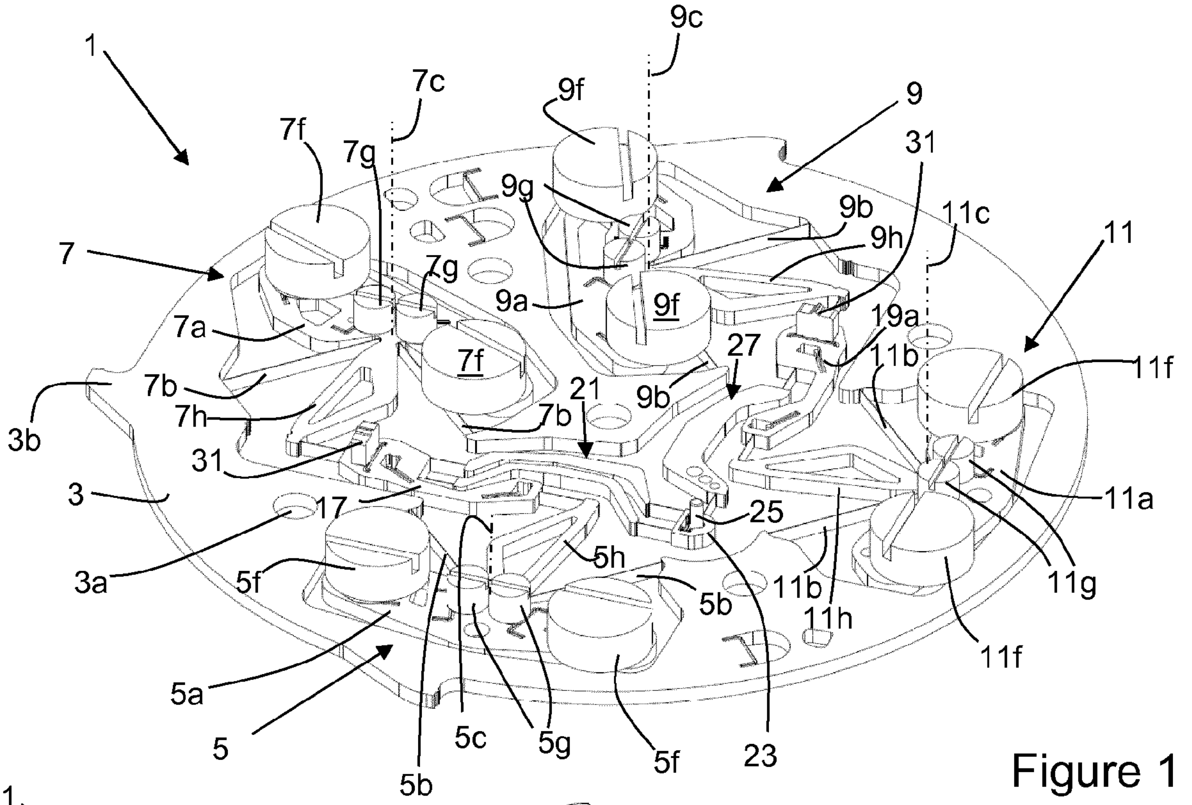


Figure 1

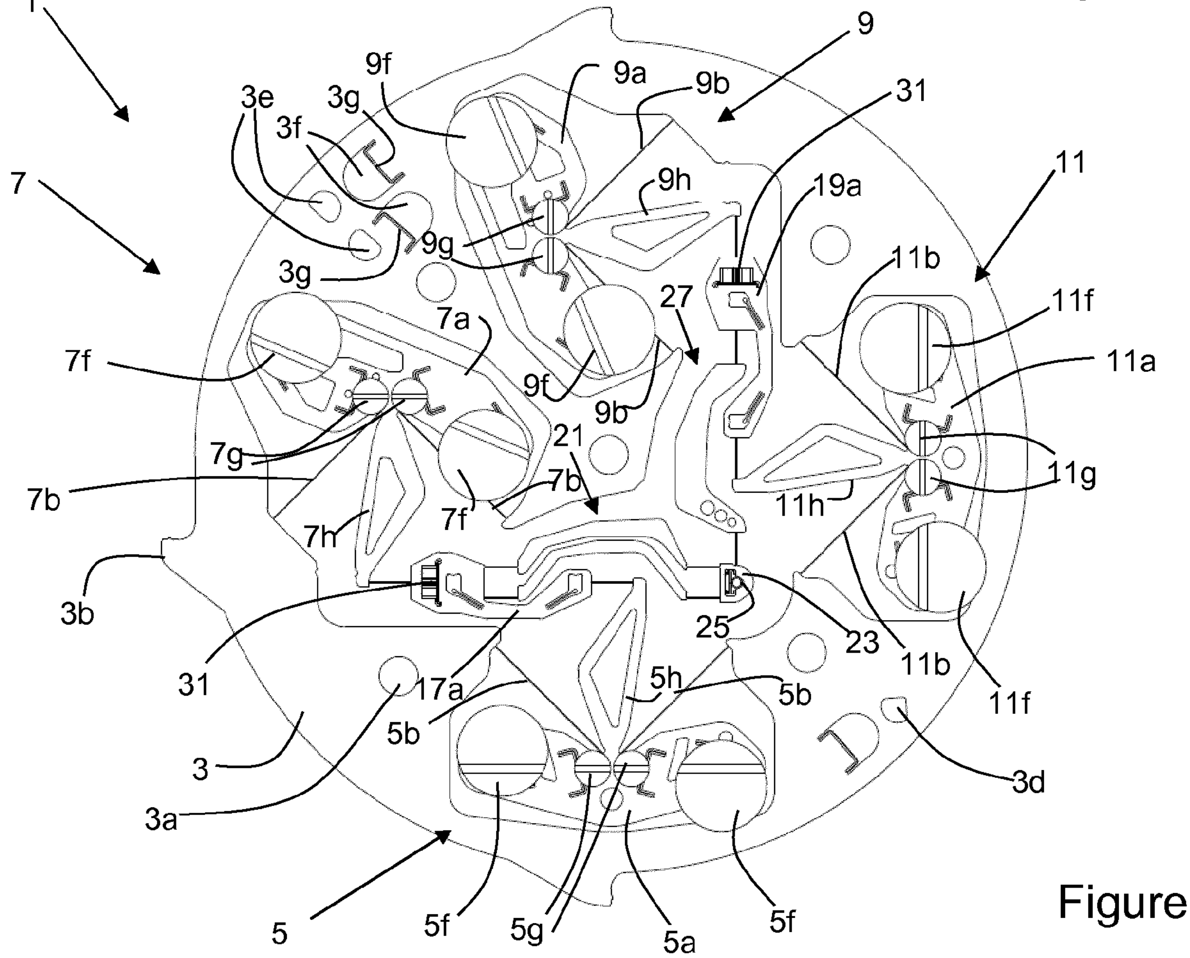
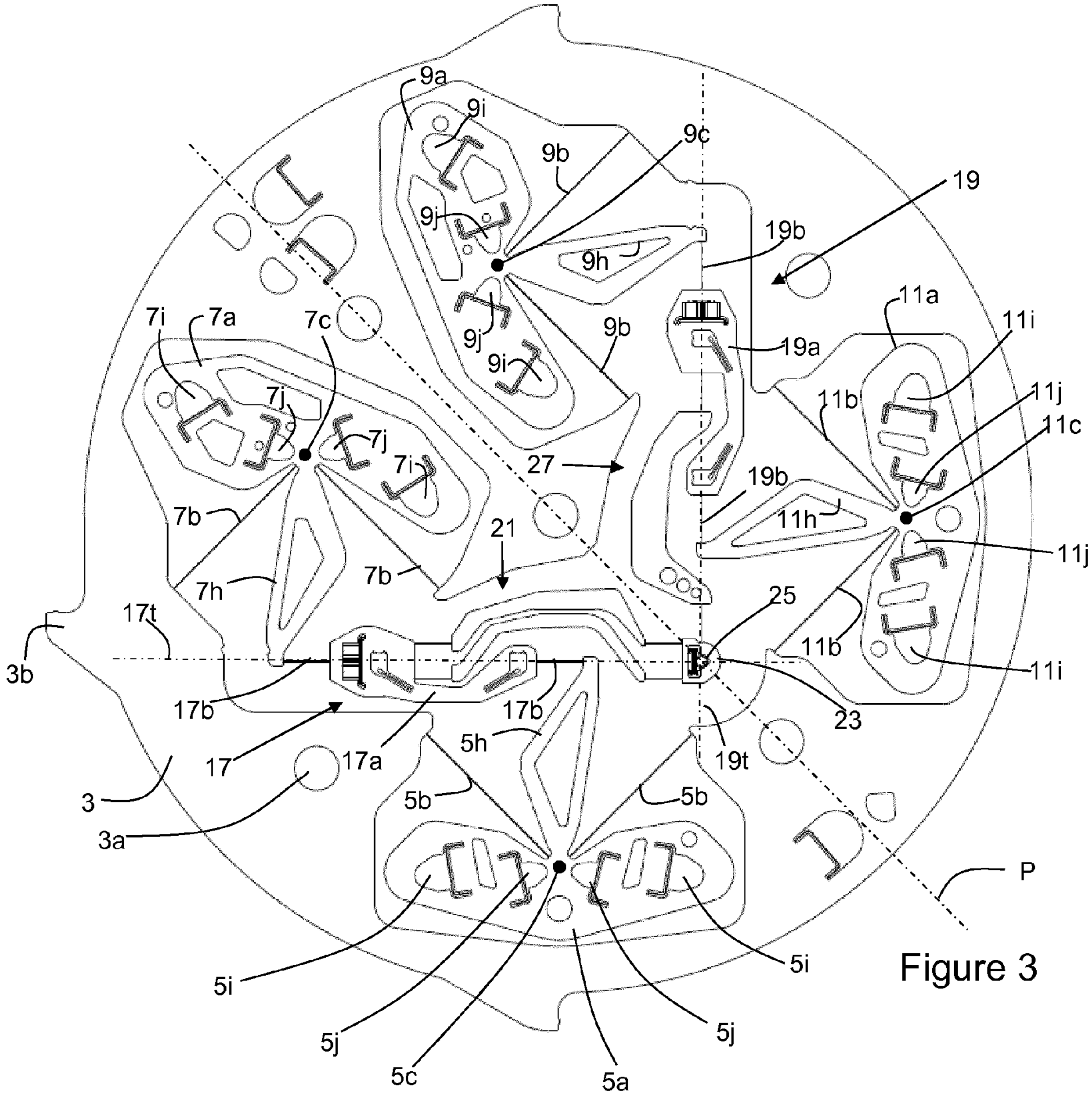


Figure 2


9a
9i
9b
9c
19
19b
9j
9h
9b
9j
9i
7i
7a
7c
19a
11a
11i
7j
11b
11j
11c
7j
7i
27
19b
11h
7b
21
11j
7h
7b
25
17t
11b
3b
17b
17b
11i
23
17
17a
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5b
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3a
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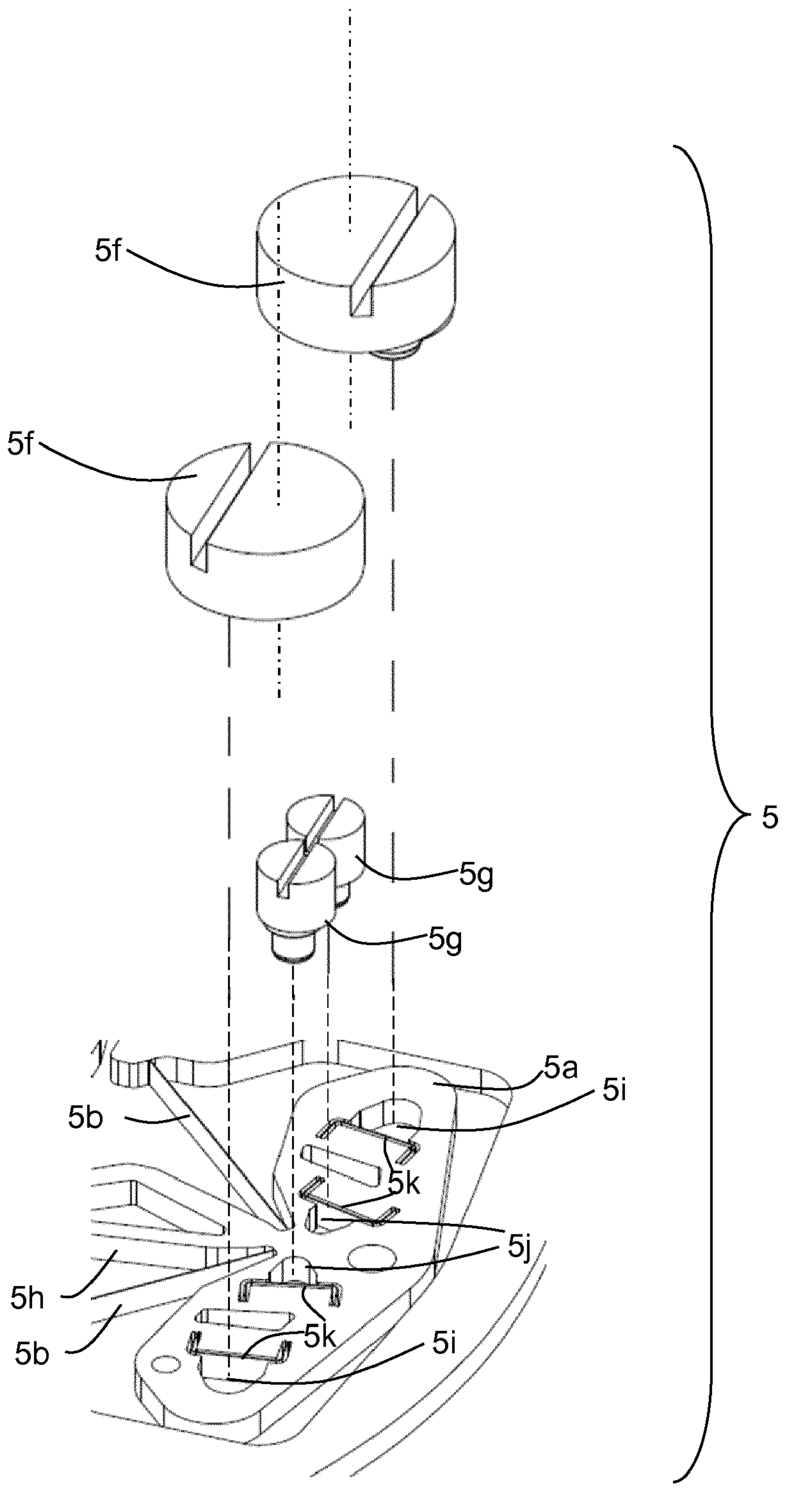
5i
5i
5j
5j
5c
5a

Figure 3



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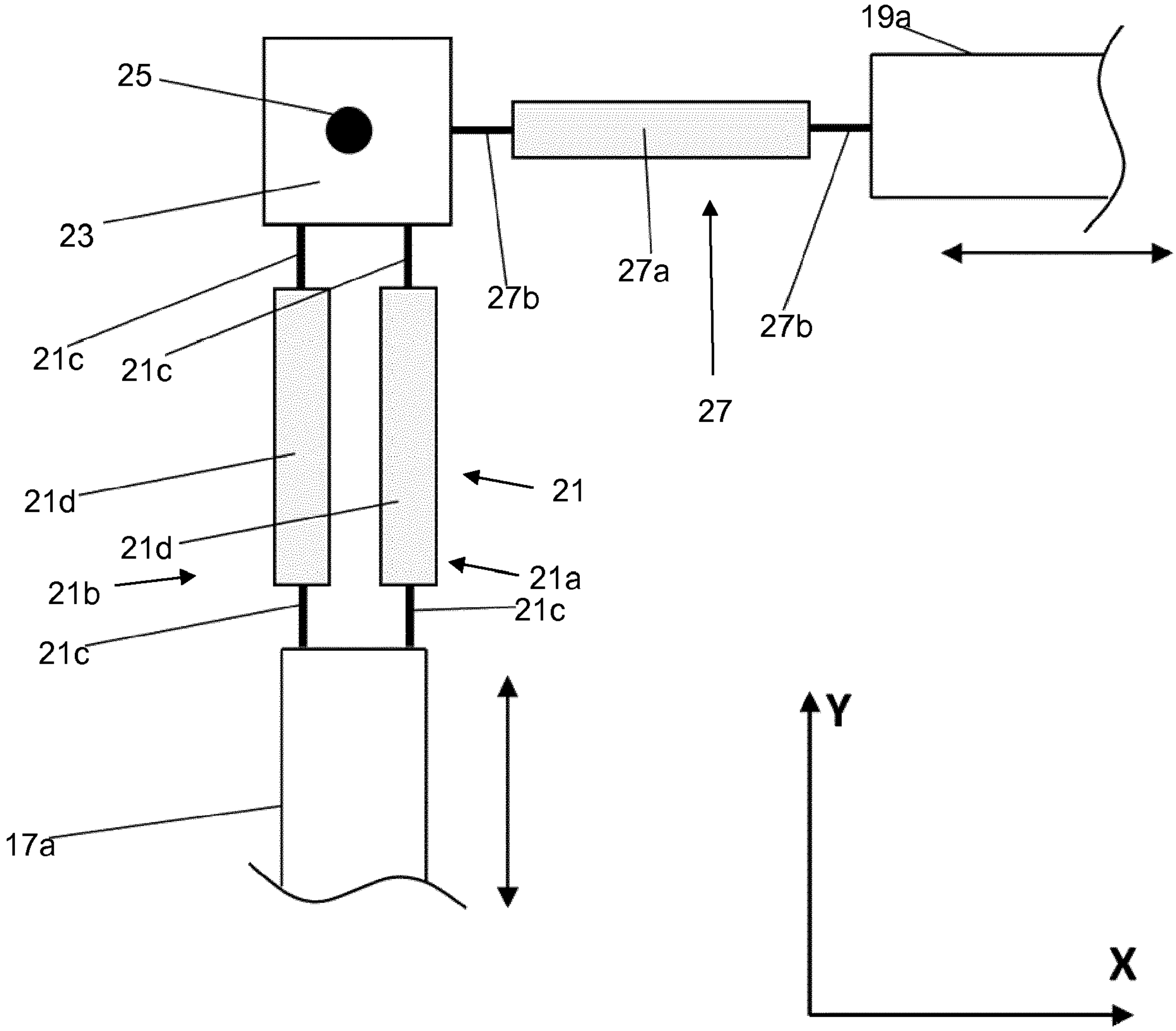
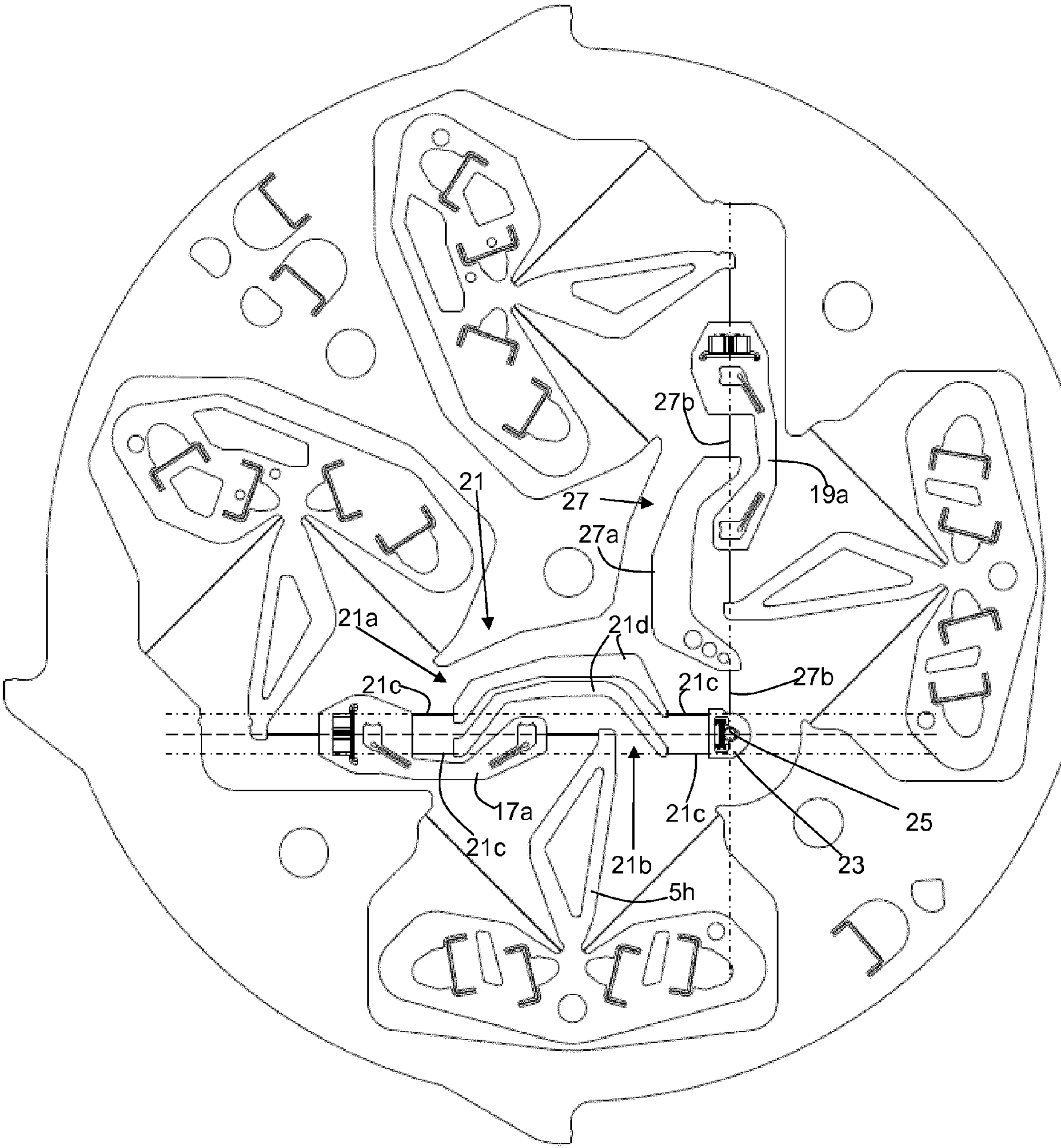


Figure 5



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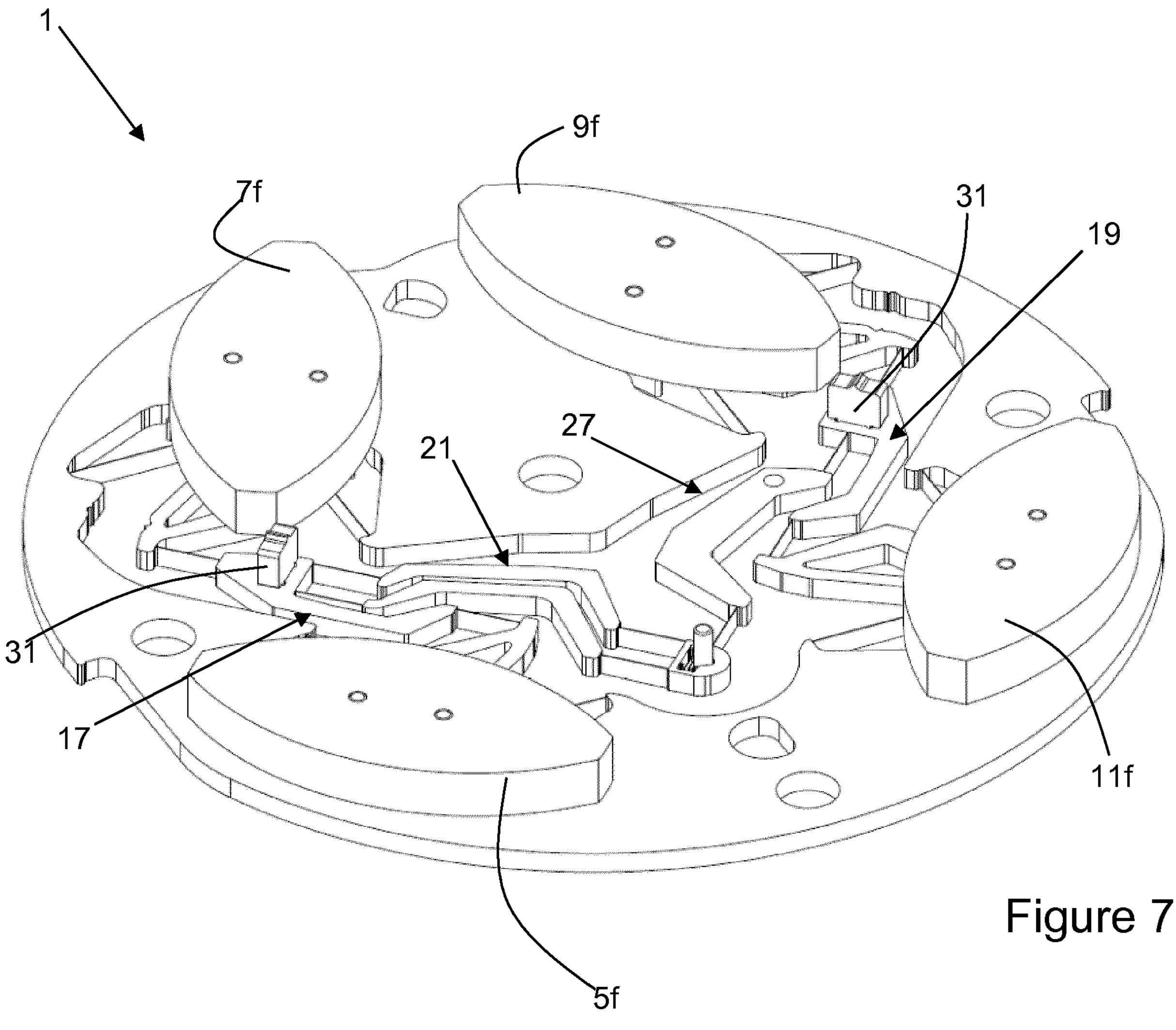

Figure 7

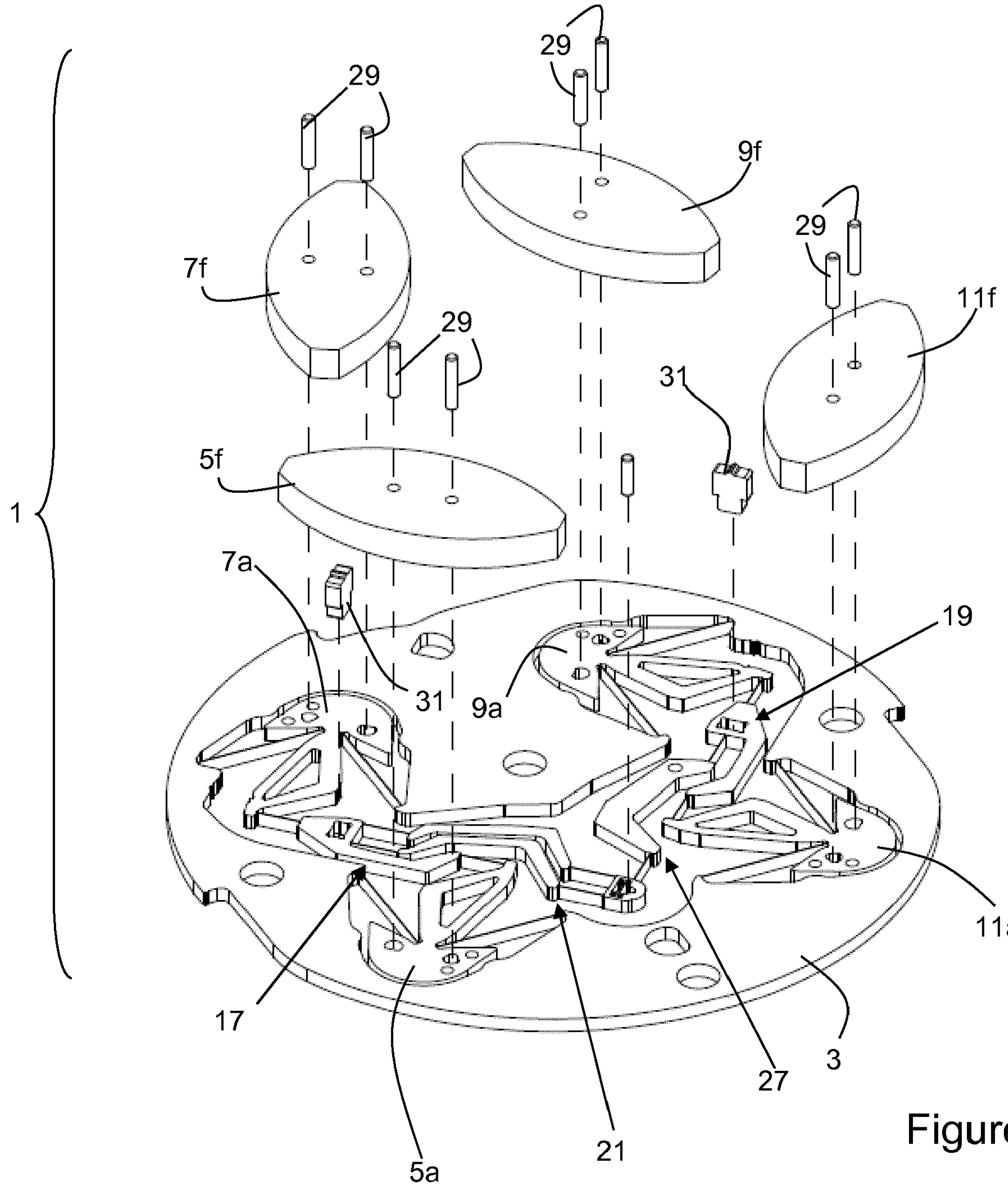

Figure 7a

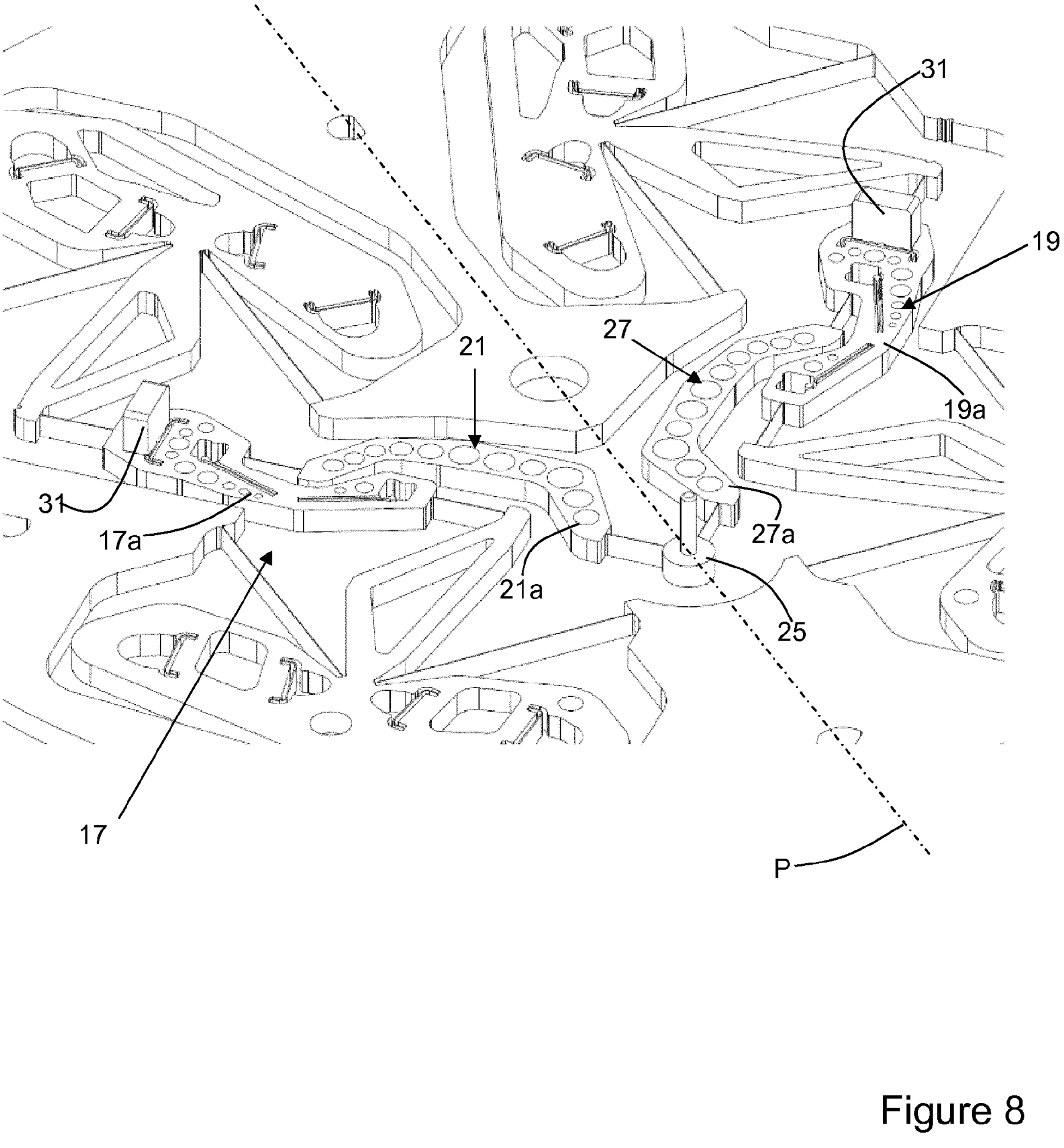

Figure 8

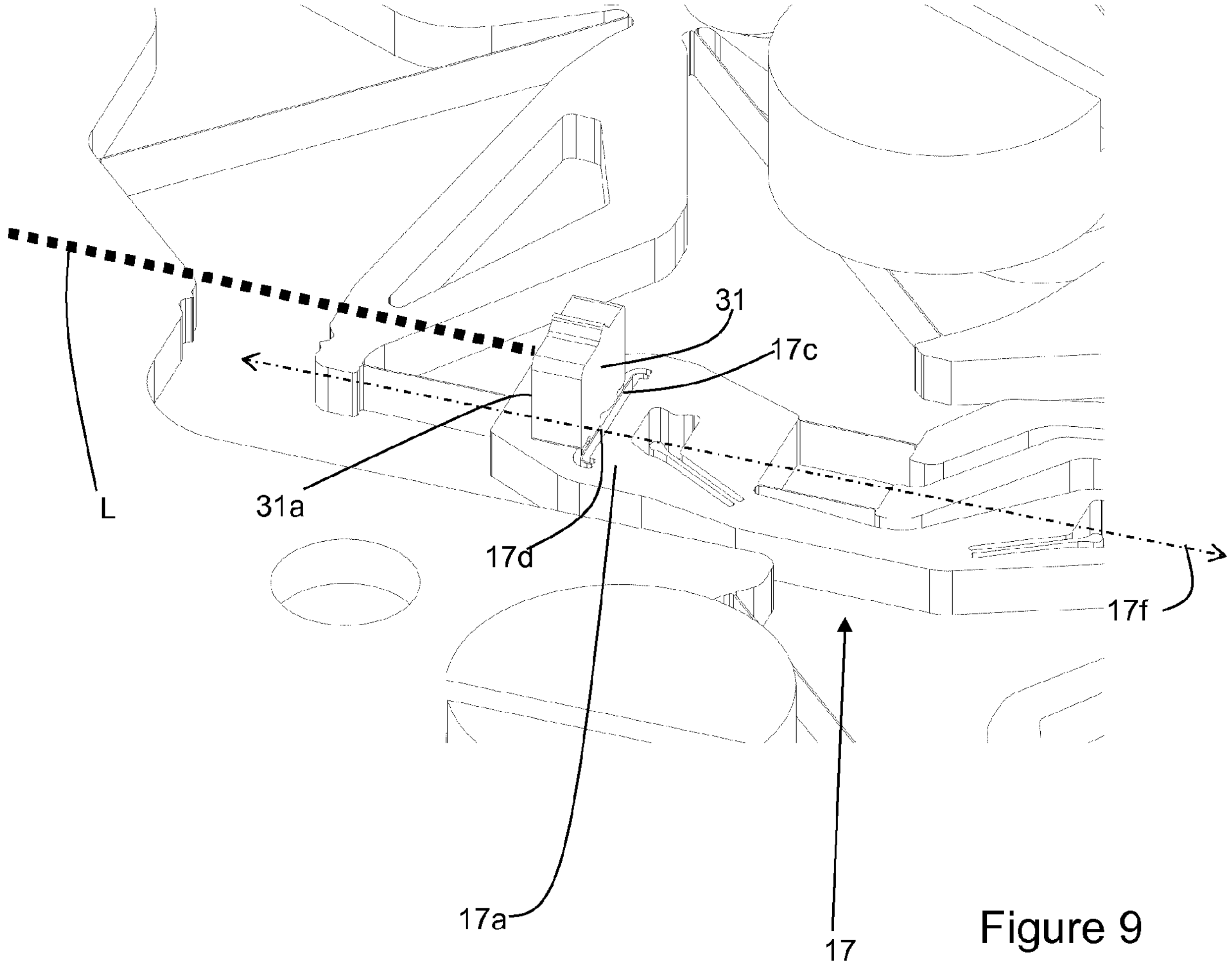

Figure 9

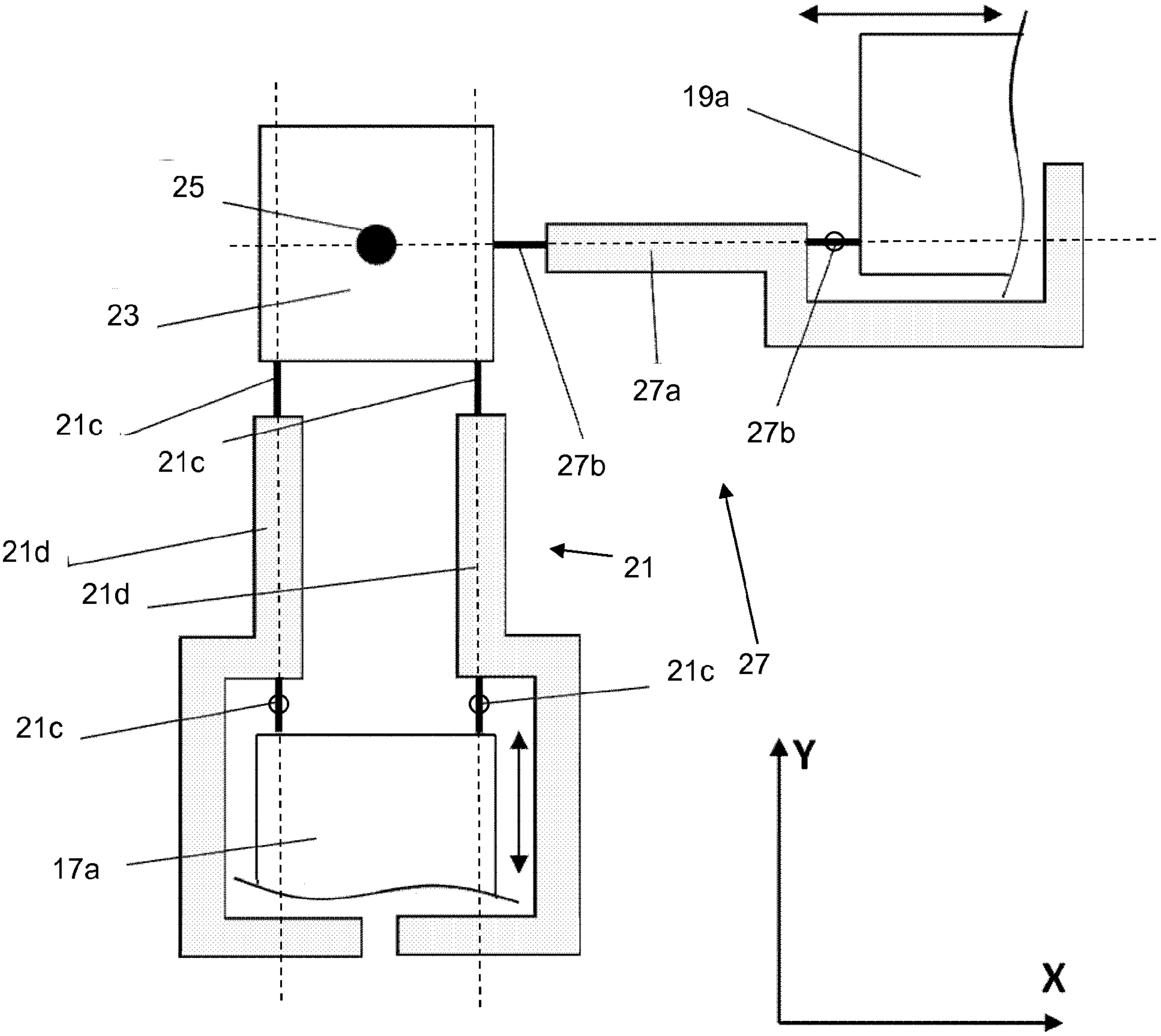

Figure 10

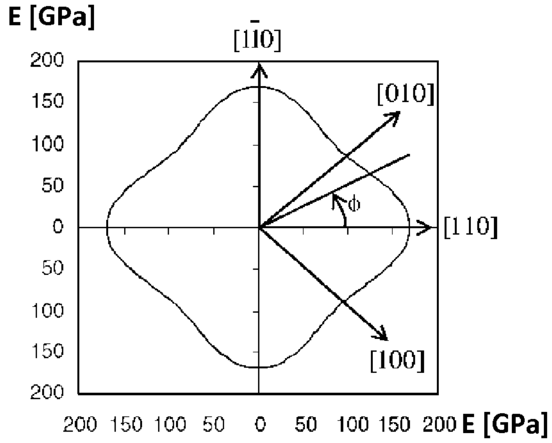

Figure 11

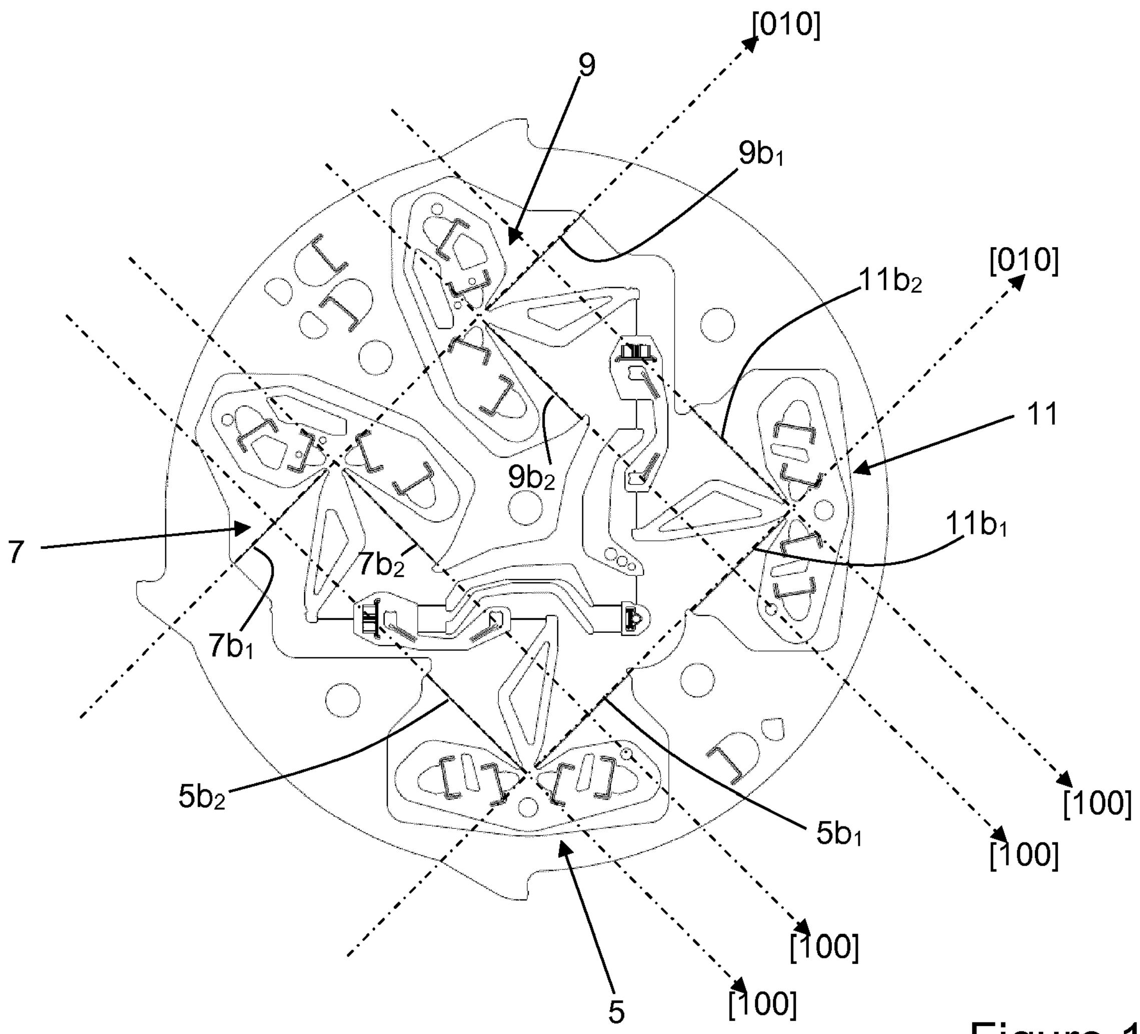

Figure 12

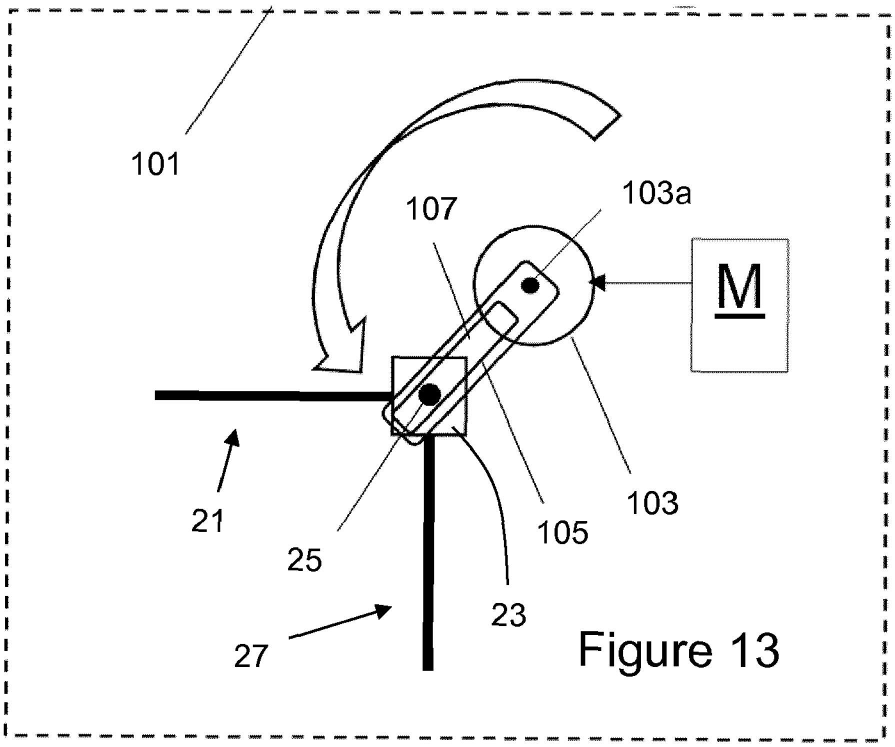

Figure 13

Europäisches Patentamt
European Patent Office
Office européen des brevets

PARTIAL EUROPEAN SEARCH REPORT

under Rule 62a and/or 63 of the European Patent Convention. This report shall be considered, for the purposes of subsequent proceedings, as the European search report

Application Number
EP 19 16 6857

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	EP 3 054 357 A1 (ETA SA MFT HORLOGERE SUISSE [CH]) 10 August 2016 (2016-08-10) * paragraphs [0015], [0019], [0038], [0040]; figure 3 *	1-3	INV. G04B17/04
A,D	& US 9 465 363 B2 (ETA SA MFT HORLOGERE SUISSE [CH]) 11 October 2016 (2016-10-11) * the whole document * -----	1-3	
A	WO 2018/215284 A1 (SA DE LA MFT DHORLOGERIE AUDEMARS PIGUET & CIE [CH]) 29 November 2018 (2018-11-29) * page 19, line 26 - page 21, line 15; figure 2 * -----	1-3	

TECHNICAL FIELDS SEARCHED (IPC)

G04B
G04F

INCOMPLETE SEARCH

The Search Division considers that the present application, or one or more of its claims, does/do not comply with the EPC so that only a partial search (R.62a, 63) has been carried out.

Claims searched completely :

Claims searched incompletely :

Claims not searched :

Reason for the limitation of the search:

see sheet C

1

Place of search	Date of completion of the search	Examiner
The Hague	28 January 2020	Lahousse, Alexandre

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04E07)

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INCOMPLETE SEARCH SHEET C

Application Number
EP 19 16 6857

Claim(s) completely searchable:
1-3

Claim(s) not searched:
4-23

Reason for the limitation of the search:

The application contains 5 independent product claims : 1, 4, 9, 12, 15. The 5 independent claims distinguish themselves from each other with the following features:
- claim 1: a coplanar arrangement,
- claim 4: a second inertial mass,
- claim 9: a reflector,
- claim 12: monocrystalline silicon,
- claim 15: pivot points.

Consequently, these independent claims do not constitute alternative solutions to a common problem, complementary products, or different uses of a same product. Hence, the subject matter of claims 1, 4, 9, 12 and 15 does not comply with the requirement of R43(2).
On the 25-11-2019, the applicant was invited to indicate on which claim the search should be carried. The applicant did not reply. As a consequence, the search was carried on the subject of claims 1 to 3.

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 19 16 6857

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

28-01-2020

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EP 3054357 A1	10-08-2016	CH 710692 A2	15-08-2016
		CN 105843026 A	10-08-2016
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		WO 2018215284 A1	29-11-2018

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

REFERENCES CITED IN THE DESCRIPTION

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- CH 700747 **[0002]**
- FR 322419 **[0002]**
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- EP 3095010 A **[0004] [0068]**
- US 2017269551 A **[0006]**
- US 9465363 B **[0007]**
- EP 3339969 A **[0068]**

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- **FLORENT COSANDIER ; SIMON HENEIN ; MURIELLE RICHARD ; LENNART RUBBERT.** The Art of Flexure Mechanism Design. EPFL Press, 2017 **[0032] [0056]**
- Conception des Guidages Flexibles. **PROF. SIMON HENEIN.** PPUR. 2003 **[0056]**