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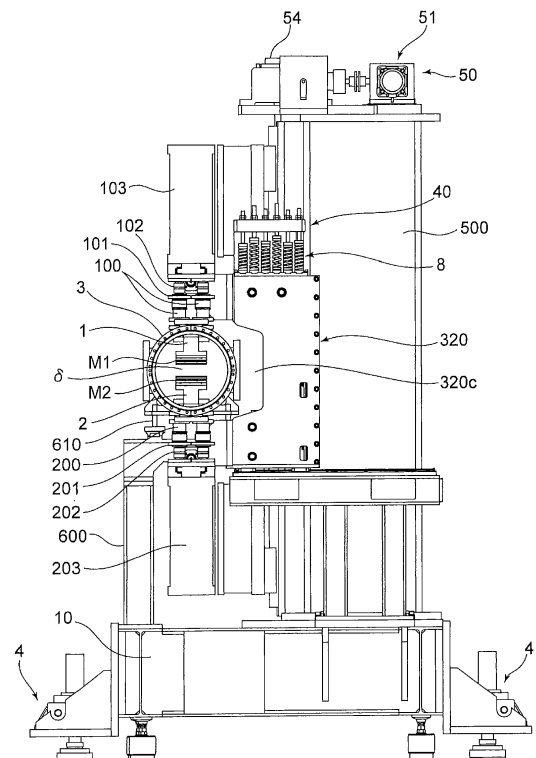
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(54) **INSERTION DEVICE**

(57) An insertion device includes: a gap driving mechanism (50) for driving magnet supporting members (1 and 2) vertically in order to change the gap (δ) between magnet arrays (M1, M2); a first coupling beam (103 and a second coupling beam (203) coupled to the magnet supporting members (1 and 2); a mechanism that couples the coupling beams (103 and 203 and the gap driving mechanism (50) together; a compensation spring mechanism (40) adapted to cancel an attractive force acting between the magnet arrays (M1, M2); and a spring conjunction mechanism (30) that couples the compensation spring mechanism (40) to the magnet supporting members (1 and 2), in which the spring conjunction mechanism includes a first auxiliary frame (91) coupled to the first coupling beam (103) via a pair of first coupling portions (91A), a second auxiliary frame (92) coupled to the second coupling beam (203) via a pair of second coupling portions (92A), and a first spring supporting frame (31) and a second spring supporting frame (32) mounted to the first and second auxiliary frames (91 and 92), and the compensation spring mechanism (40) is mounted to the first and second spring supporting frames (31 and 32).

Fig.5



Description

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The present invention relates to insertion devices including a first magnet array constituted by a plurality of magnets placed in an array, a first magnet supporting member for supporting the first magnet array mounted thereto, a second magnet array which is constituted by a plurality of magnets placed in an array and facing the first magnet array with a gap interposed therebetween, a second magnet supporting member for supporting the second magnet array mounted thereto, a gap driving mechanism for driving the first magnet supporting member and/or the second magnet supporting member in the direction in which the magnet arrays are facing each other, in order to change the size of the gap, and a driving conjunction mechanism for coupling the gap driving mechanism and the magnet supporting members to each other.

Description of the Related Art

[0002] If an electron beam having been accelerated to near the light velocity in a vacuum is bent within a magnet field, radiated light is emitted in tangential directions of the trajectory of the movement of the electron beam. This is called synchrotron radiation. There have been made studies for practical applications of various techniques for installing light sources for generating such synchrotron radiation in straight sections of electron storage rings (electron-beam accumulating rings), in order to utilize their properties such as high directivity, high intensity, and high polarization properties. Existing electron storage rings have been provided with plural insertion devices (undulators), as high-brightness light sources with higher beam electric currents and smaller beam cross-sectional areas.

[0003] As such insertion devices, there has been known an insertion device disclosed in the following Non-Patent Document 1, for example. This insertion device has a structure including a first magnet array constituted by a plurality of magnets placed in an array, and a second magnet array constituted by a plurality of magnets placed in an array, which are facing each other with a gap interposed therebetween. Since the arrays of the plural magnets are facing each other, large attractive forces are exerted between both of them.

[0004] Due to the exertion of the attractive forces, large loads are induced in gap driving mechanisms, which causes degradation of precise gap driving and deformations of magnet supporting members supporting the magnet arrays, thereby disordering the magnetic-field intensity distribution in the direction of an electron beam, which has been initially set in the magnetic-field generating space (the gap). This has resulted in the problem of im-

possibility of generation of synchrotron radiation with desired properties.

[0005] The following Patent Document 1 discloses a structure provided with a compensation spring mechanism, in order to overcome the aforementioned problem. The magnet supporting members mentioned above are coupled to coupling beams via mechanisms (coupling shafts) that are vertical to the coupling beams, and the size of the gap is changed by moving the coupling beams in the vertical direction. The compensation spring mechanism is also coupled to the coupling beams via coupling portions.

[0006] As is understood from FIG. 3 of the following Patent Document 1, the coupling portions of the compensation spring mechanisms are placed between a plurality of coupling shafts. This is because they physically interfere with each other. Therefore, the positions of the coupling shafts once determined, inevitably and substantially determine the positions of the coupling portions and the compensation spring mechanisms.

Prior Art Document

Patent Document

[0007] Patent Document 1: WO2018/143253 A1

Non-Patent Document

[0008] Non-Patent Document 1: Winick, Herman; George Brown; Klaus Halbach; John Harris (May 1981). "Synchrotron Radiation Wiggler and Undulator Magnets" Physics Today, May 1981, Volume 34, Issue 5, pp. 50 - 63

SUMMARY OF THE INVENTION

[0009] The inventors of the present invention have found out that optimal positions of the compensation spring mechanisms relative to the positions of the coupling shafts in the insertion device having the configuration described above could be determined by simulation. Namely, it has been found out that there have been optimal positions for the compensation spring mechanisms where deformation of coupling beams could be most suppressed, depending on the length of the coupling beams, mounting positions of the coupling shafts, the number of compensation spring mechanisms to be placed, and so on.

[0010] However, since the coupling portions cannot be placed at positions where the coupling shafts will be placed as described above, the optimal positions of the coupling shafts and the optimal positions of the compensation spring mechanisms sometimes conflict with each other. For this reason, there has been the problem that the compensation spring mechanisms could not be placed at optimal positions and deformation of the coupling beams could not be minimized.

[0011] The present invention has been made in view

of the circumstances described above, and it is an object of the present invention to provide an insertion device that can minimize deformation of coupling beams through optimization of the position of the compensation spring mechanism.

[0012] In order to solve the above problem, an insertion device according to the present invention includes:

a first magnet array including a plurality of magnets placed in an array;
 a first magnet supporting member adapted to support the first magnet array mounted to the first magnet supporting member;
 a second magnet array including a plurality of magnets placed in an array and facing the first magnet array with a gap interposed therebetween;
 a second magnet supporting member adapted to support the second magnet array mounted to the second magnet supporting member;
 a gap driving mechanism for driving the first magnet supporting member and/or the second magnet supporting member in a direction in which the magnet arrays are facing each other, in order to change a size of the gap;
 a first coupling beam coupled integrally to the first magnet supporting member;
 a second coupling beam coupled integrally to the second magnet supporting member;
 a driving conjunction mechanism for coupling at least one of the first coupling beam and the second coupling beam to the gap driving mechanism;
 a compensation spring mechanism adapted to act in such a direction as to cancel an attractive force acting between the first magnet array and the second magnet array; and
 a spring conjunction mechanism for coupling the compensation spring mechanism and the coupling beams to each other, wherein the spring conjunction mechanism includes:

a first auxiliary frame coupled, through a pair of first coupling portions, to one of the first coupling beam and the second coupling beam;
 a second auxiliary frame coupled, through a pair of second coupling portions, to the other one of the first coupling beam and the second coupling beam;
 a first spring supporting frame mounted to the first auxiliary frame;
 a second spring supporting frame mounted to the second auxiliary frame; and
 a guide mechanism for guiding relative movement of the first spring supporting frame and the second spring supporting frame, in the direction in which the magnet arrays are facing each other,

wherein the compensation spring mechanism is

mounted to both the first spring supporting frame and the second spring supporting frame and configured to operate, when the size of the gap is changed, by allowing relative movement of the first spring supporting frame and the second spring supporting frame, in the direction in which the magnet arrays are facing each other, wherein the first auxiliary frame is capable of placing a mechanism for coupling the first magnet supporting member and the first coupling beam to each other between the pair of first coupling portions, and wherein the second auxiliary frame is capable of placing a mechanism for coupling the second magnet supporting member and the second coupling beam to each other between the pair of second coupling portions.

[0013] With the insertion device having the aforementioned structure, it is possible to provide effects and advantages as follows. The first magnet supporting member is integrally coupled to the first coupling beam, and the second magnet supporting member is integrally coupled to the second coupling beam.

[0014] The gap driving mechanism drives at least one of the first coupling beam and the second coupling beam for changing the size of the gap. The spring conjunction mechanism includes the first spring supporting frame and the second spring supporting frame, which are mounted to the first auxiliary frame and the second auxiliary frame, respectively.

[0015] These first auxiliary frame and second auxiliary frame are coupled to the first coupling beam and the second coupling beam via the pairs of first coupling portions and second coupling portions, respectively. Further, the first spring supporting frame and the second spring supporting frame are allowed to move relative to each other, through the guide mechanism, in the direction in which the magnet arrays are facing each other.

[0016] With this structure, moments induced by the operations of the compensation spring mechanism can be received by the guide mechanism, which inhibits such moments from influencing the gap driving mechanism through the first and second coupling portions. This can prevent the operations of the compensation spring from influencing the precise gap driving.

[0017] Further, the first auxiliary frame and second auxiliary frame are formed to make a space available for placing a mechanism for coupling the magnet supporting member and the coupling beam to each other. The compensation spring mechanism can thus be placed in a location other than the space noted above, which makes it possible to optimally place the compensation spring mechanism.

[0018] Further, the direction in which the magnet arrays are facing each other depends on the state where the magnet arrays are installed. The direction in which the magnet arrays are facing each other includes the vertical direction, the horizontal direction and arbitrary

oblique directions, for example. Further, movements in the direction in which the magnet arrays are facing each other include both cases where the magnet arrays get closer to each other and cases where the magnet arrays get farther away from each other.

[0019] In the present invention, preferably, the first auxiliary frame includes a pair of first front and back plates extending in a forward and rearward direction, and a first left and right plate extending in a leftward and rightward direction for coupling the pair of first front and back plates to each other,

the second auxiliary frame includes a pair of second front and back plates extending in a forward and rearward direction, and a second left and right plate extending in a leftward and rightward direction for coupling the pair of second front and back plates to each other, the pair of first front and back plates is coupled to the first coupling beam via the first coupling portions, and the pair of second front and back plates is coupled to the second coupling beam via the second coupling portions.

[0020] The auxiliary frame having this configuration allows a mechanism for coupling the magnet supporting member and the coupling beam to each other to be placed between a pair of front and back plates. Also, the spring supporting frame can be mounted to a left and right plate, so that an optimal position as its mounting position can be determined.

[0021] In the present invention, preferably, the first auxiliary frame and the second auxiliary frame have a gate-like shape in plan view.

[0022] By having a gate-like shape, it is possible to secure a space for placing a mechanism for coupling the magnet supporting member and the coupling beam to each other.

[0023] In the present invention, preferably, the first left and right plate and the second left and right plate are formed with both mounting holes for mounting the first spring supporting frame and mounting holes for mounting the second spring supporting frame.

[0024] This enables production of the first left and right plate and second left and right plate from a common member, which contributes to better parts management and cost reduction.

BRIEF DESCRIPTION OF THE DRAWINGS

[0025]

FIG. 1 is a perspective view of the front surface side of an insertion device according to the present embodiment;
 FIG. 2 is a perspective view of the rear surface side of the insertion device according to the present embodiment;
 FIG. 3 is a front view of the insertion device according to the present embodiment;
 FIG. 4 is a plan view seen from above of the insertion device according to the present embodiment;

FIG. 5 is a side view of the insertion device according to the present embodiment;
 FIG. 6 is a cross-sectional view taken along A-A in FIG. 3;
 FIG. 7 is a cross-sectional view taken along B-B in FIG. 3;
 FIG. 8 is a cross-sectional view taken along C-C in FIG. 3;
 FIG. 9 is a perspective view of the front surface side illustrating the structure of the spring conjunction mechanism;
 FIG. 10 is a perspective view of the rear surface side illustrating the structure of the spring conjunction mechanism;
 FIG. 11 is a side view illustrating the structure of the spring conjunction mechanism;
 FIG. 12 is a rear view illustrating the structure of the spring conjunction mechanism;
 FIG. 13 is a cross-sectional view taken along F-F in FIG. 12;
 FIG. 14 is a plan view seen from above illustrating the structure of the spring conjunction mechanism;
 FIG. 15 is a cross-sectional view taken along E-E in FIG. 12; and
 FIG. 16 is a cross-sectional view taken along D-D in FIG. 11.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0026] A preferred embodiment of an insertion device according to the present invention will be described with reference to the drawings. FIG. 1 is a perspective view of the insertion device according to the present embodiment, from the front surface side. FIG. 2 is a perspective view of the same from the rear surface side. FIG. 3 is a front view of the same. FIG. 4 is a plan view of the same when viewed from above. FIG. 5 is a side view when viewed from the right side.

[0027] FIG. 6 is a cross-sectional view taken along A-A in FIG. 3. FIG. 7 is a cross-sectional view taken along B-B in FIG. 3. FIG. 8 is a cross-sectional view taken along C-C in FIG. 3. In the following description, for convenience of explanation, the leftward and rightward direction of the paper plane of FIG. 3 shall be the leftward and rightward direction of the insertion device, and the direction perpendicular thereto shall be the forward and rearward direction.

[0028] As illustrated in FIG. 5, the insertion device includes a first magnet array M1 constituted by a plurality of magnets placed in an array, and a second magnet array M2 constituted by a plurality of magnets placed in an array similarly, which are facing each other with a gap δ interposed therebetween. An electron beam passes through this gap space. Further, as the magnet arrays, it is possible to employ various types of examples of structures, such as ones disclosed in JP 2001-143899 A and

JP 2014-13658 A, as well as one disclosed in Patent Document 1, for example. Accordingly, the magnet arrays are not limited to particular placement of magnets.

[0029] The first magnet array M1 is supported by a first magnet supporting member 1, and the second magnet array M2 is supported by a second magnet supporting member 2. For example, each of the magnets constituting the first magnet array M1 is coupled to the first magnet supporting member 1, through bolts and the like. The same applies to the second magnet array M2.

[0030] Further, the magnetic arrays, which are the first magnet array M1 and the second magnet array M2, are facing each other in the vertical direction. However, the insertion device is not limited to the aforementioned structure and can also include magnet arrays in a horizontal direction or in an oblique direction or a combination of magnet arrays in two or more directions.

[0031] Further, the vacuum vessel 3 is supported on the base 10 through a supporting body 600. As also illustrated in FIG. 5, a supporting member 610 is provided on the supporting body 600, thereby receiving the lower portion of the vacuum vessel 3. The supporting body 600, the supporting member 610 and the vacuum vessel 3 are coupled to each other through mechanical means (for example, bolts and nuts) which are not illustrated. Further, the supporting body 600 is also coupled to the base 10 through appropriate mechanical means (for example, bolts and nuts).

[0032] Coupling shafts 100 are mounted to an upper portion of the first magnet supporting member 1, and the coupling shafts 100 are coupled at their upper ends to coupling plates 101. As illustrated in FIG. 3, fourteen coupling shafts 100 are placed along the leftward and rightward direction, and fourteen coupling plates 101 are placed similarly.

[0033] As illustrated in FIG. 5 and others, two coupling shafts 100 are placed along the forward and rearward direction when viewed from the front surface side, and these two coupling shafts 100 are coupled to each other through a single coupling plate 101. Namely, in the example illustrated in FIGS. 3 and 5, a total of 28 coupling shafts 100 is placed, and the respective two of these 28 coupling shafts 100 are coupled to each other through the fourteen coupling plates 101.

[0034] A first coupling beam 103 is placed above the placement of the coupling shafts 100. The first coupling beam 103 and the coupling plates 101 are coupled to each other, through a magnet supporting member guide mechanism 102 such as a linear guide. This is provided for absorbing the change of the length of the first magnet supporting member 1, if the first magnet supporting member 1 changes in length in the horizontal direction due to thermal expansion thereof.

[0035] Accordingly, the gap driving mechanism and the driving conjunction mechanism are prevented from being influenced by the thermal expansion. As described above, the first magnet supporting member 1 and the first coupling beam 103 are integrally coupled to each

other.

[0036] If the first coupling beam 103 moves in the vertical direction (an example of the direction in which the magnet arrays are facing each other: the same applies to the following), the first magnet supporting member 1 also moves in the vertical direction integrally therewith, in conjunction with the first coupling beam 103. They move in the vertical direction by the same amount. Further, the mechanism for integrally coupling the first coupling beam 103 and the first magnet supporting member 1 to each other is not limited to the aforementioned structure, and various examples of modifications can be applied thereto.

[0037] The second magnet supporting member 2 is also integrally coupled to a second coupling beam 203, through coupling shafts 200, coupling plates 201, and a magnet supporting member guide mechanism 202. The structure thereof is the same as that for the first coupling beam 103 and is not described herein. The same applies to the following description.

[0038] As illustrated in FIG. 1, the first coupling beam 103 includes a main-body frame 103a having a rectangular parallelepiped shape extending along the leftward and rightward direction. Further, supporting frames 103b are coupled, at two positions, to the rear side of the main-body frame 103a and are extended along the forward and rearward direction when viewed from the front surface side.

The Gap Driving Mechanisms

[0039] There is provided the gap driving mechanism 50 for changing the size of the aforementioned gap δ , in an upper portion of the rear portion of the insertion device.

The gap driving mechanism 50 is installed on the base 10 with frames 500 interposed therebetween. As illustrated in FIG. 2, the frames 500 have a rectangular parallelepiped shape with a rectangular cross section in the horizontal direction, and there are provided two such frames 500. A placement plate 501 is provided on the upper portions of the frames 500, and the gap driving mechanism 50 is placed thereon.

[0040] The gap driving mechanism 50 includes a driving motor 51, and conversion portions 52, 53 and 54. The conversion portion 52 converts the driving transmission direction by 90 degrees. The conversion portion 53 converts the driving transmission direction and transmits the motive power such that it diverges leftwardly and rightwardly. There are provided a pair of the conversion portions 54 in the left and right sides which are adapted to convert the driving in the horizontal direction into driving in the vertical direction. The concrete structure thereof is constituted by known mechanical elements such as bevel gears.

[0041] The conversion portions 54 convert the driving transmission into driving transmission in the vertical direction, which drives ball screw mechanisms 7 including a vertical shaft, as illustrated in FIG. 8, for example. The

ball screw mechanisms 7 are a well-known structure and are constituted by respective screw shaft portions 70 and respective nut portions 71. The screw shaft portions 70 are supported at their upper and lower sides by bearings 70a, and the bearings 70a are mounted to the frames 500. The nut portions 71 are mounted to the supporting frames 103b.

[0042] By driving the ball screw mechanisms 7, the screw shaft portions 70 are rotated, thereby moving the nut portions 71 upwardly and downwardly. This can move the first coupling beam 103 in the vertical direction. There are provided the supporting frames 103b (see FIG. 1, FIG. 8 and others), in order to move the first coupling beam 103 in the vertical direction.

[0043] When viewed from the front surface side, the supporting frames 103b are mounted at their rear sides to the front sides of the frames 500 when viewed from the front surface side, through two frame guide mechanisms 103c. When viewed from the front surface side, the supporting frames 103b are mounted, at their front sides, to the first coupling beam 103.

[0044] The ball screw mechanisms 7, which are driven by the frame guide mechanisms 103c and the conversion portions 54 as described above, correspond to a driving conjunction mechanism for coupling the first coupling beam 103 and the gap driving mechanism 50 to each other. By driving the driving motor 51, the first coupling beam 103 can be moved in the vertical direction, thereby moving the first magnet supporting member 1 and the first magnet array M1 in the vertical direction. Namely, the size of the gap δ can be changed.

[0045] Further, the second coupling beam 203, which is placed in the lower side, can also be moved in the vertical direction, similarly, through a gap driving mechanism (not illustrated) which is placed in the lower side. The structure thereof is basically the same as that for the first coupling beam 103 and is not described herein. By moving the first coupling beam 103 and the second coupling beam 203 in the vertical direction using the aforementioned structure, it is possible to change the size of the gap δ . By moving the first coupling beam 103 and the second coupling beam 203 in such a direction that they get closer to each other, the gap δ can be made smaller. By moving them in such a direction that they get farther away from each other, the gap δ can be made larger.

Compensation Modules

[0046] Next, as a preferred embodiment of compensation modules according to the present invention, there will be described, at first, a spring conjunction mechanism 30, out of compensation spring mechanisms 40 and spring conjunction mechanisms 30 which constitute compensation modules 8, mainly with reference to Figs. 9 to 15. FIG. 9 is a perspective view illustrating the structure of the spring conjunction mechanism 30 viewed from the front surface side. FIG. 10 is a perspective view illustrating the same from the rear surface side.

[0047] FIG. 11 is a side view. FIG. 12 is a front view. FIG. 13 is a cross-sectional view taken along F-F in FIG. 12. FIG. 14 is a plan view (seen from above). FIG. 15 is a cross-sectional view taken along E-E in FIG. 12. FIG. 16 is a cross-sectional view taken along D-D in FIG. 11. These drawings are drawings for explaining the compensation module and do not show other mechanisms.

[0048] The spring conjunction mechanism 30 is constituted by a first spring supporting frame 31, and a second spring supporting frame 32. The second spring supporting frame 32 includes a pair of second plate portions 320, and the thickness direction thereof corresponds to the leftward and rightward direction. The second plate portions 320 are installed in such a way that the plates are erected in the vertical direction. The second plate portions 320 include an upper-portion protruding portion 320a, a lower-portion protruding portion 320b, and the concave portion 320c formed therebetween. As also illustrated in FIG. 5, the concave portion 320c is shaped to secure a space for placing the vacuum vessel 3 therein. As illustrated in FIGS. 9, 11 and others, the lower-portion protruding portion 320b and the upper-portion protruding portion 320a are protruded toward the magnet arrays in the same amount.

[0049] As illustrated in FIG. 9, the pair of second plate portions 320 are joined together by bolts 321 via shaft-like spacing members 322. The bolts 321 are provided at two locations on the lower side and two locations on the upper side. The length of the spacing members 322 determines the spacing between the pair of second plate portions 320.

[0050] As illustrated in FIG. 10, the pair of second plate portions 320 are integrally coupled to each other, at their rear surface side (their sides farther from the magnet arrays), through a coupling plate 34 (which corresponds to a plate coupling portion). The coupling plate 34 and the pair of second plate portions 320 are joined together by a large number of bolts 323.

[0051] The first spring supporting frame 31 includes a single first plate portion 310 and is installed in such a way that the plate is erected in the vertical direction. The first plate portion 310 is provided in its upper portion with the upper-portion protruding portion 310a, on its side closer to the magnet arrays (see FIG. 13). This upper-portion protruding portion 310a protrudes in the same amount as the upper-portion protruding portion 320a of the second plate portion 320.

[0052] As can be seen also from FIG. 12, the first plate portion 310 is placed in such a way as to be sandwiched between the pair of second plate portions 320, and they are placed with respective predetermined gaps interposed therebetween. The first plate portion 310 is positioned right in the middle between the pair of second plate portions 320.

[0053] As illustrated in FIG. 13, the spacing members 322 on the lower side are provided at positions where they do not interfere with the first plate portion 310. The spacing members 322 on the upper side (at two locations)

are formed with long holes 310e that are elongated along the upward and downward direction so as not to interfere with the first plate portion 310. The holes are formed as long holes 310e in order to allow relative upward and downward movements of the first plate portion 310 and second plate portions 320, as will be described later.

[0054] As illustrated in FIG. 13, a placement plate 35 is placed on the rear side of the first plate portion 310, which is its side farther from the magnet arrays, and a guide mechanism 36 is placed between the placement plate 35 and the coupling plate 34. The placement plate 35 and the first plate portion 310 are joined together by a large number of bolts 350.

[0055] Incidentally, in the following description, the guide mechanism 36 will be referred to as a vertical guide mechanism 36, in order to distinguish it from guide mechanisms installed in other portions for facilitating understanding. However, it is not intended that the guide mechanism 36 should be installed restrictively in the vertical direction.

[0056] The vertical guide mechanism 36 can be constituted by a linear guide, for example, such that a guide rail 360 therein is placed on the coupling plate 34, and a guide block 361 therein is placed on the first plate portion 310 (see FIGS. 13 and 15). Further, the guide rail and the guide block can also be interchanged in placement. The vertical guide mechanism 36 can also be constituted by other guide mechanisms than linear guides. The vertical guide mechanism 36 corresponds to a guide mechanism for guiding the relative movement of the first spring supporting frame 31 and the second spring supporting frame 32 in the vertical direction (in which the magnet arrays are facing each other).

[0057] With this structure, the first spring supporting frame 31 can be moved relative to the second spring supporting frame 32 in the vertical direction.

[0058] The second plate portions 320 are provided, at their upper end faces, with respective spring placement portions 320d. Further, the first plate portion 310 is provided at its upper end portion with a compressive-force exertion portion 310b. The compressive-force exertion portion 310b is formed to have a plate shape with a horizontal surface. Compensation springs 42 are placed between the spring placement portions 320d and the compressive-force exertion portion 310b. Accordingly, the compressive-force exertion portion 310b also functions as a spring placement portion.

[0059] There will be described the compensation spring mechanism 40 which constitutes the compensation module 8 together with the spring conjunction mechanism 30, with reference to FIG. 9. Spring installation plates 41 are provided on the upper surfaces of the spring placement portions 320d. A plurality of compensation springs 42 are installed on the spring installation plates 41.

[0060] Six compensation springs 42 are placed in the forward and rearward direction when viewed from the front surface side. Incidentally, the number of the com-

pensation springs placed thereon can be properly determined. As illustrated in the plan view of FIG. 4 which illustrates them from above, the compensation modules 8 (the spring conjunction mechanisms 30 and the compensation spring mechanisms 40) are placed at four positions in the leftward and rightward direction (the direction of propagation of the electron beam).

[0061] The number of the compensation modules placed therein can be properly determined, depending on the length of the insertion device in the leftward and rightward direction. With respect to the compensation spring mechanism 40 at a single position, the compensation springs 42 are arranged in two rows (since there is the pair of the second plate portions 320), and there is a total of 12 compensation springs 42.

[0062] The compensation springs 42 are constituted by compression coil springs. The compensation springs 42 are placed at their lower end portions on the spring installation plates 41. Respective pushers 43 are placed on the upper end portions of the compensation springs 42. The pushers 43 are each constituted by a pressing portion 43a and a bolt portion 43b, which are integrally formed. The pressing portions 43a are structured to press the upper end portions of the compensation springs 42.

[0063] The pushers 43 can be fastened to the compressive-force exertion portion 310b, through the bolt portions 43b. The pushers 43 can be positioned and secured through nuts 44. The amounts of initial compression of the respective compensation springs 42 can be adjusted, through the pushers 43. The compressive-force exertion portion 310b is joined to the upper end face of the first plate portion 310 by bolts 310d at six locations.

[0064] Next, there will be described the structure for coupling the spring conjunction mechanism 30 to the first and second coupling beams 103 and 203. As illustrated in FIG. 9, the first spring supporting frame 31 is mounted to a first auxiliary frame 91 on the upper side, and the second spring supporting frame 32 is mounted to a second auxiliary frame 92 on the lower side.

[0065] Namely, the first and second spring supporting frames 31 and 32 are mounted to the first and second coupling beams 103 and 203 not directly but via the first and second auxiliary frames 91 and 92. Since the first auxiliary frame 91 and second auxiliary frame 92 have the same basic structure, the first auxiliary frame 91 will be mainly described.

[0066] The first auxiliary frame 91 is configured by a first left and right plate 910 and a pair of first front and back plates 911. The pair of first front and back plates 911 are joined to the first left and right plate 910 at its left and right end portions by bolts 912 (see FIG. 10). With these plates joined, the first auxiliary frame has a gate-like shape in plan view from above. Therefore, there is formed a space between the pair of first front and back plates 911. The second auxiliary frame 92, similarly, is configured by a second left and right plate 920 and a pair of second front and back plates 921.

[0067] Three rows of five holes formed along the upward and downward direction are provided in the leftward and rightward direction in the first left and right plate 910. Note that, the number of holes and the number of rows of holes and the like are not limited to those in the present embodiment. As illustrated in FIG. 12, the first plate portion 310 of the first spring supporting frame 31 is joined to the first left and right plate 910 by bolts 913 (see FIG. 12), using the middle row of the three rows of holes.

[0068] The second plate portions 320 of the second spring supporting frame 32 are joined by bolts 923 (see FIG. 12), using the left and right rows of the three rows of holes. Accordingly, the same member can be used as the first left and right plate 910 and the second left and right plate 920.

[0069] To join the first auxiliary frame 91 to the first coupling beam 103, there is provided a pair of first coupling portions 91A. The first coupling portions 91A are provided to distal end portions of the pair of first front and back plates 911 on the left and right. The first coupling portion 91A includes a coupling member 914 and a coupling shaft 915. The coupling member 914 is integrally formed with a shaft bore portion 914a (see FIG. 10) and a planar portion 914b. The planar portion 914b is coupled to the first coupling beam 103 from the lower surface side by bolts 916.

[0070] As illustrated in FIG. 16, the coupling shaft 915 is inserted in a hole 911a formed in the first front and back plate 911 such that it is allowed to slide. The coupling shaft 915 has such an outside diameter that there is formed a clearance between the coupling shaft 915 and the hole 914c in the coupling member 914 when the shaft fits therein. Bolts 917 are positioned below the coupling shaft 915 so that the coupling member 914 and the coupling shaft 915 are secured by the bolts 917. The first front and back plate 911 is not secured and allowed to rotate.

[0071] To join the second auxiliary frame 92 on the lower side to the second coupling beam 203, there is provided a pair of second coupling portions 92A. The second coupling portions 92A are positioned above the second coupling beam 203. The structure of the second coupling portion 92A is the same as that of the first coupling portion 91A, and is not described herein.

[0072] With the configuration described above, the spring conjunction mechanism 30 and the first and second coupling beams 103 and 203 are coupled to each other. Namely, the compensation spring mechanisms 40 and the first magnet supporting member 1 and the second magnet supporting member 2 are coupled to each other through the spring conjunction mechanisms 30, with various members such as the coupling beams 103 and 203 interposed therebetween. The first auxiliary frame 91 and second auxiliary frame 92 are allowed to rotate and move, rather than being completely secured to the first coupling beam 103 and the second coupling beam 203, respectively.

[0073] Further, in FIGS. 1 to 8, the compensation mod-

ules 8 are all installed on the rear side of the magnet arrays (on the side of the frames 500 with respect to the vacuum vessel 3). However, the compensation modules 8 can also be installed on the front side (on the opposite side from the frames 500 with respect to the vacuum vessel 3) or can be installed on the both sides of the vacuum vessel 3, depending on the structure of the insertion device in which the compensation modules 8 are installed and depending on the required sizes of the spring forces.

[0074] As illustrated in FIG. 5, the coupling shafts 100, coupling plates 101, magnet supporting member guide mechanism 102, and so on, are provided as a magnet/beam coupling mechanism for coupling the first magnet supporting member 1 and the first coupling beam 103. The same applies to the magnet/beam coupling mechanism for coupling the second magnet supporting member 2 and the second coupling beam 203.

[0075] As illustrated in FIG. 3, the first coupling portions 91A and second coupling portions 92A are placed in the space between the magnet/beam coupling mechanisms (see also FIG. 14). However, the compensation spring mechanisms 40 are not placed in this space. If there were no auxiliary frames, the first spring supporting frame 31 and second spring supporting frame 32 would be placed between adjacent magnet/beam coupling mechanisms, which naturally would cause the compensation spring mechanism 40 to be placed in this space. However, the position of the compensation spring mechanism 40 where deformation of the magnet supporting members can be minimized is not necessarily between the adjacent magnet/beam coupling mechanisms.

[0076] The inventors of the present invention found out that an optimal position of the compensation spring mechanism 40 could be determined by simulation. Namely, it has been found out that there has been an optimal position for the compensation spring mechanism 40 where deformation of coupling beams 103 and 203 could be most suppressed, depending on the lengths of the coupling beams 103 and 203, mounting positions of the coupling shafts 100 and 200, the number of compensation spring mechanisms 40 to be placed, and so on.

[0077] However, as described above, the first and second coupling portions 91A and 92A cannot be placed at the positions where the magnet/beam coupling mechanisms (coupling shafts 100 and 200 and others) will be placed, because of which the optimal positions of the coupling shafts 100 and 200 sometimes conflict with the optimal positions of the coupling portions 91A and 92A. For this reason, previously, there has been the problem that the compensation spring mechanism 40 could not be placed at an optimal position and deformation of the coupling beams 103 and 203 could not be minimized.

[0078] The configuration of the present invention, however, provides flexibility to the possible placement position of the compensation spring mechanism 40. As illustrated in FIG. 14, in the present embodiment, the compensation spring mechanism 40 is placed substantially

behind the coupling shaft 100. While the compensation spring mechanism 40 could normally not be placed at this location (the position that conflicts with the position of the coupling shaft 100 in front view) without the auxiliary frames, the configuration of the present invention enables such placement.

[0079] The mounting point of the compensation spring mechanism 40 can be changed within the range of width W of the first left and right plate 910, as is understood also from FIG. 14. It only requires a design change wherein the rows of holes for mounting the first and second spring supporting frames 31 and 32 are matched with the optimal position.

Gap Changing Operations

[0080] There will be described operations for changing the gap δ , with reference to FIGS. 6 to 8. Through the gap driving mechanisms 50, the first coupling beam 103 is moved downwardly, and the second coupling beam 203 is moved upwardly. Thus, the first magnet supporting member 1 and the first magnet array M1 are moved downwardly, and the second magnet supporting member 2 and the second magnet array M2 are moved upwardly. Consequently, the first magnet array M1 and the second magnet array M2 get closer to each other, thereby making the gap δ smaller. At the same time, the attractive force between the magnets is made larger.

[0081] Further, the first plate portion 310 is moved downwardly since the first coupling beam 103 is moved downwardly. Further, the second plate portions 320 are moved upwardly since the second coupling beam 203 is moved upwardly. As a result thereof, the compensation springs 42 in the compensation spring mechanisms 40 are compressed. As the gap δ is made smaller, the attractive force from the magnets is made larger and, in conjunction therewith, the spring forces in the compensation spring mechanisms 40 are made larger. If the attractive force is made larger, this exerts forces which attempt to deform the coupling beams, which are integrally coupled to the magnet supporting bodies supporting the magnet arrays.

[0082] If the coupling beams are deformed, the magnet supporting bodies are also deformed, which makes the size of the gap δ non-constant in the rightward and leftward direction, which is the direction of the electron beam, thereby making it impossible to maintain the magnetic-field intensity distribution in the direction of the electron beam which has been initially set. For coping therewith, the compensation spring mechanisms 40 are provided, in order to suppress the deformations of the coupling beams due to attractive forces.

[0083] Along with the increase of the compressive forces of the compensation springs 42, respective moments in opposite directions may be exerted on the first coupling portions 91A and the second coupling portions 92A. These both moments are cancelled by the portion of the vertical guide mechanism 36. This prevents so large mo-

ments from being exerted on the first and second coupling portions 91A, 92A. Further, in the present embodiment, the first and second coupling portions 91A, 92A are constituted by coupling structures including a shaft and a fitting hole.

[0084] Therefore, even if a residual moment is exerted thereon due to cancelling errors, the moment can be absorbed by slight relative rotation of the shaft and the fitting hole. This can inhibit moments induced by the compensation spring mechanisms 40 from adversely influencing the gap driving mechanisms 50, thereby preventing the accurate gap driving from being influenced thereby.

[0085] Further, in the present embodiment, the first and second coupling portions 91A, 92A are provided on the lower end portion of the first coupling beam 103 and on the upper end portion of the second coupling beam 203, respectively. Namely, both of the first and second coupling portions are provided in the side closer to the magnet arrays. This can inhibit the increase of the sizes of the first spring supporting frame 31 and the second spring supporting frame 32 in the upward and downward direction.

[0086] Further, the compensation spring mechanisms 40 are provided in the rear side with respect to the vacuum vessel 3 when viewed from the front surface side. When viewed from the front surface side, the front side with respect to the vacuum vessel 3 is opened. This prevents the compensation spring mechanisms 40 from obstructing works which necessitate accessing the vacuum vessel 3 and the magnet arrays from the front side when viewed from the front surface side.

[0087] Further, regarding the respective elements constituting the spring conjunction mechanisms 30, it is possible to properly determine the materials thereof, the methods for fabricating them, and the constitutions of members therein, such as whether the respective elements are constituted by a single member or by a combination of plural members, for example. For example, the mechanism may be integrally formed of a single component, or may be formed by connecting a plurality of components with bolts or the like. Further, the same applies to the structures of the plate portions, and the shapes thereof are not limited to complete plates (flat plates).

[0088] Where numbers of components are specified herein in accordance with the drawings, it should be understood that these numbers are not limited to the numbers of components as illustrated in the drawings but may be set suitably.

Other Embodiments

[0089] While all the compensation modules 8 are coupled together using auxiliary frames in the present embodiment, depending on the results of simulation, there may be compensation modules 8 that use the auxiliary frame and that do not use the auxiliary frame mixedly placed.

DESCRIPTION OF REFERENCE SIGNS

[0090]

M1	First magnet array	5
M2	Second magnet array	
δ	Gap	
1	first magnet supporting member	
2	Second magnet supporting member	
3	Vacuum vessel	10
4	Pedestal	
10	Base	
100	Coupling shaft	
101	Coupling plate	
102	Magnet supporting member guide mechanism	15
103	First coupling beam	
200	Coupling shaft	
201	Coupling plate	
202	magnet supporting member guide mechanism	
203	Second coupling beam	20
30	Spring conjunction mechanism	
31	First spring supporting frame	
32	Second spring supporting frame	
34	Coupling plate	
36	Guide mechanism (Vertical guide mechanism)	25
310	First plate portion	
310a	Upper-portion protruding portion	
310b	Compressive-force exertion portion	
320	Second plate portion	
320a	Upper-portion protruding portion	30
320b	Lower-portion protruding portion	
40	Compensation spring mechanisms	
42	Compensation spring	
43	Pusher	
43a	Pressing portion	35
50	Gap driving mechanism	
7	Ball screw mechanisms	
70	Screw shaft portion	
71	Nut portion	
8	Compensation module	40
91	First auxiliary frame	
91A	First coupling portion	
910	First left and right plate	
911	First front and back plate	
914	Coupling member	45
915	Coupling shaft	
92	Second auxiliary frame	
92A	Second coupling portion	
920	Second left and right plate	
921	second front and back plate	50

Claims

1. An insertion device comprising: 55
- a first magnet array (M1) comprising a plurality of magnets placed in an array;

- a first magnet supporting member (1) adapted to support the first magnet array (M1) mounted to the first magnet supporting member (1);

- a second magnet array (M2) comprising a plurality of magnets placed in an array and facing the first magnet array (M1) with a gap (δ) interposed therebetween;

- a second magnet supporting member (2) adapted to support the second magnet array (M2) mounted to the second magnet supporting member (2);

- a gap driving mechanism (50) for driving the first magnet supporting member (1) and/or the second magnet supporting member (2) in a direction in which the magnet arrays (M1, M2) are facing each other, in order to change a size of the gap (δ);

- a first coupling beam (103) coupled integrally to the first magnet supporting member (1);

- a second coupling beam (203) coupled integrally to the second magnet supporting member (2);

- a driving conjunction mechanism for coupling at least one of the first coupling beam (103) and the second coupling beam (203) to the gap driving mechanism (50);

- a compensation spring mechanism (40) adapted to act in such a direction as to cancel an attractive force acting between the first magnet array (M1) and the second magnet array (M2); and

- a spring conjunction mechanism (30) for coupling the compensation spring mechanism (40) and the coupling beams to each other, wherein the spring conjunction mechanism (30) includes:

- a first auxiliary frame (91) coupled, through a pair of first coupling portions (91A), to one of the first coupling beam (103) and the second coupling beam (203);

- a second auxiliary frame (92) coupled, through a pair of second coupling portions (92A), to the other one of the first coupling beam (103) and the second coupling beam (203);

- a first spring supporting frame (31) mounted to the first auxiliary frame (91);

- a second spring supporting frame (32) mounted to the second auxiliary frame (92); and

- a guide mechanism (36) for guiding relative movement of the first spring supporting frame (31) and the second spring supporting frame (32), in the direction in which the magnet arrays (M1, M2) are facing each other,

wherein the compensation spring mechanism (40) is mounted to both the first spring supporting frame (31) and the second spring supporting frame (32) and configured to operate, when the size of the gap (δ) is changed, by allowing relative movement of the first spring supporting frame (31) and the second spring supporting frame (32), in the direction in which the magnet arrays (M1, M2) are facing each other, wherein the first auxiliary frame (91) is capable of placing a mechanism for coupling the first magnet supporting member (1) and the first coupling beam (103) to each other between the pair of first coupling portions (91A), and wherein the second auxiliary frame (92) is capable of placing a mechanism for coupling the second magnet supporting member (2) and the second coupling beam (203) to each other between the pair of second coupling portions (92A).

2. The insertion device according to claim 1, wherein the first auxiliary frame (91) includes a pair of first front and back plates (911) extending in a forward and rearward direction, and a first left and right plate (910) extending in a leftward and rightward direction for coupling the pair of first front and back plates (911) to each other, wherein the second auxiliary frame (92) includes a pair of second front and back plates (921) extending in a forward and rearward direction, and a second left and right plate (920) extending in a leftward and rightward direction for coupling the pair of second front and back plates (921) to each other, wherein the pair of first front and back plates (911) is coupled to the first coupling beam (103) via the first coupling portions (91A), and wherein the pair of second front and back plates (921) is coupled to the second coupling beam (203) via the second coupling portions (92A).
3. The insertion device according to claim 1 or 2, wherein the first auxiliary frame (91) and the second auxiliary frame (92) have a gate-like shape in plan view.
4. The insertion device according to claim 2, wherein the first left and right plate (910) and the second left and right plate (920) are formed with both mounting holes for mounting the first spring supporting frame (31) and mounting holes for mounting the second spring supporting frame (32).

Fig.1

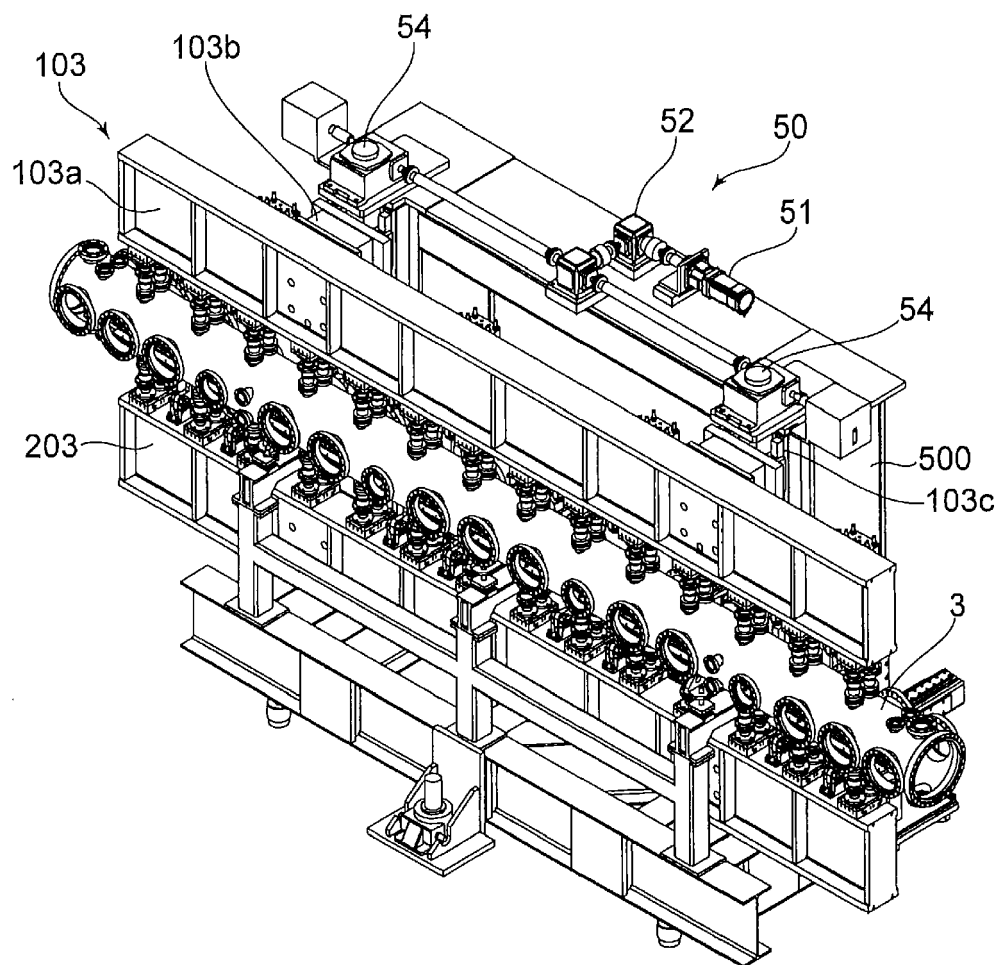


Fig.2

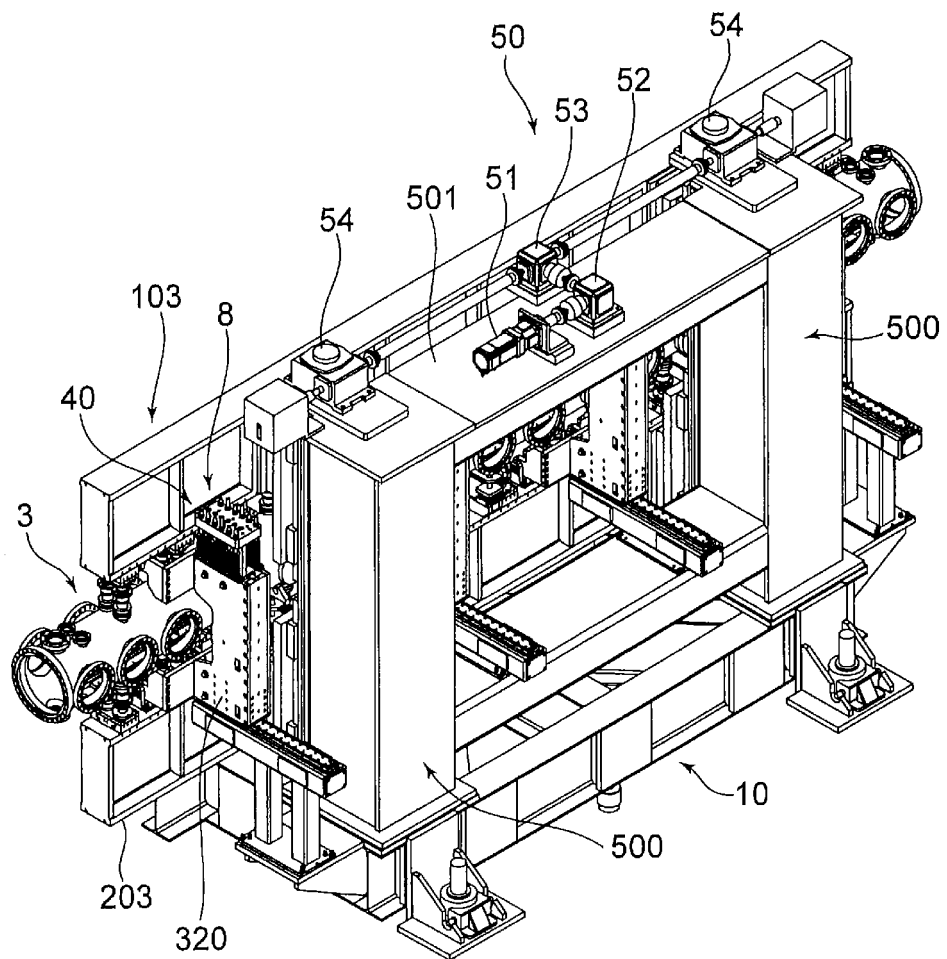


Fig.3

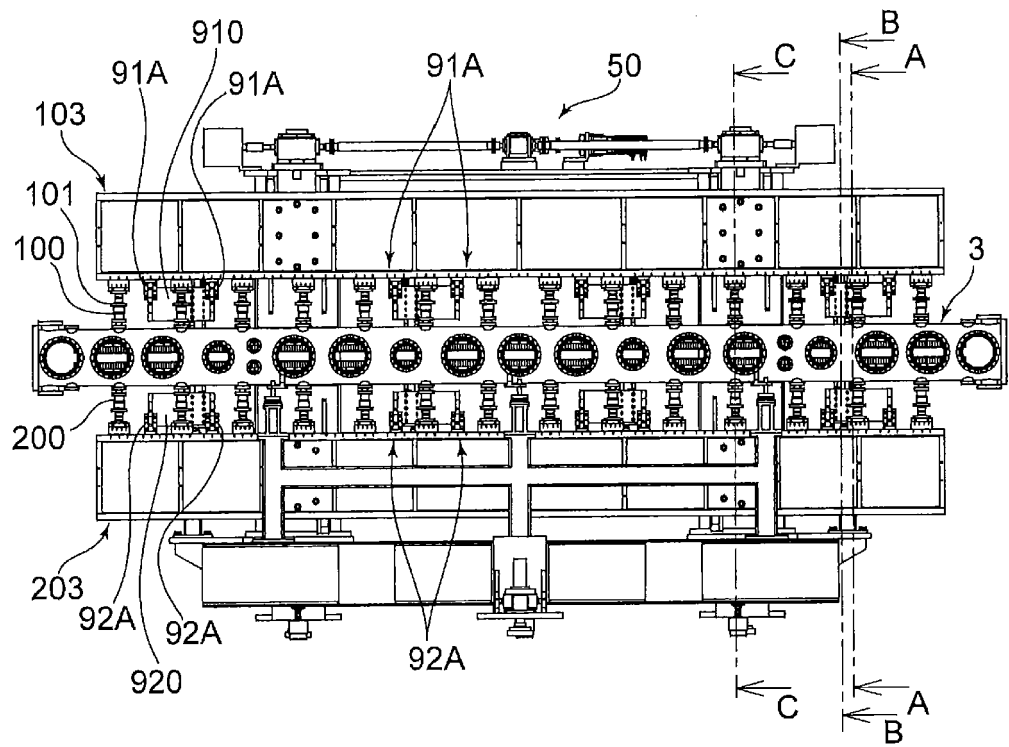


Fig.4

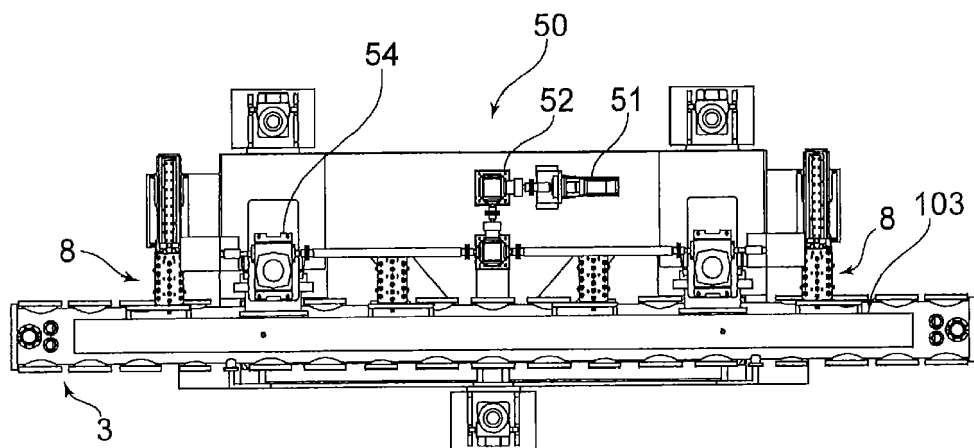


Fig.5

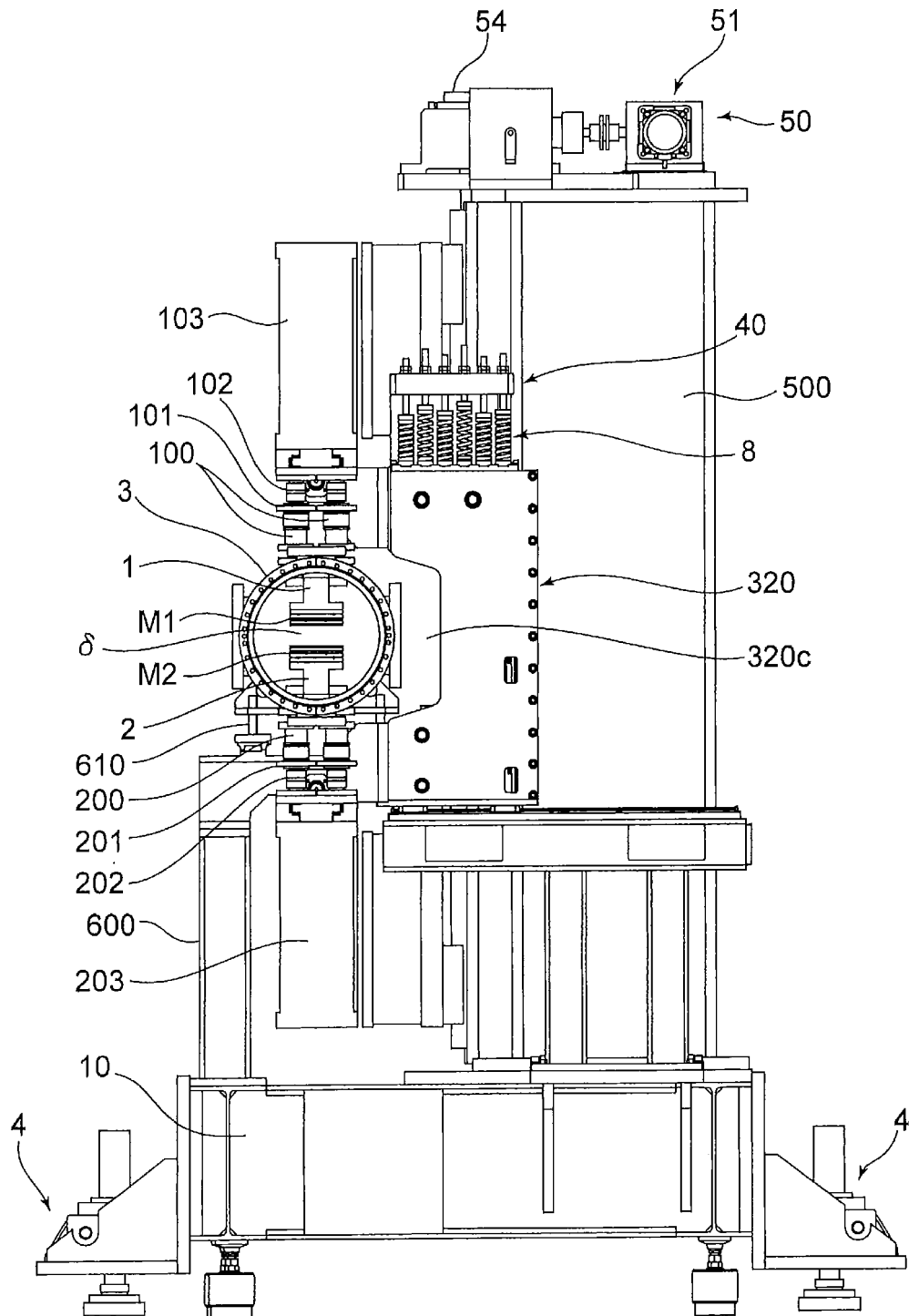


Fig.6

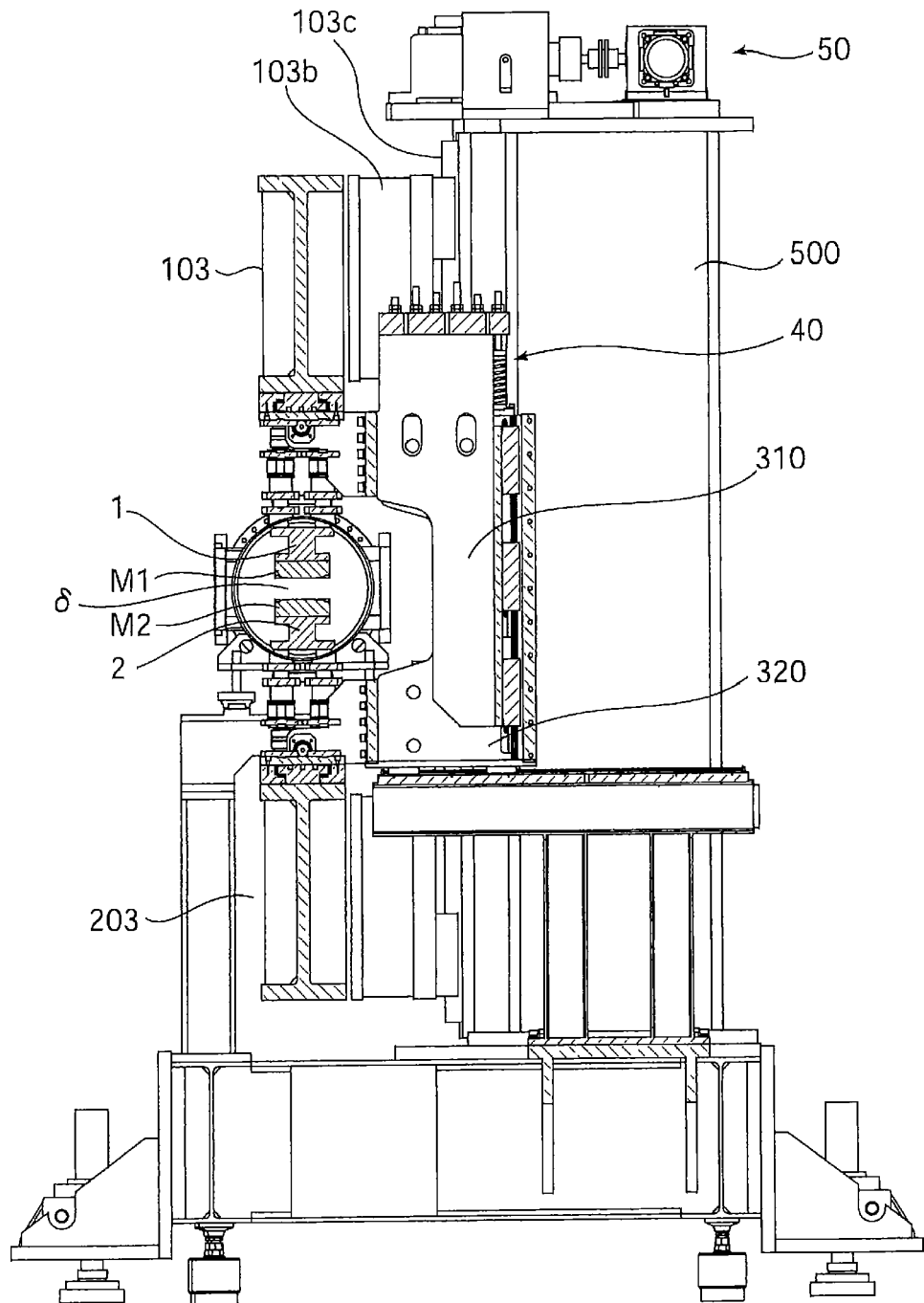


Fig.7

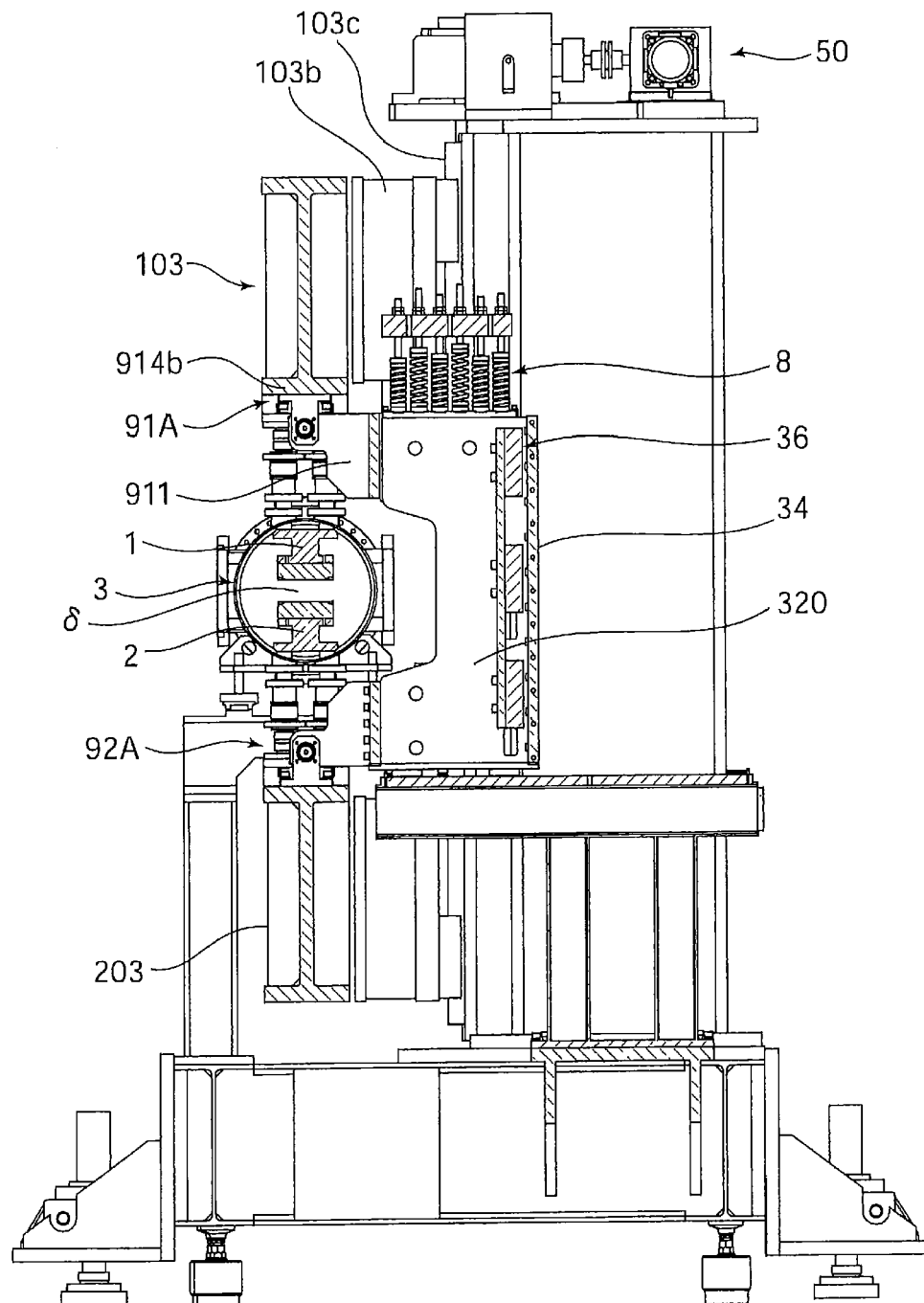


Fig.8

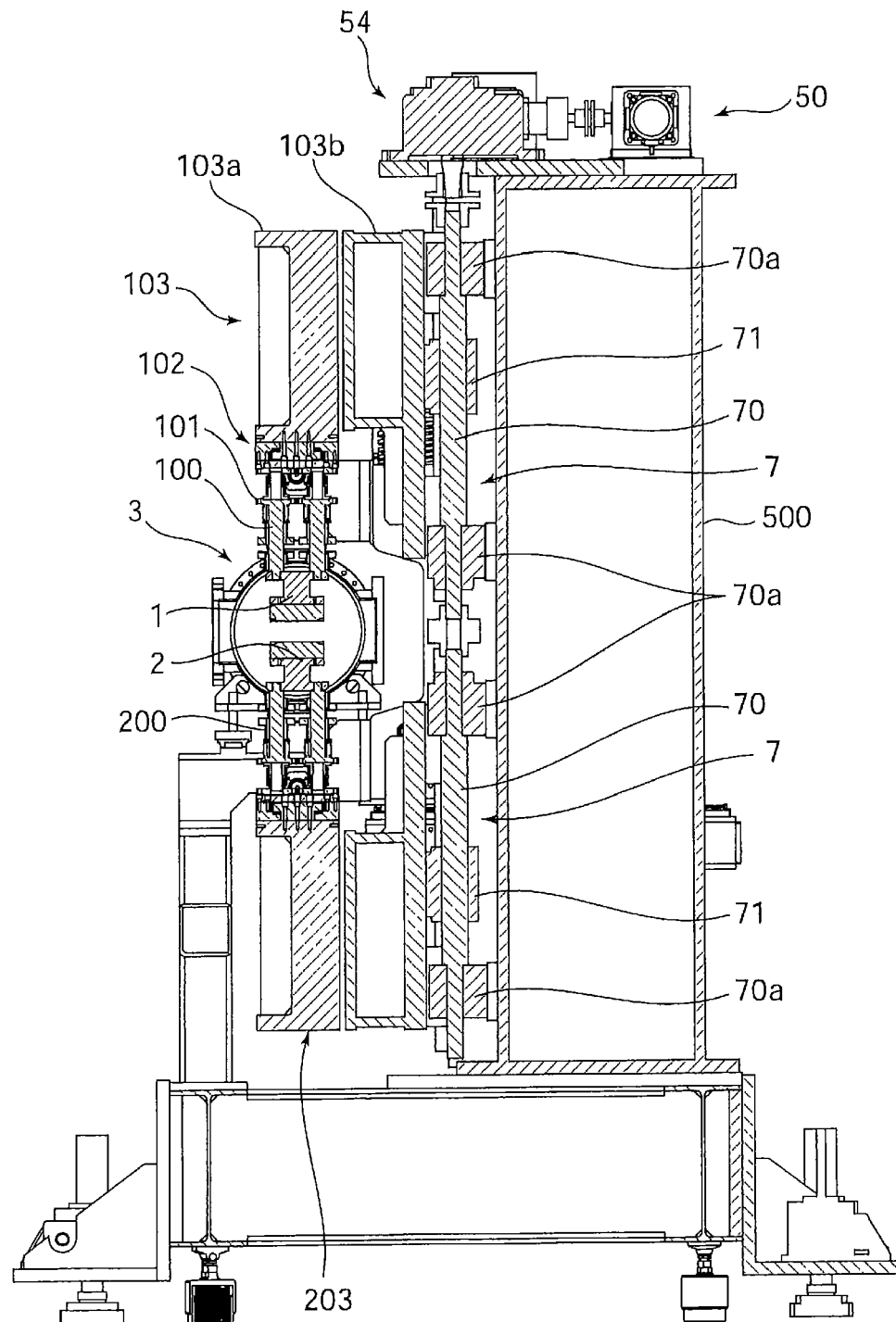


Fig.9

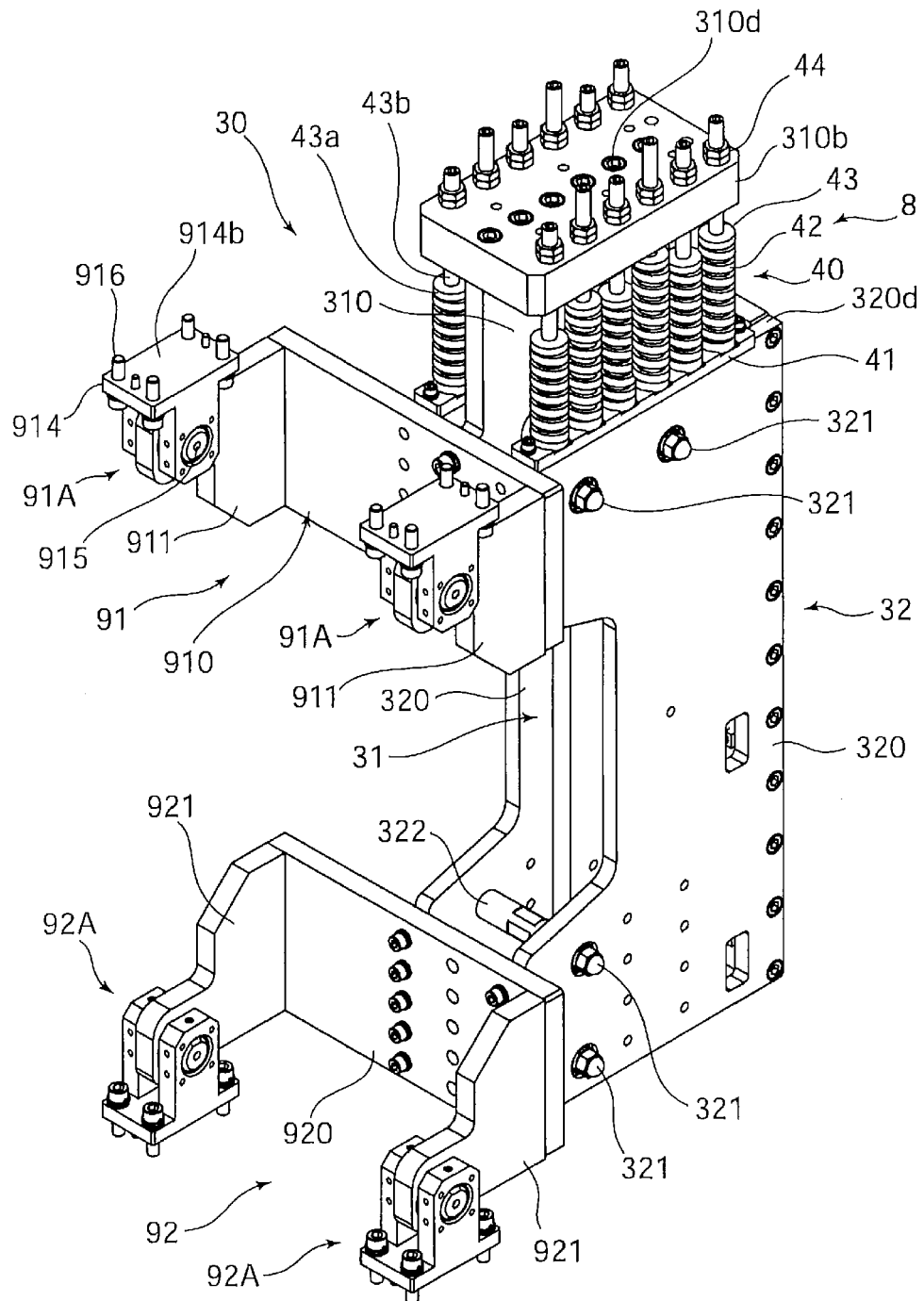


Fig.10

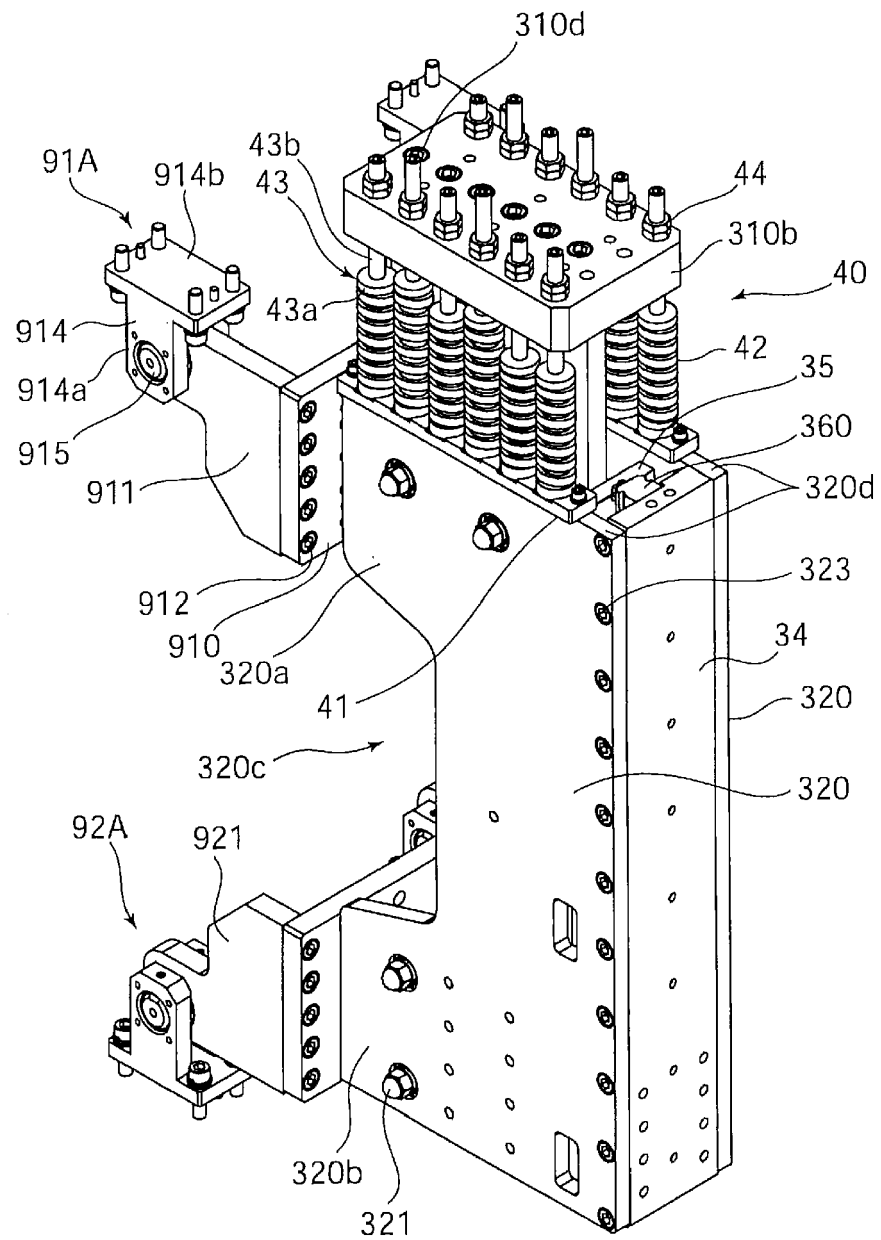


Fig.11

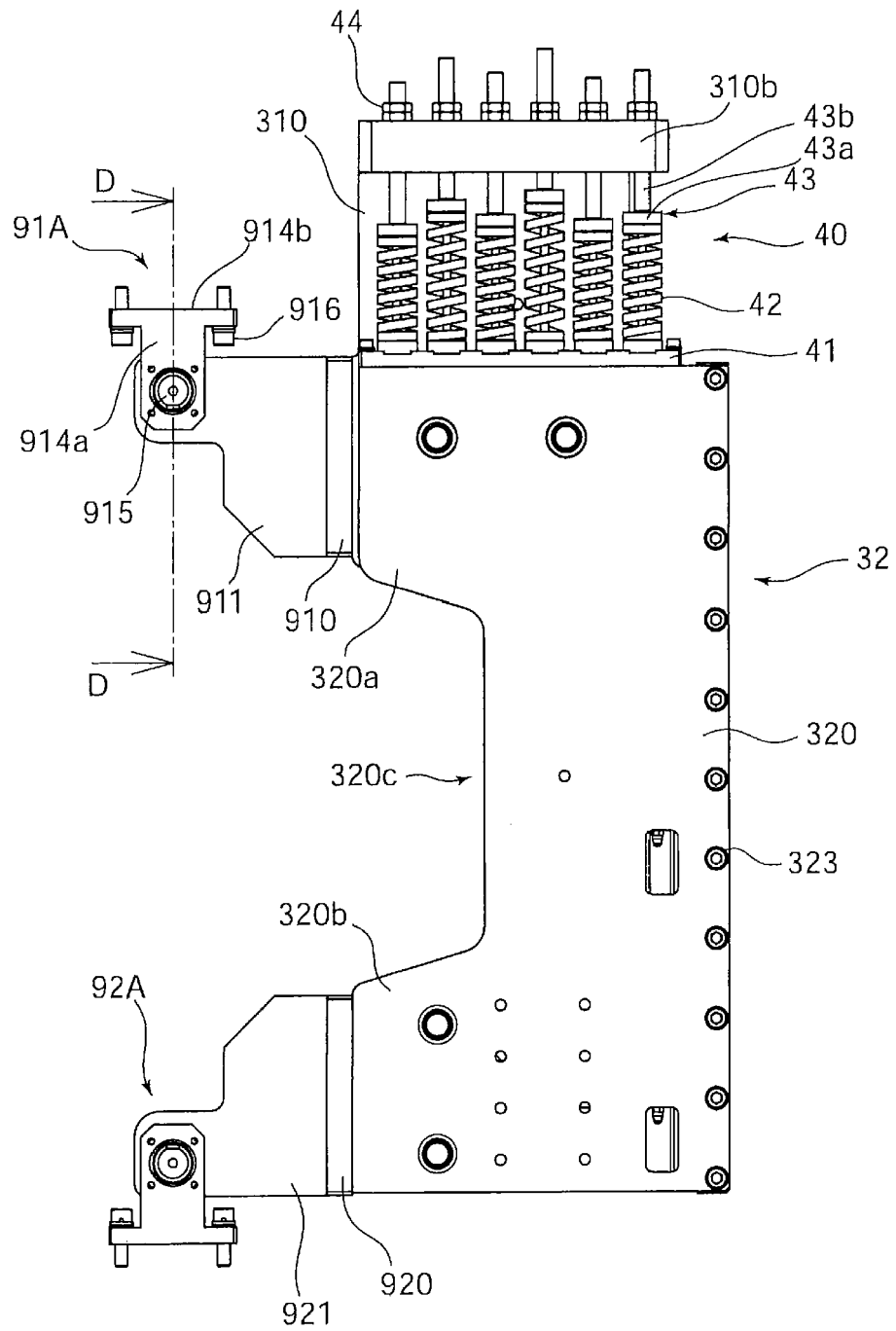


Fig.12

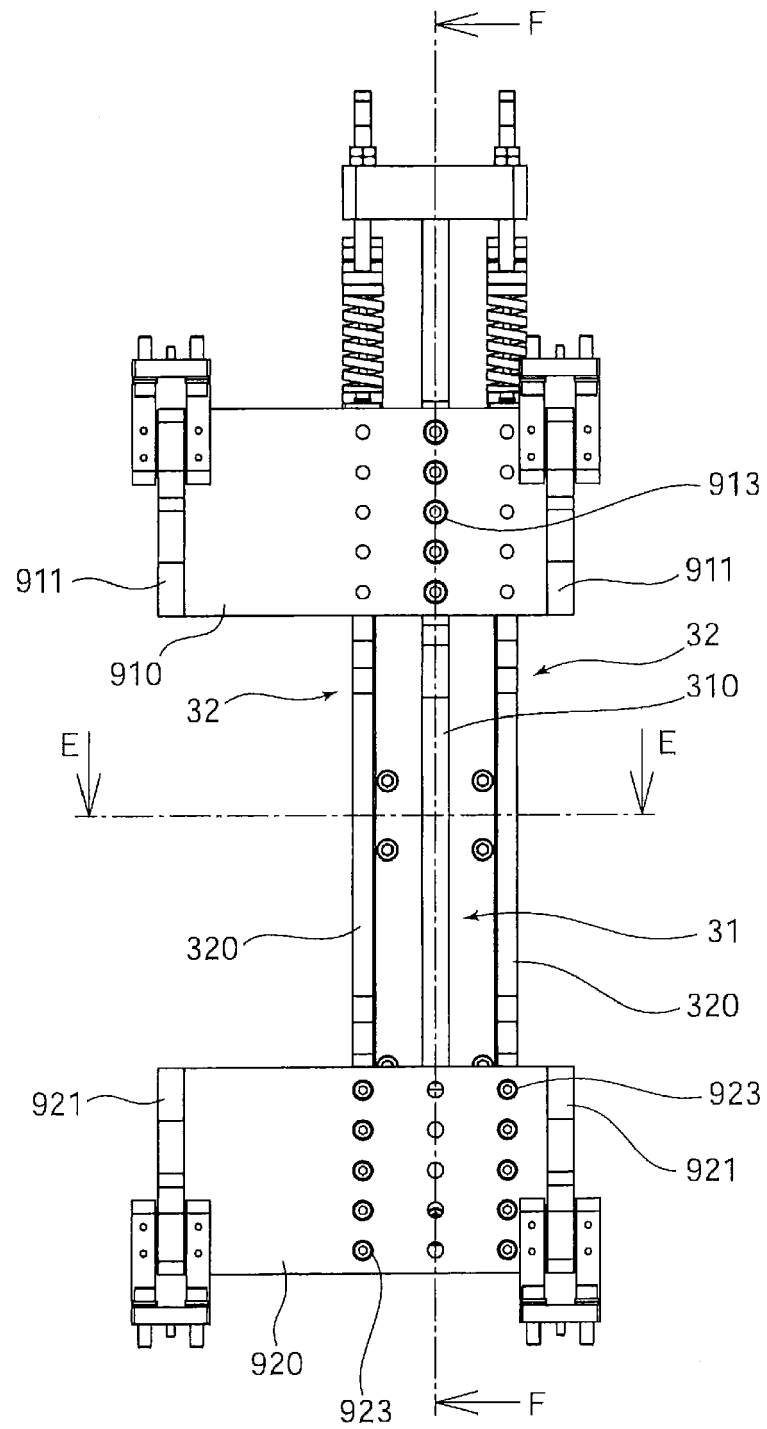


Fig.13

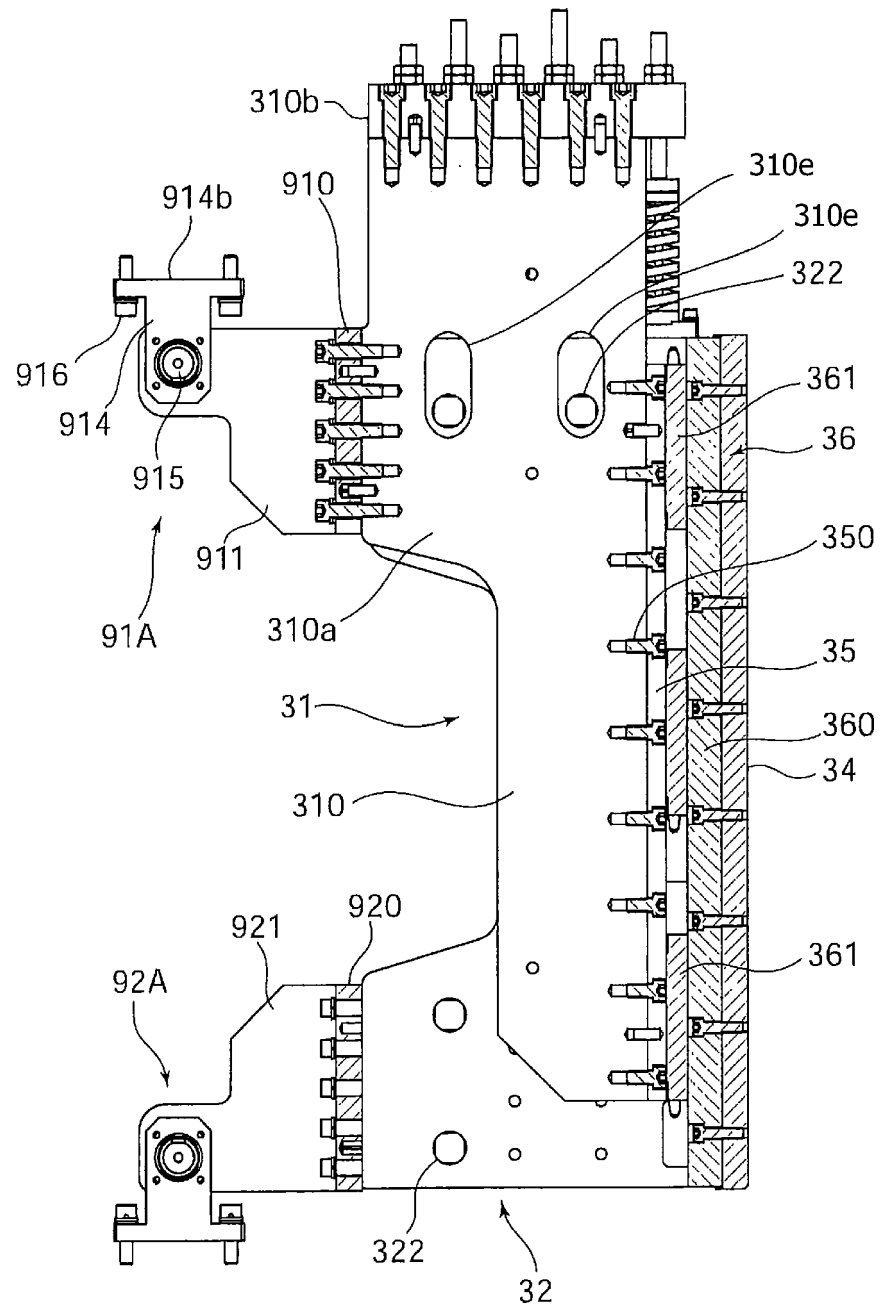


Fig.14

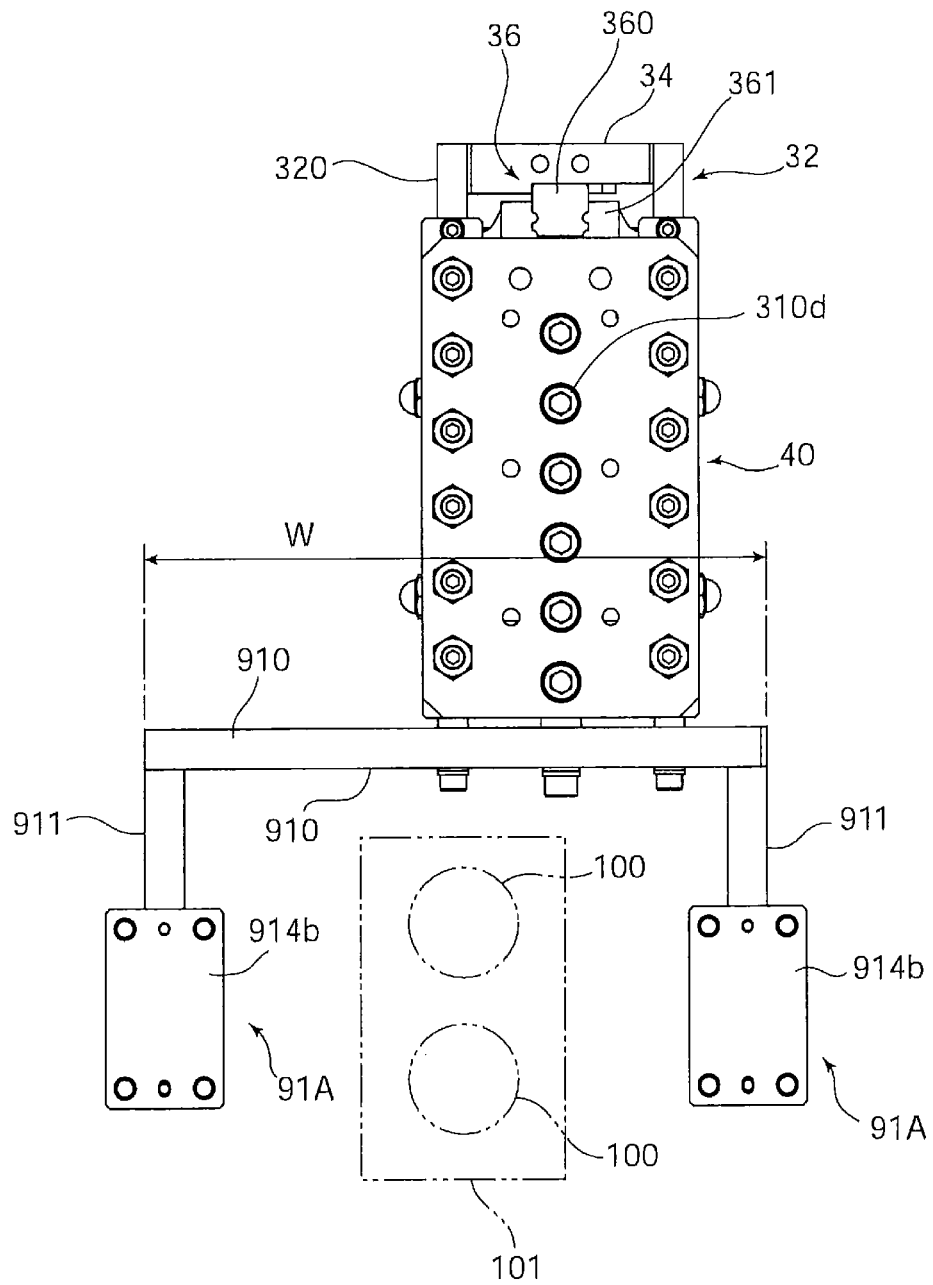


Fig.15

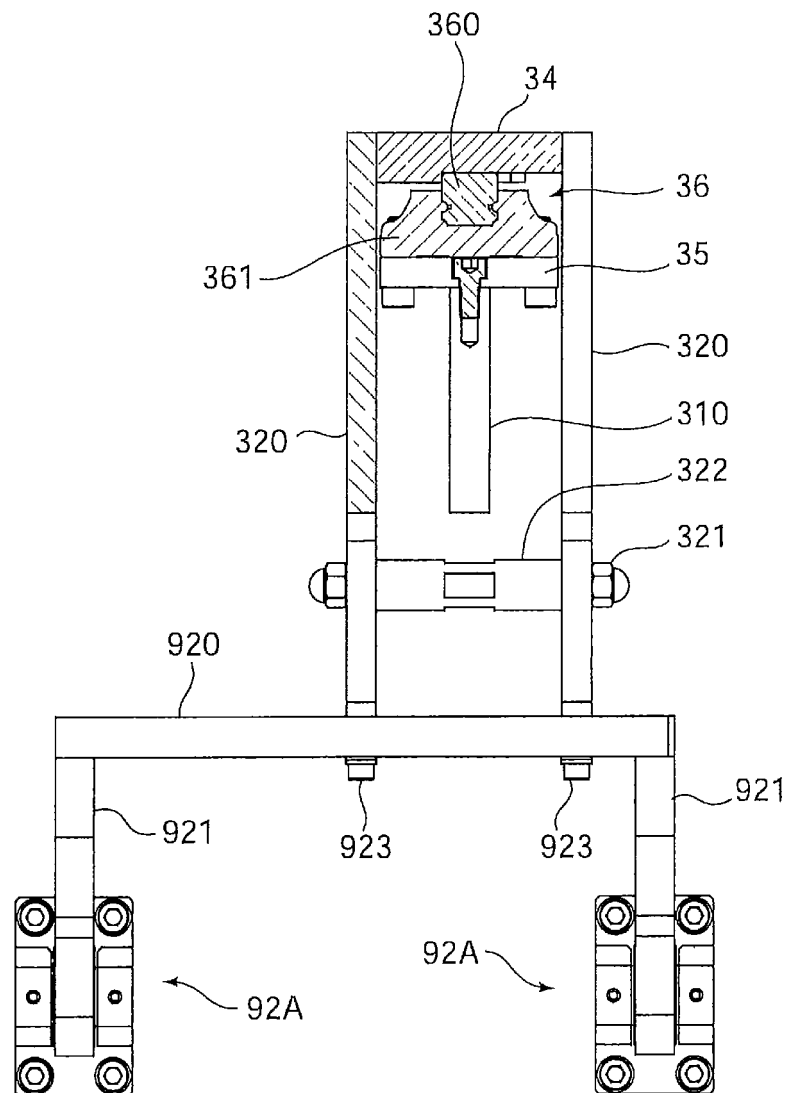
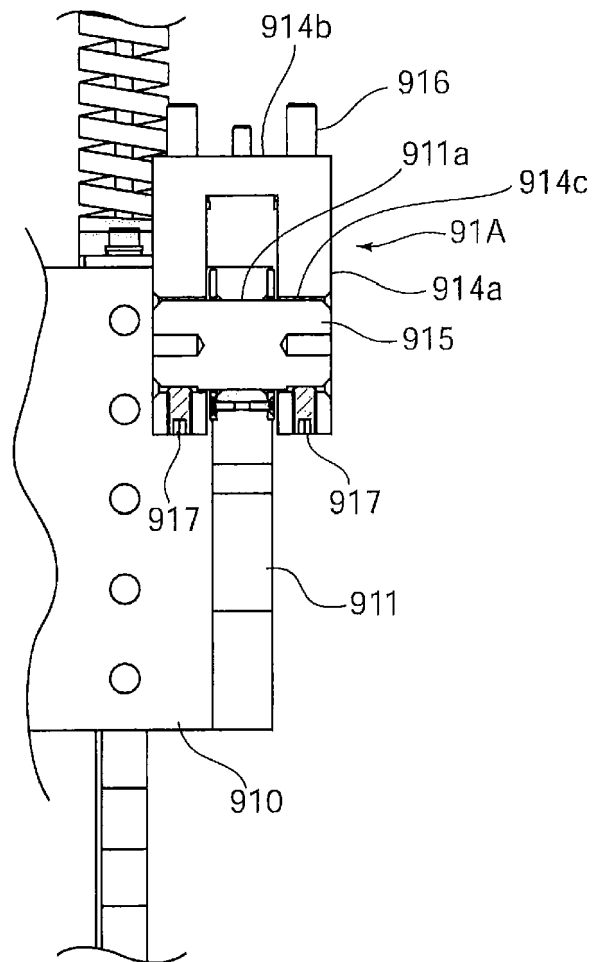


Fig.16





EUROPEAN SEARCH REPORT

Application Number
EP 20 16 5160

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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,D	WO 2018/143253 A1 (HITACHI METALS LTD [JP]) 9 August 2018 (2018-08-09) * figures 1-12B * * paragraph [0035] - paragraph [0084] *	1-4	INV. H05H7/04 H05G2/00
A	US 2018/124911 A1 (KITAMURA HIDEO [JP] ET AL) 3 May 2018 (2018-05-03) * paragraph [0087] - paragraph [0143] * * figures 1-8 *	1-4	
A	EP 1 715 731 A1 (NEOMAX CO LTD [JP]; RIKEN [JP]) 25 October 2006 (2006-10-25) * figures 6-12 * * paragraph [0024] - paragraph [0052] *	1-4	
A,D	JP 2001 143899 A (RIKAGAKU KENKYUSHO; SUMITOMO SPEC METALS; SUMIJIYUU TEC KK) 25 May 2001 (2001-05-25) * figures 1-12 * * paragraph [0001] - paragraph [0071] *	1-4	
A	JUI-CHE HUANG ET AL: "A Mechanical Undulator Frame to Minimize Intrinsic Phase Errors", PROCEEDINGS OF THE 10TH MECHANICAL ENGINEERING DESIGN OF SYNCHROTRON RADIATION EQUIPMENT AND INSTRUMENTATION, vol. MEDSI2018, 1 December 2018 (2018-12-01), page France, XP055716085, DOI: 10.18429/jacow-meds2018-tuph19 * the whole document *	1-4	TECHNICAL FIELDS SEARCHED (IPC) H05H H01F H05G
The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 17 July 2020	Examiner Clemente, Gianluigi
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 (P04C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 20 16 5160

5

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
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17-07-2020

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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2018143253 A1	09-08-2018	AU 2018214391 A1 CN 110249713 A EP 3579667 A1 JP WO2018143253 A1 TW 201840252 A US 2020053863 A1 WO 2018143253 A1	15-08-2019 17-09-2019 11-12-2019 21-11-2019 01-11-2018 13-02-2020 09-08-2018
US 2018124911 A1	03-05-2018	EP 3331329 A1 JP WO2017022669 A1 TW 201717711 A US 2018124911 A1 WO 2017022669 A1	06-06-2018 24-05-2018 16-05-2017 03-05-2018 09-02-2017
EP 1715731 A1	25-10-2006	EP 1715731 A1 JP 4251648 B2 JP 5105089 B2 JP 2009004388 A JP WO2005072029 A1 US 2008231215 A1 WO 2005072029 A1	25-10-2006 08-04-2009 19-12-2012 08-01-2009 27-12-2007 25-09-2008 04-08-2005
JP 2001143899 A	25-05-2001	JP 4347966 B2 JP 2001143899 A	21-10-2009 25-05-2001

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- WO 2018143253 A1 [0007]
- JP 2001143899 A [0028]
- JP 2014013658 A [0028]

Non-patent literature cited in the description

- **WINICK, HERMAN ; GEORGE BROWN ; KLAUS HALBACH ; JOHN HARRIS.** Synchrotron Radiation Wiggler and Undulator Magnets. *Physics Today*, May 1981, vol. 34 (5), 50-63 [0008]