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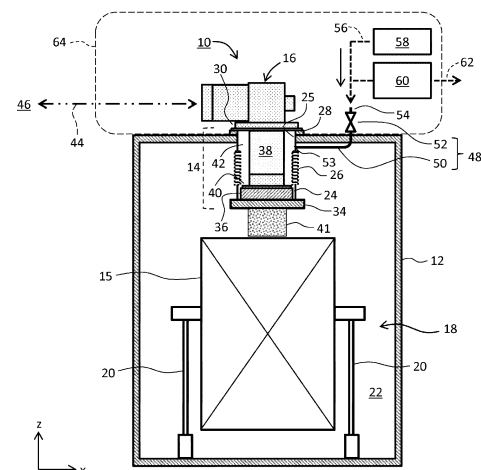
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(54) **COOLING DEVICE AND COLD HEAD EXCHANGE METHOD**

(57) An object of the present invention is to reduce a load of an operation of pulling out a cold head from a refrigerator port.

A refrigerator port 14 includes a sleeve 24 and a pedestal 34. A pipe 50 is drawn out from the refrigerator port 14. The pipe 50 is provided with a valve 52. Before a cold head 16 is pulled out, helium gas in a tank 58 is supplied to a port space 42 via the pipe 50. Accordingly, a pressure in the port space 42 becomes the atmospheric pressure or approaches the atmospheric pressure. A pressure adjustment facility 48 can also function when residual gas is discharged from the port space 42.

[FIG. 1]



Description

Technical Field

[0001] The present invention relates to a cooling device and a cold head replacement method, and particularly, to a technique used when a cold head is replaced under a conduction cooling method.

Background Art

[0002] As a cooling method, a refrigerant cooling method in which an object to be cooled is cooled by a refrigerator via a liquid or gas refrigerant, and a conduction cooling method in which an object to be cooled is cooled by a refrigerator without using such a refrigerant are known. In the latter conduction cooling method, a cold head of the refrigerator is connected to the object to be cooled directly or via a heat conductor. The cold head is connected to a compressor via a refrigerant circulation pipe. The cold head is a portion that absorbs heat, in other words, a portion that generates cold, and is also referred to as a refrigerator unit. When the cold head is used for a long period of time, periodic maintenance of the cold head is required. The maintenance includes, for example, replacement of consumable items such as a seal member and a valve.

[0003] As a maintenance method of the cold head, the following three methods are known. In a first maintenance method, maintenance of the cold head is performed by disassembling the cold head while maintaining a cooled state of the cold head and the object to be cooled. In a second maintenance method, maintenance is performed by increasing a temperature of the cold head and the object to be cooled to a room temperature without maintaining the cooled state of the cold head and the object to be cooled.

[0004] In a third maintenance method, maintenance of the cold head is performed after the cold head is removed while maintaining the cooled state of the object to be cooled. In this case, a new cold head is usually disposed after the cold head is removed. A vacuum container accommodating the object to be cooled is provided with a refrigerator port such that the cold head can be replaced while a vacuum state inside the vacuum container is maintained. The refrigerator port is a hollow structure that accommodates the cold head and functions as a partition wall. According to the third maintenance method, the cooled state of the object to be cooled can be maintained. In addition, the maintenance of the cold head can be performed at the room temperature, and thus workability of the maintenance can be improved.

[0005] PTL 1 and PTL 2 each disclose a cooling device premised on the third maintenance method described above. In the cooling device disclosed in PTL 1, a plurality of bellows are provided in a refrigerator port that receives a refrigerator unit. The cooling device disclosed in PTL 2 includes a coupling actuator that functions when a re-

frigerator unit is coupled to a refrigerator port, and a separating actuator that functions when the refrigerator unit is separated from the refrigerator port. In each of PTL 1 and PTL 2, there is no recognizable configuration configured to operate a pressure inside the refrigerator port.

Citation List

Patent Literature

[0006]

PTL 1: JP-A-2019-200003

PTL 2: JP-T-2010-506134

Summary of Invention

Technical Problem

[0007] In a state where a cold head is installed to a refrigerator port, a port space inside the refrigerator port becomes an airtight space. When the cold head is operated in this state, gas remaining in the port space is condensed, and a pressure in the port space becomes considerably lower than the atmospheric pressure, that is, becomes a negative pressure. Accordingly, the atmospheric pressure is applied to the cold head to press the cold head. In such a state, a considerably large force is required to pull out the cold head from a cooler port. This causes deterioration in replacement workability.

[0008] An object of the present disclosure is to improve workability when maintenance of a cold head is performed. Another object of the present disclosure is to operate a pressure in a port space when the maintenance of the cold head is performed.

Solution to Problem

[0009] A cooling device according to the present disclosure includes: a vacuum container accommodating an object to be cooled; a refrigerator port provided in the vacuum container and including a port space in which a cold head of a refrigerator configured to cool the object to be cooled is accommodated in a replaceable manner; and a pressure adjustment facility configured to supply gas to the port space to increase a pressure in the port space before the cold head is pulled out.

[0010] A cold head replacement method according to the present disclosure includes: in a state where a cold head of a refrigerator is disposed in a refrigerator port provided in a vacuum container, supplying gas from an outside to a port space in the refrigerator port and thereby increasing a pressure in the port space; and pulling out the cold head from the refrigerator port after the pressure in the port space is increased.

Advantageous Effects of Invention

[0011] According to the present disclosure, it is possible to improve the workability when the maintenance of the cold head is performed. Alternatively, according to the present disclosure, it is possible to operate the pressure in the port space when the maintenance of the cold head is performed.

Brief Description of Drawings

[0012]

[FIG. 1] FIG. 1 is a cross-sectional view showing a cooling device according to a first embodiment.

[FIG. 2] FIG. 2 is a plan view showing a flange overlapping portion.

[FIG. 3] FIG. 3 is a cross-sectional view showing a cooling device according to a second embodiment.

[FIG. 4] FIG. 4 is an enlarged cross-sectional view showing a part of the cooling device shown in FIG. 3.

[FIG. 5] FIG. 5 is an enlarged cross-sectional view showing a modification.

[FIG. 6] FIG. 6 is a cross-sectional view showing a cooling device according to a third embodiment.

[FIG. 7] FIG. 7 is an enlarged cross-sectional view showing a part of the cooling device shown in FIG. 6.

[FIG. 8] FIG. 8 is a flowchart showing a cold head replacement method according to an embodiment.

[FIG. 9] FIG. 9 is a diagram showing an example of a facility in which the cooling device according to each embodiment is installed.

Description of Embodiments

[0013] Hereinafter, various embodiments will be described with reference to the drawings.

(1) Outline of Embodiment

[0014] A cooling device according to an embodiment includes a vacuum container, a refrigerator port, and a pressure adjustment facility. The vacuum container is a container in which an object to be cooled is accommodated. The refrigerator port is a port provided in the vacuum container, and includes a port space in which a cold head of a refrigerator configured to cool the object to be cooled is accommodated in a replaceable manner. The pressure adjustment facility is a facility configured to supply gas to the port space to increase a pressure in the port space before the cold head is pulled out.

[0015] According to the above configuration, before the cold head is pulled out from the refrigerator port, the pressure adjustment facility is caused to function, the gas is supplied to the port space, and the pressure in the port space is increased. Therefore, a pressure difference between the outside and the port space is eliminated or reduced, and a force applied to the cold head due to the

pressure difference is eliminated or reduced. Accordingly, the cold head is easily pulled out.

[0016] In the embodiment, the pressure adjustment facility functions not only when the gas is supplied to the port space but also when the gas is discharged from the port space. Further, the pressure adjustment facility may also be used for other purposes. In the embodiment, the refrigerator port is a hollow structure in which all or a part of the cold head is accommodated. The refrigerator port functions as a partition wall that partitions an internal space of the vacuum container and the port space.

[0017] In the embodiment, the pressure adjustment facility includes a pipe and a valve. The pipe includes a gas flow path communicating with the port space, and is drawn out from the refrigerator port. The valve is provided in the pipe. The valve closes the gas flow path during operation of the refrigerator, and allows supply of gas to the gas flow path during replacement of the cold head.

[0018] According to the above configuration, the gas can be supplied to the port space with a simple configuration. The pipe may be provided to penetrate the vacuum container, or the pipe may be provided to penetrate a flange (attachment plate) of the cold head. According to the former configuration, the existing cold head can be used directly.

[0019] In the embodiment, a first end portion of the pipe is connected to the refrigerator port, and a second end portion of the pipe is guided to the outside of the vacuum container. The valve is provided on an exposed portion (a portion exiting from the vacuum container) of the pipe. When this configuration is adopted, opening and closing of the valve can be manually performed. Of course, the opening and closing of the valve may also be controlled by an electric signal.

[0020] In the embodiment, the refrigerator port includes a bellows that expands and contracts in a port central axis direction.

[0021] The pipe is drawn out from a room temperature side of the bellows in the refrigerator port. The bellows includes a bellows structure, has deformability, and exhibits a heat inflow reducing effect. By drawing out the pipe from a room temperature side portion of the refrigerator port, the pipe is thermally separated from a stage (heat absorption unit, cold generation unit) of the cold head. In addition, according to the above configuration, it is possible to obtain an advantage that no load is applied to the pipe or a load is hardly applied to the pipe even when the bellows is deformed.

[0022] In the embodiment, the refrigerator port includes a sleeve and a pedestal. The sleeve is a member surrounding the port space. The pedestal is a member provided on a cooling-side end portion of the sleeve, and is directly or indirectly connected to the stage of the cold head. The refrigerator is further provided with an elastic mechanism that applies an elastic force to the pedestal so as to increase a connecting force between the pedestal and the stage.

[0023] According to this configuration, the connecting

force between the pedestal and the stage can be increased by the elastic mechanism, and thus a thermal conductivity therebetween can be improved. By providing the elastic mechanism independently of the sleeve, a sufficient elastic action can be obtained without depending on an elastic action of the bellows. Of course, a part of the refrigerator port may include a portion that generates an auxiliary elastic force. In the embodiment, a mechanism that mechanically generates an elastic force is provided as the elastic mechanism. In a situation in which the cooling device vibrates or vibration reaches the cooling device, it can also be expected that the vibration is absorbed and relaxed by the elastic mechanism. In a case where a posture of the cooling device changes, the good thermal conductivity described above can be stably obtained by the elastic mechanism.

[0024] In the embodiment, the port space includes a first port space and a second port space arranged in the port central axis direction. The refrigerator port includes a first sleeve, a second sleeve, a first pedestal, and a second pedestal. The first sleeve is a member surrounding the first port space. The second sleeve is a member surrounding the second port space. The first pedestal is a member provided on a cooling-side end portion of the first sleeve, and is directly or indirectly connected to a first stage of the cold head. The second pedestal is a member provided on a cooling-side end portion of the second sleeve, and is directly or indirectly connected to a second stage of the cold head. The cooling device further includes a first elastic mechanism and a second elastic mechanism. The first elastic mechanism applies an elastic force to the first pedestal so as to increase a connecting force between the first pedestal and the first stage. The second elastic mechanism applies an elastic force to the second pedestal so as to increase a connecting force between the second pedestal and the second stage.

[0025] The above configuration is premised on a two-stage configuration (two-stage cold head) including two cold generation units connected in series. A first thermal conductivity between the first pedestal and the first stage is improved by the first elastic mechanism, and a second thermal conductivity between the second pedestal and the second stage is improved by the second elastic mechanism. In the embodiment, the first elastic mechanism is provided between the vacuum container and the first pedestal, and the second elastic mechanism is provided between the vacuum container and the second pedestal separately from the first elastic mechanism. That is, an independent traction method is adopted. By adopting such a configuration, it is possible to reliably improve each of the first thermal conductivity and the second thermal conductivity. A modification in which two elastic mechanisms are connected or linked is also conceivable.

[0026] In the embodiment, the first elastic mechanism includes a plurality of first support elements provided around the first sleeve, and each of the first support elements includes an elastic member. The second elastic

mechanism includes a plurality of second support elements provided around the first sleeve and the second sleeve, and each of the second support elements includes an elastic member.

[0027] According to the above configuration, since the plurality of first support elements are provided outside the first sleeve, and the plurality of second support elements are provided outside the second sleeve, it is possible to avoid an increase in sizes of the first sleeve and the second sleeve. In other words, the first sleeve and the second sleeve can be downsized. Since volumes of a first sleeve space in the first sleeve and a second sleeve space in the second sleeve can be reduced, gas consumption can be reduced.

[0028] In the embodiment, the refrigerator port is provided with a heater configured to prevent liquefaction of the gas supplied to the port space. The heater is a liquefaction preventing unit. At the time of maintenance of the cold head, when the gas is supplied into the port space in a state where a temperature of the stage of the cold head is extremely low, the gas liquefies (or becomes particles), and an effect of the gas supply decreases. Otherwise, the gas consumption increases. In some cases, liquid (or particles) generated due to cooling reduces an action of thermally conductive grease or the like. According to the above configuration, it is possible to avoid or reduce such problems.

[0029] A cold head replacement method according to the embodiment includes a first process and a second process. In the first process, in a state where the cold head of the refrigerator is disposed in the refrigerator port provided in the vacuum container, gas is supplied from the outside to the port space in the refrigerator port, thereby increasing a pressure in the port space. In the second process, the cold head is pulled out from the refrigerator port after the pressure in the port space is increased.

[0030] According to the above configuration, since the cold head can be pulled out after the pressure in the port space is increased, it is not required to apply a large force when pulling out the cold head. Accordingly, workability at the time of pulling out the cold head is improved. It is desirable to increase the pressure in the port space to the atmospheric pressure, and the pressure in the port space may also be increased to a level lower than the atmospheric pressure.

[0031] In the embodiment, a process of discharging the gas in the port space to the outside after a new cold head is disposed into the refrigerator port is further provided. According to this configuration, it is possible to further reduce heat conduction caused by convection of residual gas in the port space.

(2) Details of Embodiment

[0032] FIG. 1 shows a cooling device according to a first embodiment. The shown cooling device is a cooling device according to a conduction cooling method. In FIG. 1, an x direction and a z direction orthogonal to the x

direction are shown. A direction orthogonal to the x direction and the z direction is a y direction. In FIG. 1, the y direction is not shown. The x direction, the y direction, and the z direction do not necessarily coincide with a vertical direction in which gravity acts. Hereinafter, for convenience of description, the terms "up", "down", "left", and "right" are used with reference to the drawings.

[0033] The shown cooling device includes a refrigerator 10, a vacuum container 12, and a refrigerator port 14. An object to be cooled 15 is provided in the vacuum container 12. The object to be cooled 15 is, for example, a superconducting coil for generating a magnetic field. The object to be cooled 15 is supported by a support mechanism 18 in the vacuum container 12. The inside of the vacuum container 12 is a vacuum space 22. The vacuum container 12 is made of, for example, stainless steel. The support mechanism 18 includes a plurality of support columns 20 each made of a heat insulating material. Each of the support columns 20 is made of, for example, fiber-reinforced plastics (FRP) having a high heat insulating effect. Examples of such an FRP include GFRP containing glass fibers, CFRP containing carbon fibers, and the like.

[0034] The refrigerator 10 includes a cold head (also referred to as a refrigerator unit) 16 and a compressor (also referred to as a compression unit) 46. These components are connected by a refrigerant circulation pipe 44. Examples of the refrigerator 10 include a GM refrigerator, a Solvay refrigerator, a pulse tube refrigerator, and the like.

[0035] The vacuum container 12 is provided with the refrigerator port 14. The refrigerator port 14 is a hollow structure in which the cold head 16 is accommodated. From this viewpoint, the refrigerator port 14 is a cold head port. The cold head 16 includes a plurality of elements that execute a heat exchange cycle. The plurality of elements include a syringe, a piston, and the like. An internal space of the refrigerator port 14 is a port space 42. In a state where the cold head 16 is attached to the refrigerator port 14, the port space 42 is an airtight space isolated from the outside and the vacuum space 22.

[0036] A circular opening 25 is formed in the vacuum container 12. A flange 28 serving as a peripheral edge portion or an attachment base is formed so as to surround the opening 25. The refrigerator port 14 includes a sleeve 24 and a pedestal 34. The sleeve 24 is a cylindrical hollow body, and a bellows 26 is formed at an intermediate portion thereof. The bellows 26 has a bellows structure, is formed of a plurality of folded chains, and expands and contracts in a central axis direction of the refrigerator port 14. The bellows 26 has a function of preventing heat inflow caused by heat conduction from a room temperature side toward the object to be cooled 15. In addition, the bellows 26 has deformability, and has a function of absorbing a deviation (dimension difference) when an actual spatial relationship is deviated from a specified spatial relationship between the refrigerator port 14 and the cold head 16.

[0037] A room-temperature-side end portion (upper end portion in FIG. 1) of the sleeve 24 is connected to the opening 25, and a cooling-side end portion (lower end portion in FIG. 1) of the sleeve 24 is connected to the pedestal 34. The sleeve 24 as a whole is made of, for example, stainless steel. A thickness of the bellows 26 of the sleeve 24 is, for example, 0.1 to 0.2 mm, and a thickness of a portion of the sleeve 24 other than the bellows 26 is, for example, 0.2 to 0.4 mm. Numerical values mentioned in the present specification are merely examples.

[0038] The pedestal 34 is a disc made of a material having good thermal conductivity, for example, copper (specifically, oxygen-free copper). In the configuration example shown in FIG. 1, a first surface (upper surface in FIG. 1) of the pedestal 34 is connected to the cold head 16 via a heat conduction member 36. The heat conduction member 36 is, for example, a disc made of copper. The heat conduction member 36 is provided for a purpose of, for example, protecting a stage 40 of the cold head 16. The pedestal 34 may also be directly joined to the stage 40 of the cold head 16 without providing the heat conduction member 36.

[0039] Thermally conductive grease is provided between the respective members as necessary. In the configuration example shown in FIG. 1, a second surface (lower surface in FIG. 2) of the pedestal 34 is connected to the object to be cooled 15 via a heat conduction member 41. The heat conduction member 41 is made of a material (for example, copper) that is freely deformable and has good thermal conductivity.

[0040] A portion 38 of the cold head 16 is inserted into the refrigerator port 14. The cold head 16 includes a flange 30 provided on a room temperature side. The flange 30 is an attachment plate that is an annular disc spreading in a flange shape. The flange 30 is attached to the flange 28 by a plurality of bolts (not shown).

[0041] As will be described later, a ring-shaped groove is formed in the flange 28. An O-ring that serves as a seal member is disposed in the groove. In a state where the flange 28 and the flange 30 are overlapped and fastened, a gap between the flange 28 and the flange 30 is completely sealed by the O-ring. Accordingly, the port space 42 becomes an airtight space. The flange 28 and the flange 30 are made of, for example, stainless steel. The flange 28 and the sleeve 24 may be connected by methods such as welding.

[0042] The cold head 16 includes the stage 40 that serves as a cooling end portion. Cold generated in the cold head 16 is transferred from the stage 40 to the object to be cooled via the heat conduction member 36, the pedestal 34, and the heat conduction member 41. In other words, heat of the object to be cooled 15 is absorbed by the stage 40 via the heat conduction member 41, the pedestal 34, and the heat conduction member 36. In this way, the object to be cooled 15 is cooled by the conduction cooling method.

[0043] When the cold head 16 is operated after the

cold head 16 is installed into the refrigerator port 14, gas (usually, helium gas) in the port space 42 aggregates as cold is generated in the cold head 16, and a pressure in the port space 42 becomes considerably lower than the atmospheric pressure. During operation of the cooling device, this state is maintained.

[0044] During maintenance of the refrigerator, for example, an entire work space including the cold head 16 is covered with a bag-shaped cover 64. After atmospheric air in the cover 64 is removed, helium gas or the like is introduced into the cover 64. Accordingly, atmospheric air is prevented from entering the port space 42. If atmospheric air enters the port space 42, problems such as generation of frost occur. The cover 64 also functions to prevent entry of foreign matter.

[0045] During the maintenance of the refrigerator, by simply loosening the plurality of bolts described above, an action of the O-ring is maintained without change, that is, the pressure in the port space 42 remains at a negative pressure. In this state, an atmospheric pressure is applied to the cold head 16, and a considerably large force is required to pull out the cold head 16 from the refrigerator port 14. Otherwise, the pulling-out cannot be performed. Therefore, in the embodiment, a pressure adjustment facility 48 is provided. Hereinafter, the pressure adjustment facility 48 will be described in detail.

[0046] In the shown configuration example, the pressure adjustment facility 48 includes a pipe 50 and a valve 52. A first end portion 53 of the pipe 50 is connected to the sleeve 24, and a second end portion 54 of the pipe 50 is located outside the vacuum container 12. The pipe 50 penetrates a specific wall (upper wall in FIG. 1) of the vacuum container 12, and a part of the pipe 50 constitutes an exposed portion belonging to the outside. The valve 52 is provided at the exposed portion. The specific wall is a wall in which the opening 25 is formed, and is a wall adjacent to the work space. A position where the valve 52 is installed is determined in consideration of workability during replacement of the cold head 16 and operability of the valve 52.

[0047] An internal flow path of the pipe 50 communicates with the port space 42. When the valve 52 is closed, the internal flow path is in a closed state, and when the valve 52 is opened, the internal flow path is in an opened state, that is, in a flowing state. The first end portion 53 is connected to a portion, which is located on the room temperature side relative to the bellows 26, of the sleeve 24. Accordingly, heat inflow via the pipe 50 is prevented. Even if the bellows 26 is deformed, no particular stress is generated in the pipe 50.

[0048] The pipe 50 is formed of, for example, a stainless steel tube. An inner diameter thereof is, for example, 4 to 6 mm, and an outer diameter thereof is, for example, 5 to 7 mm. As the valve 52, a valve that can be opened and closed manually is provided. An electromagnetic valve or the like may be used instead of such a valve. The opening and closing of the valve 52 may also be controlled by an electric signal.

[0049] Before the cold head 16 is pulled out, a tank 58 is connected to the second end portion 54. In this case, the tank 58 may be connected to the second end portion 54 via a relay pipe 56. The tank 58 is a small tank in which helium gas is accommodated. When the valve 52 is opened in a state where the tank 58 is connected to the second end portion 54, the helium gas in the tank 58 is sent to the port space 42 through an internal space of the pipe 50. Accordingly, the pressure in the port space 42 becomes the atmospheric pressure or approaches the atmospheric pressure. In this state, the cold head 16 can be easily pulled out.

[0050] Also, when a new cold head (which may be the cold head 16 after maintenance) is installed into the refrigerator port 14, a suction pump 60 is connected to the second end portion 54 as necessary. In this case, the suction pump 60 may also be connected to the second end portion 54 via the relay pipe 56. By operating the suction pump 60 while opening the valve 52 in a state where the port space 42 is an airtight space, it is possible to discharge residual gas (usually, helium gas) in the port space 42 to the outside (see reference numeral 62).

[0051] After operating of the cold head 16 is started, the residual gas in the port space 42 aggregates and the pressure in the port space 42 decreases. Prior to that, by reducing the residual gas as much as possible, it is possible to further reduce convection generated in the port space 42. After the residual gas is discharged, the valve 52 is closed. Although the tank 58 and the suction pump 60 are disposed in the cover 64 at the time of maintenance in the configuration example shown in FIG. 1, the tank 58 and the suction pump 60 may also be disposed outside the cover 64.

[0052] A pipe may be provided to penetrate the flange 30 of the cold head 16. In this case, a valve is provided on an atmospheric air side on the pipe. A through hole may be formed in the flange 30, and a valve may be provided on an outlet side of the through hole. In this case, the through hole corresponds to the pipe. Of course, according to the configuration shown in FIG. 1, it is possible to obtain an advantage that the existing cold head 16 can be used directly. Various types of installation modes of the pipe and the valve may be adopted.

[0053] The state where the tank 58 and the suction pump 60 are connected to the second end portion 54 via the relay pipe 56 may be maintained. In this case, a switching valve that switches a flow path may be provided in the relay pipe 56. A slight amount of atmospheric air is included in the second end portion 54. In order to prevent the small amount of atmospheric air from entering the port space 42, the residual atmospheric air may be expelled at the time of connection of the tank 58. A common tank 58 or a common suction pump 60 may be connected to a plurality of pipes drawn out from a plurality of refrigerator ports.

[0054] In the above configuration, the gas supplied to the port space 42 may be other inert gas such as nitrogen gas. A gas supply pipe and a gas discharge pipe may be

connected to the refrigerator port 14. In this case, a valve is provided in each of the pipes. A concept of the valve includes a switch such as a check valve.

[0055] In a state where the cover 64 is filled with the helium gas and in a state where the second end portion 54 faces the inside of the cover 64, the valve 52 may be in the opened state. In this case, the port space 42 and the outside (the inside of the cover 64) communicate with each other via the pipe 50, and a natural pressure balance occurs. When such a configuration is adopted, the tank 58 is not necessary.

[0056] The port space 42 may be filled with a material having flexibility or deformability, for example, urethane as a foam material. According to this configuration, it is possible to reduce an effective volume in which gas can exist in the port space 42, and thus it is possible to further reduce heat inflow caused by gas convection.

[0057] FIG. 2 shows a coupled body (overlapping body) of the flange 28 and the flange 30. Reference numeral 38 denotes an insertion portion of the cold head. The port space 42 is formed outside the insertion portion and inside the sleeve 24. A ring-shaped groove is formed in the flange 28, and an O-ring 70 that exerts a sealing action is disposed therein. The two flanges 28 and 30 are fastened by a bolt row 68. The bolt row 68 includes, for example, 8 bolts 71 arranged in an annular shape. The bolt row 68 is provided outside the O-ring 70. In a case where the pressure in the port space 42 is a negative pressure, even if the plurality of bolts 71 are loosened, the sealing action of the O-ring 70 is maintained without change. Therefore, the pressure adjustment facility is provided as described above.

[0058] FIG. 3 shows a cooling device according to a second embodiment. In FIG. 3, illustration of the cover is omitted. In FIG. 3, the same elements as those already described are denoted by the same reference numerals, and the description thereof will be omitted. This also applies to elements shown in FIG. 4 and the subsequent drawings.

[0059] In a cooling device 10A shown in FIG. 3, an elastic mechanism 72 is provided outside the refrigerator port 14 so as to surround the refrigerator port 14. The refrigerator port 14 and the elastic mechanism 72 are separated from each other and function independently of each other. The elastic mechanism 72 applies an elastic force (pressing force) directed toward an atmospheric air side (upward in FIG. 4) to the pedestal so as to improve physical bonding between the cold head 16 and the pedestal 34, in particular, improve thermal conductivity.

[0060] In the shown example, the heat conduction member 36 is disposed between the pedestal 34 and the stage 40 of the cold head 16. In this case, by applying the pressing force to the pedestal 34, a degree of close contact between the pedestal 34 and the heat conduction member 36 is improved, and at the same time, a degree of close contact between the heat conduction member 36 and the stage 40 is improved.

[0061] FIG. 4 shows a part of the cooling device 10A

shown in FIG. 3 in an enlarged manner. The elastic mechanism 72 includes, for example, three elastic elements 74 arranged at equal angular intervals around the refrigerator port 14. Each elastic element 74 independently applies an elastic force to the pedestal 34. Four or more elastic elements 74 may be provided.

[0062] Specifically, each elastic element 74 includes an elastic piece 76, a support column 78, and a connecting plate 80. The elastic piece 76 includes a first portion 76a extending in the z direction and a second portion 76b extending in the x direction from an end portion of the first portion 76a. In the shown example, the elastic piece 76 is a leaf spring and functions like a cantilever.

[0063] Specifically, the elastic piece 76 generates an elastic force that pulls up an end portion of the second portion 76b toward a room temperature side (upward in FIG. 4). By using an elastic piece having a desired spring constant as the elastic piece 76, the elastic force generated by the elastic piece 76 can be adjusted. A first end portion of the support column 78 is fixed to the second portion 76b by a fixing member 82. A second end portion of the support column 78 is fixed to the connecting plate 80. The connecting plate 80 is connected to the pedestal 34.

[0064] The elastic force generated by the elastic piece 76 is applied to the pedestal 34 via the support column 78 and the connecting plate 80. The elastic piece 76 is made of, for example, stainless steel, and the connecting plate 80 is also made of, for example, stainless steel. The support column 78 is made of a material having a high heat-insulating property, and is made of, for example, FRP.

[0065] Three elastic forces from the three elastic elements 74 are applied to the pedestal 34 at angular intervals of 120 degrees around a central axis of the refrigerator port. A larger number of elastic elements 74 may be provided. By providing the elastic mechanism 72 outside the refrigerator port 14, it is possible to reduce a size, specifically, a diameter of the refrigerator port 14. Accordingly, a volume of the port space 42 is reduced, so that a total amount of residual gas can be reduced. As a result, it is possible to reduce heat conduction caused by retention of the residual gas.

[0066] As described above, when the residual gas is discharged from the port space 42 by using the pressure adjustment facility 48, it is possible to further reduce the heat conduction caused by the convection of the residual gas. The size of the refrigerator port 14 is reduced, and thus physical strength thereof can be improved.

[0067] A total elastic force applied on the pedestal 34 may be adjusted by changing the number of installed elastic elements 74. As a unit that generates an elastic force or a pressing force in each elastic element 74, a helical spring, a disc spring, or the like may be adopted in addition to the leaf spring. The elastic force may also be generated by a member or a mechanism other than the spring. For example, a wire pulling force or a magnetic force may be used.

[0068] In the configuration example shown in FIG. 4, a heater 84 is provided at a cooling-side end portion of the refrigerator port 14 or in the vicinity of the cooling-side end portion. Specifically, the heater 84 includes a plurality of heater elements that are in close contact with an outer circumferential surface of the sleeve 24.

[0069] By operating the heater 84 in a process of supplying helium gas to the port space 42 and at other necessary timings, liquefaction (and gas-to-particle conversion) of the helium gas can be prevented. That is, when the helium gas is supplied to the port space 42 in a cooling state of the cold head, a part of the helium gas may be liquefied (and converted into particles). In this case, consumption of the helium gas increases. Moreover, there may be a concern about problems such as a decrease in an action of thermally conductive grease due to the liquefaction or the like.

[0070] By operating the heater 84, the liquefaction or the like of the helium gas can be prevented, and occurrence of the above-described problems can be prevented in advance. The heater 84 may also be provided inside the sleeve. Naturally, the heater 84 does not operate during operation of the refrigerator.

[0071] FIG. 5 shows a modification. In a cooling device 10B, an elastic mechanism 72A is provided outside the refrigerator port. The elastic mechanism 72A includes, for example, three elastic elements 74A. Each elastic element 74A includes a support column 88 and an elastic piece 86. The elastic piece 86 includes a first portion 86a and a second portion 86b. A first end portion of the support column 88 is connected to the vacuum container 12. A second end portion of the support column 88 is connected to the first portion 86a. The second portion 86b is connected to the pedestal 34. The elastic piece 86 is a leaf spring and applies an elastic force to the pedestal 34 toward a room temperature side.

[0072] According to such a modification, it is still possible to apply the elastic force to the pedestal 34 so as to improve a degree of close contact with the cold head or the like. In the modification, the support column 88 is also made of a material having a good heat-insulating property.

[0073] FIG. 6 shows a cooling device 10C according to a third embodiment. A refrigerator port 96 includes a first port portion 98 and a second port portion 100. The first port portion 98 and the second port portion 100 are continuous in the z direction. Meanwhile, a cold head 16B includes a portion 90 accommodated in the refrigerator port 96. The portion 90 includes a first cooling section and a second cooling section that are continuous in the z direction. An end portion of the first cooling section is a first stage 92, and an end portion of the second cooling section is a second stage 94. A temperature of the first stage 92 is, for example, 40 to 60 K, and a temperature of the second stage is, for example, 4 K.

[0074] A first elastic mechanism 102 is provided to surround the first port portion 98, and a second elastic mechanism 104 is provided to surround the first port portion

98 and the second port portion 100 as a whole (that is, the refrigerator port 96).

[0075] A radiation shield 106 surrounding the object to be cooled 15 is provided in the vacuum container 12. The radiation shield 106 is a member that prevents radiation emitted from the vacuum container 12 from reaching the object to be cooled 15. The radiation shield 106 is separated from the vacuum container 12 and the object to be cooled 15, and is made of a material having good thermal conductivity, for example, aluminum. The radiation shield 106 is in thermal contact with the first stage 92.

[0076] FIG. 7 shows a part of the cooling device 10C shown in FIG. 6 in an enlarged manner. As described above, the refrigerator port 96 includes the first port portion 98 and the second port portion 100. The first port portion 98 includes a first sleeve 108 and a first pedestal 118. The first sleeve 108 has a cylindrical shape, and an intermediate portion thereof constitutes a first bellows 110. The first sleeve 108 is provided between a periphery of an opening formed in the vacuum container and a first surface (upper surface in FIG. 7) of the first pedestal 118. The first pedestal 118 has an annular shape.

[0077] The second port portion 100 includes a second sleeve 112 and a second pedestal 122. The second sleeve 112 has a cylindrical shape, and an intermediate portion thereof constitutes a bellows 114. The second sleeve 112 is provided between a second surface (lower surface in FIG. 7) of the first pedestal 118 and a first surface (upper surface in FIG. 7) of the second pedestal 122.

[0078] An annular heat conduction member 120 is provided between the first pedestal 118 and the first stage 92. The cold head 16B passes through an opening portion of the heat conduction member 120. A disc-shaped heat conduction member 139 is provided between the first surface (upper surface in FIG. 7) of the second pedestal 122 and the second stage 94. A second surface (lower surface in FIG. 7) of the second pedestal 122 is in contact with the heat conduction member 41.

[0079] An internal space of the refrigerator port 96 is a port space, and the port space specifically includes a first port space 116A and a second port space 116B. The first port space 116A and the second port space 116B communicate with each other. That is, the entire port space is a single airtight space.

[0080] The first elastic mechanism 102 includes, for example, three elastic elements provided so as to surround the first port portion 98. The three elastic elements are arranged at equal angular intervals. Each elastic element includes a leaf spring 124, a support column 126, and a connecting plate 128. An elastic force generated by the plate spring 124 reaches the first pedestal 118 via the support column 126 and the connecting plate 128. Accordingly, the first pedestal 118 and the heat conduction member 120 are in close contact with each other, and the heat conduction member 120 and the first stage 92 are in close contact with each other.

[0081] The second elastic mechanism 104 is a mech-

anism independent of the first elastic mechanism 102. Specifically, the second elastic mechanism 104 includes, for example, three elastic elements surrounding the refrigerator port 96. These elastic elements are arranged in an annular shape at equal angular intervals. Each elastic element includes a leaf spring 130, a support column 132, and a connecting plate 134. In the shown example, the support column 132 has a length comparable to an entire length of the refrigerator port 96. An elastic force generated by the leaf spring 130 reaches the second pedestal 122 via the support column 132 and the connecting plate 134. Accordingly, the second pedestal 122 and the heat conduction member 139 are in close contact with each other, and the heat conduction member 139 and the second stage 94 are in close contact with each other.

[0082] The three elastic elements constituting the first elastic mechanism 102 are provided at positions of, for example, 0 degree, 120 degrees, and 240 degrees around a central axis of the refrigerator port 96, and the three elastic elements constituting the second elastic mechanism 204 are provided at positions of, for example, 60 degrees, 180 degrees, and 300 degrees. Accordingly, physical interference between the first elastic mechanism 102 and the second elastic mechanism 104 is avoided.

[0083] A thermal anchor 135 is provided in the middle of each support column 132. The thermal anchor 135 is formed of an annular or cylindrical heat conduction member. A flexible thermal link 136 is provided between each thermal anchor 135 and the first stage 92. A temperature of each thermal anchor 135 is operated and fixed to substantially the same temperature as that of the first stage 92. With this configuration, heat inflow via each support column 132 is reduced. Each support column 132 may be formed of two rod-shaped members connected to each other via the thermal anchor, instead of a single rod-shaped member. A flexible thermal link 137 is provided between the first pedestal 118 and the radiation shield 106. Accordingly, the radiation shield 106 is cooled.

[0084] Since the first elastic mechanism 102 and the second elastic mechanism 104 are provided as mechanisms independent of each other, an appropriate elastic force is reliably applied to each of the first pedestal 118 and the second pedestal 122. Although it is also conceivable to provide the second elastic mechanism 104 between the first pedestal and the second pedestal 122, when such a configuration is adopted, an action of the second elastic mechanism 104 changes due to a change in a position or a posture of the first pedestal 118. According to the shown configuration, such a problem can be avoided.

[0085] The pipe 50 is drawn out from a room temperature side of the first bellows 110 in the first sleeve 108. The pipe 50 penetrates the vacuum container and is guided to the outside. The valve 52 is provided at the exposed portion of the pipe 50. The pipe 50 and the valve 52 con-

stitute the pressure adjustment facility 48. The pipe 50 is provided at a position where the pipe 50 is not in contact with the plurality of elastic elements described above. As described above, the pipe may also be provided in a flange of the cold head 16B.

[0086] A heater 138 is provided outside the second sleeve 112. The heater 138 prevents liquefaction (and gas-to-particle conversion) of the helium gas.

[0087] FIG. 8 shows a cold head replacement method according to the embodiment. S10 is a preparation process. In S10, a cover is provided so as to wrap an existing cold head. Air therein is replaced with helium gas. In S12, a tank containing helium gas is connected to a pipe. In S14, a valve is opened. Accordingly, the helium gas is supplied from the tank to a port space via the pipe. Accordingly, a pressure in the port space becomes the atmospheric pressure or approaches the atmospheric pressure. In S16, the valve is closed. Flowing of the helium gas may be continued without closing the valve.

[0088] In S18, the existing cold head is pulled out from a refrigerator port after loosening a plurality of bolts. Since a negative pressure in the port space is reduced or eliminated, no large pull-out force is required for such work. After the existing cold head is pulled out, a new cold head (or a maintained cold head) is inserted into the refrigerator port. Thereafter, the new cold head is fixed to a vacuum container by a plurality of bolts.

[0089] In S20, a suction pump is connected to the pipe. In S22, the valve is opened, and operating of the suction pump is started before and after the valve is opened. Accordingly, the helium gas in the port space is discharged to the outside. In S24, the operating of the suction pump is stopped, and the valve is closed.

[0090] Thereafter, operating of the cold head is started after necessary work such as removal of the cover. As a temperature of the cold head decreases, residual gas in the port space aggregates, and the pressure in the port space decreases. By exhausting the residual gas, an amount of the residual gas is very small, and heat inflow due to retention can be considerably prevented.

[0091] In order to prevent liquefaction of the helium gas, for example, energization of a heater is started at a timing T1. Thereafter, for example, the energization of the heater is stopped at a timing T2. The heater may also be operated in another period.

[0092] The cooling device described above is used, for example, to cool a superconducting coil. For example, a superconducting coil for generating a magnetic field installed in a particle beam therapy device is cooled by the cooling device described above. This example will be described below with reference to FIG. 9.

[0093] FIG. 9 schematically shows a gantry 140 that is a giant structure provided in the particle beam therapy device. Reference numeral 144 denotes a rotation center axis of the gantry 140. The gantry 140 rotates about the rotation center axis 144. This rotational motion changes a particle beam irradiation angle with respect to a subject. The gantry 140 includes a body 140A having a cylindrical

shape. Reference numeral 142 denotes a trajectory of a particle beam. A plurality of units U1 to U8 are provided on the trajectory 142 in order to more accurately form the appropriate trajectory 142. The units U1 to U8 are fixed to the body 140A. The units U1 to U8 include a beam focusing unit and a beam scanning unit. The plurality of units U1 to U8 are examples.

[0094] Each of the units U1 to U8 includes one or a plurality of superconducting coils. Each superconducting coil is cooled by the above-described cooling device. A pressure adjustment facility is provided for each cooling device. Of course, gas may be distributed from a common tank to a plurality of pressure adjustment facilities. In addition, a common suction pump may be connected to a plurality of pressure adjustment facilities, and a suction destination may be sequentially switched. When the configuration according to the embodiment is adopted, it is possible to improve safety and workability in maintenance of each cooling device in the particle beam therapy device. The above-described cooling device may be mounted in an NMR system or an MRI system.

[0095] Each of the pressure adjustment facility (a gas supply unit and a residual gas discharge unit), the elastic mechanism (a pressing force applying unit separated from the refrigerator port), and the heater (liquefaction preventing unit) described above may be adopted independently.

Reference Signs List

[0096]

- 10 cooling device
- 12 vacuum container
- 14 refrigerator port
- 15 object to be cooled
- 16 cold head
- 24 sleeve
- 26 bellows
- 42 port space
- 48 pressure adjustment facility
- 50 pipe
- 52 valve
- 58 tank
- 60 suction pump

Claims

1. A cooling device comprising:

a vacuum container accommodating an object to be cooled;
a refrigerator port provided in the vacuum container and including a port space in which a cold head of a refrigerator configured to cool the object to be cooled is accommodated in a replaceable manner; and

a pressure adjustment facility configured to supply gas to the port space to increase a pressure in the port space before the cold head is pulled out.

2. The cooling device according to claim 1, wherein the pressure adjustment facility includes:

a pipe including a gas flow path communicating with the port space and drawn out from the refrigerator port; and
a valve provided in the pipe, and configured to close the gas flow path during operation of the refrigerator and allow supply of the gas to the gas flow path during replacement of the cold head.

3. The cooling device according to claim 2, wherein

the refrigerator port includes a bellows configured to expand and contract in a port central axis direction, and
the pipe is drawn out from a room temperature side of the bellows in the refrigerator port.

4. The cooling device according to claim 1, wherein the refrigerator port includes:

a sleeve surrounding the port space; and
a pedestal that is a member provided on a cooling-side end portion of the sleeve, and is directly or indirectly connected to a stage of the cold head, and
the cooling device further comprising:
an elastic mechanism configured to apply an elastic force to the pedestal so as to increase a connecting force between the pedestal and the stage.

5. The cooling device according to claim 1, wherein

the port space includes a first port space and a second port space arranged in a port central axis direction,
the refrigerator port includes:

a first sleeve surrounding the first port space;
a second sleeve surrounding the second port space;
a first pedestal that is a member provided on a cooling-side end portion of the first sleeve, and is directly or indirectly connected to a first stage of the cold head; and
a second pedestal that is provided on a cooling-side end portion of the second sleeve, and is directly or indirectly connected to a second stage of the cold head, and

the cooling device further comprising:

a first elastic mechanism configured to
 apply an elastic force to the first pedestal
 so as to increase a connecting force 5
 between the first pedestal and the first
 stage; and
 a second elastic mechanism configured
 to apply an elastic force to the second
 pedestal so as to increase a connecting 10
 force between the second pedestal and the second stage.

6. The cooling device according to claim 5, wherein 15

the first elastic mechanism includes a plurality
 of first support elements provided around the
 first sleeve,
 each of the first support elements includes an
 elastic member, 20
 the second elastic mechanism includes a plurality
 of second support elements provided
 around the first sleeve and the second sleeve,
 and
 each of the second support elements includes 25
 an elastic member.

7. The cooling device according to claim 1, wherein
 a heater configured to prevent liquefaction of the gas
 supplied to the port space is provided in the refrigerator port. 30

8. A cold head replacement method comprising:

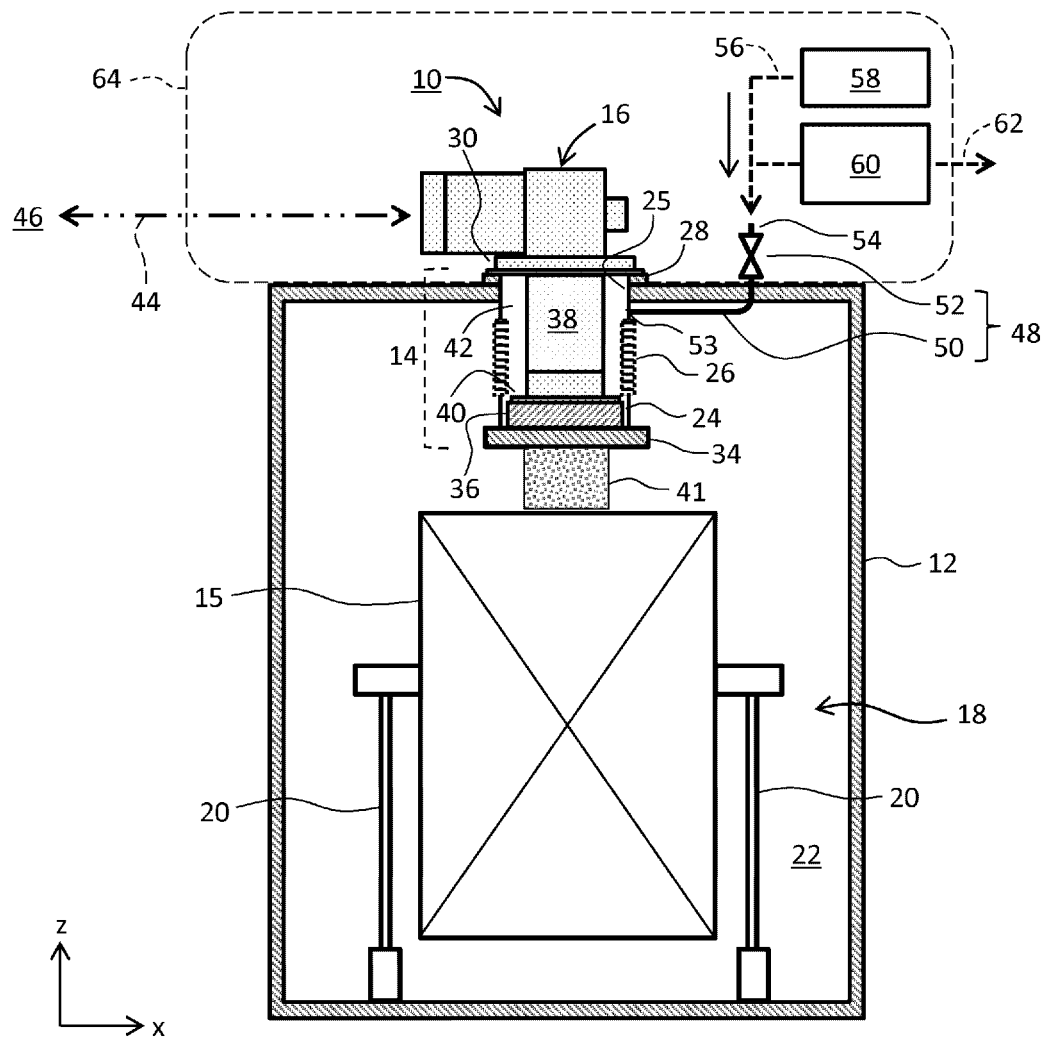
in a state where a cold head of a refrigerator is 35
 disposed in a refrigerator port provided in a vacuum
 container, supplying gas from an outside
 to a port space in the refrigerator port and thereby
 increasing a pressure in the port space; and
 pulling out the cold head from the refrigerator 40
 port after the pressure in the port space is increased.

9. The cold head replacement method according to
 claim 8, further comprising: 45
 discharging the gas in the port space to the outside
 after a new cold head is disposed in the refrigerator
 port.

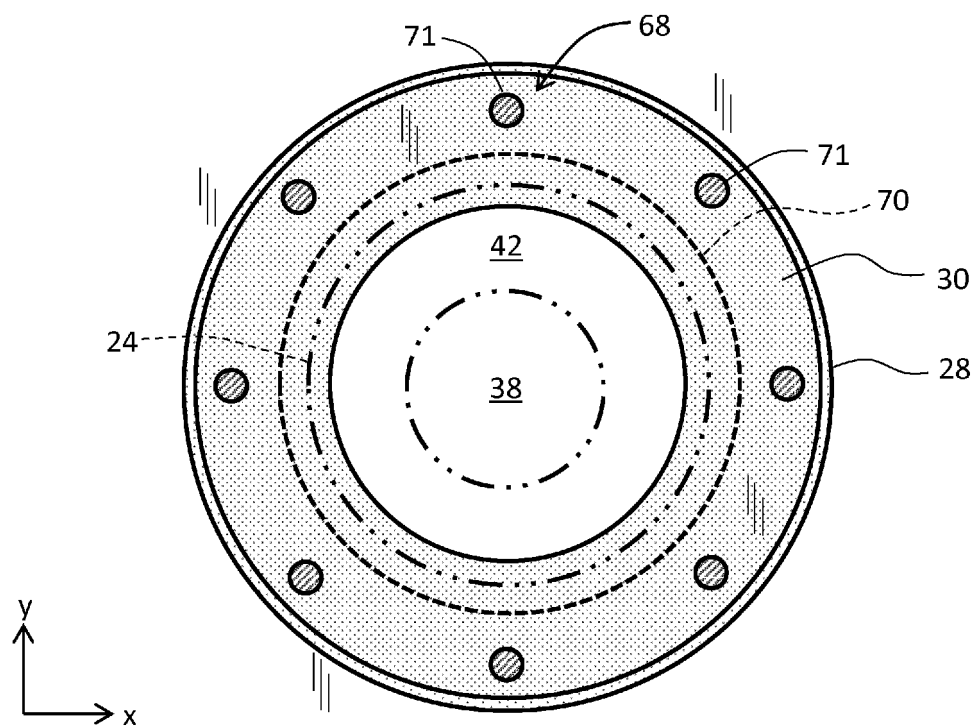
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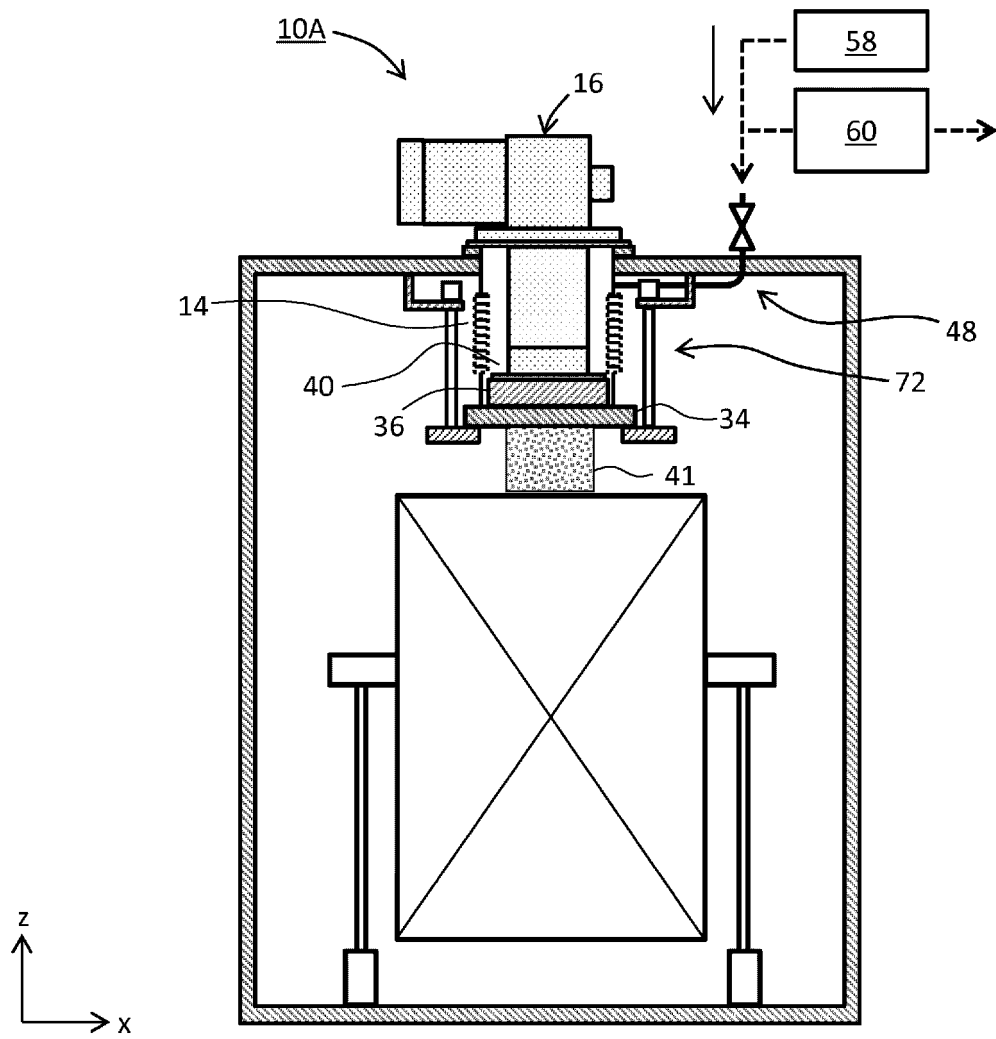
[FIG. 1]



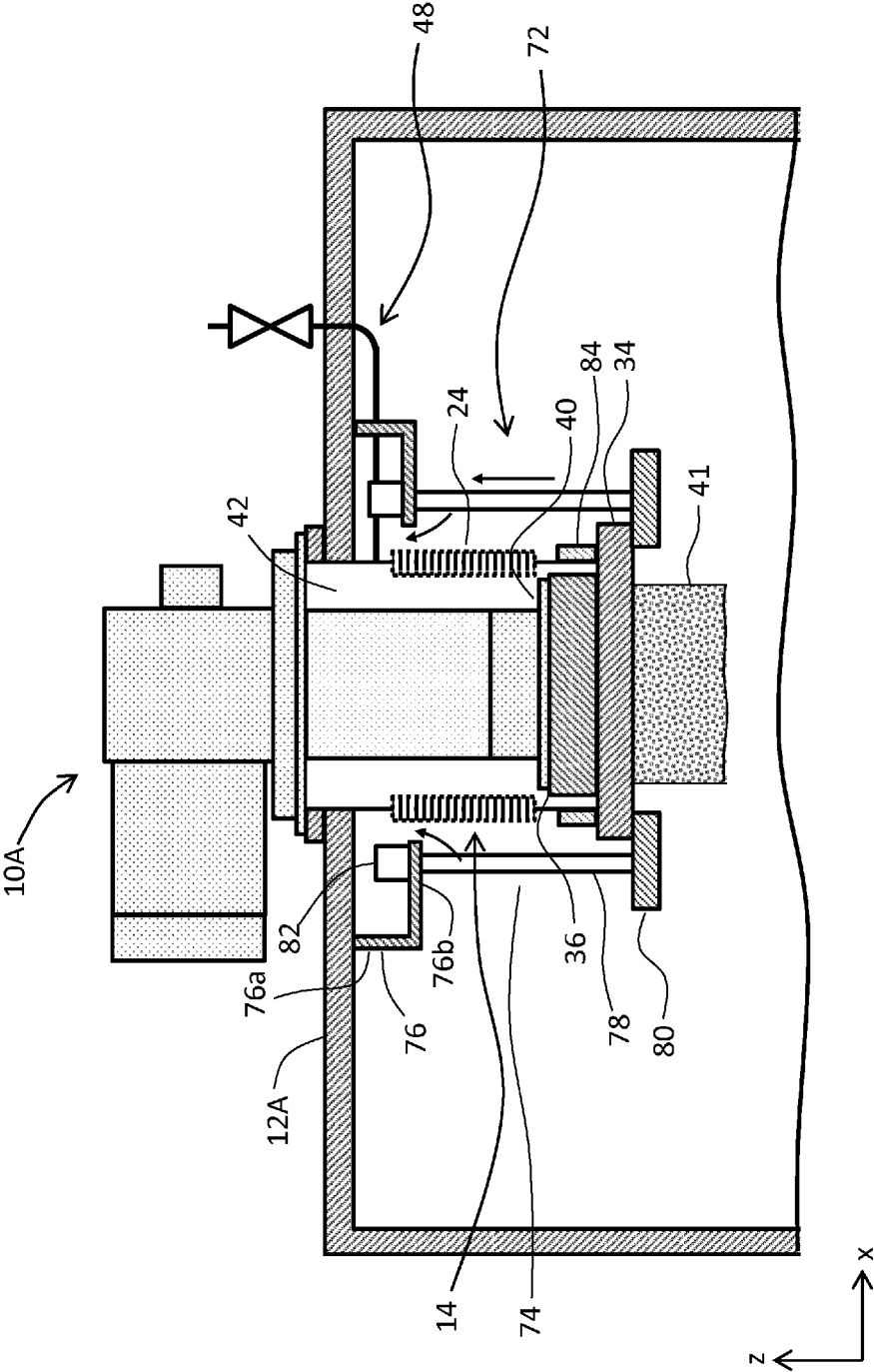
[FIG. 2]



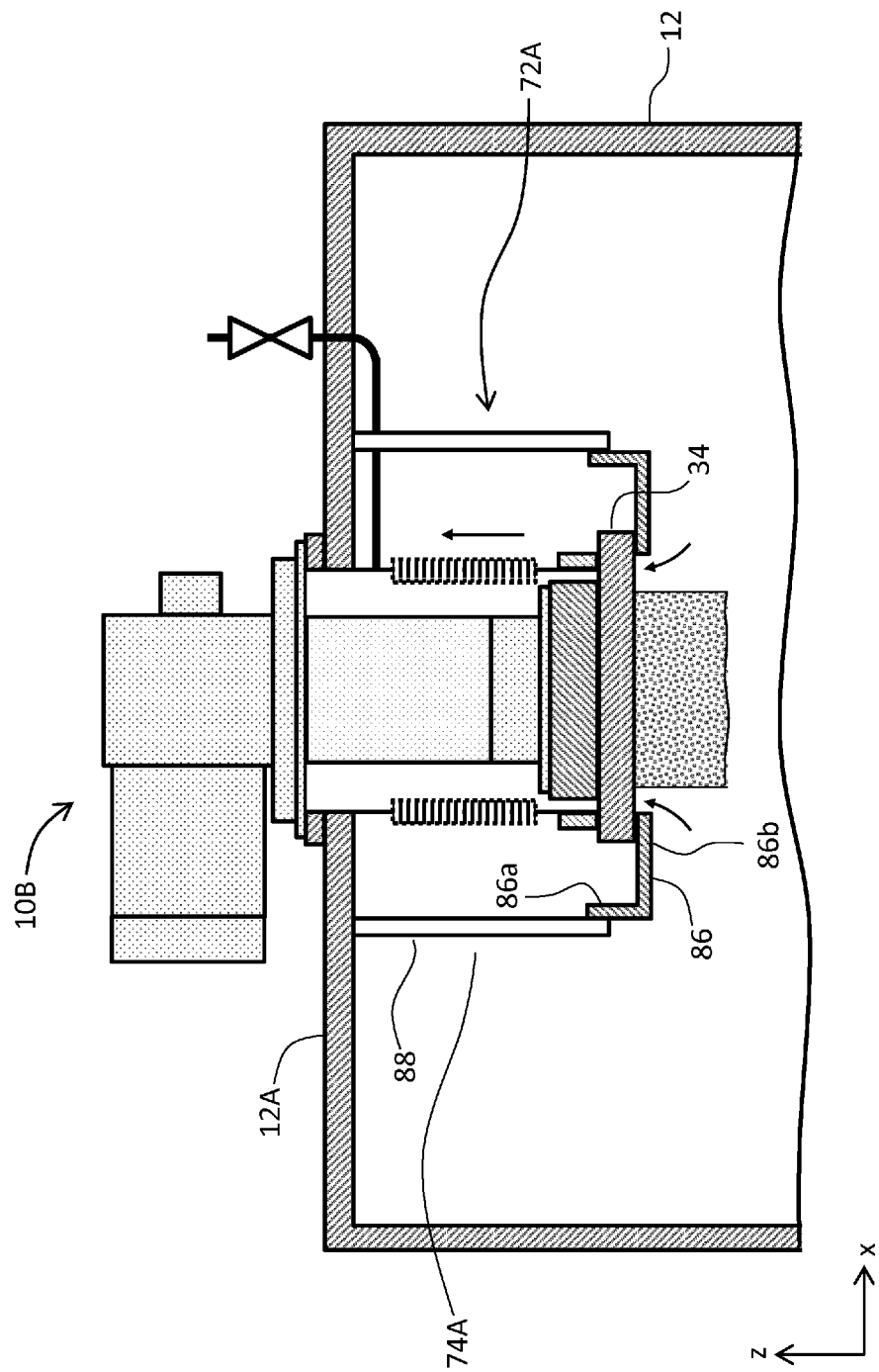
[FIG. 3]



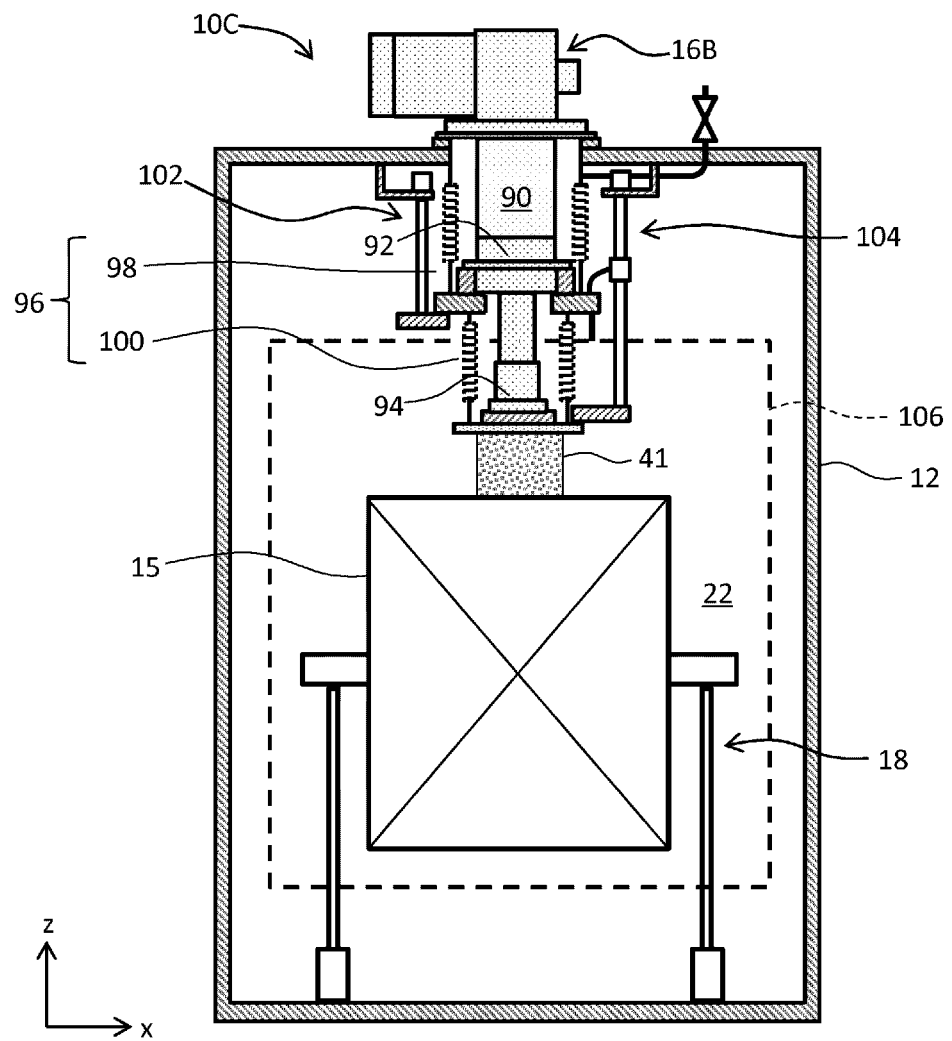
[FIG. 4]

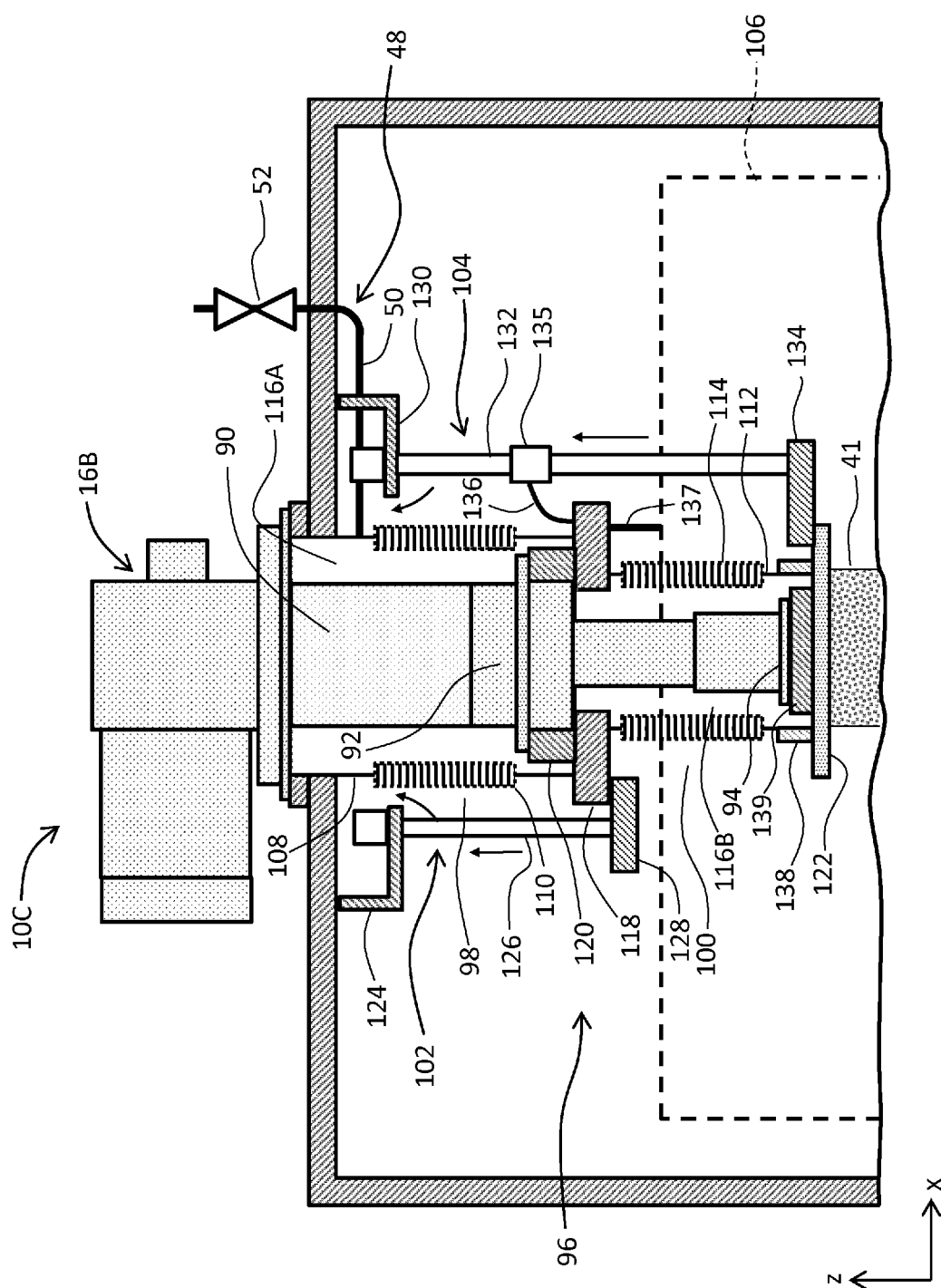


[FIG. 5]



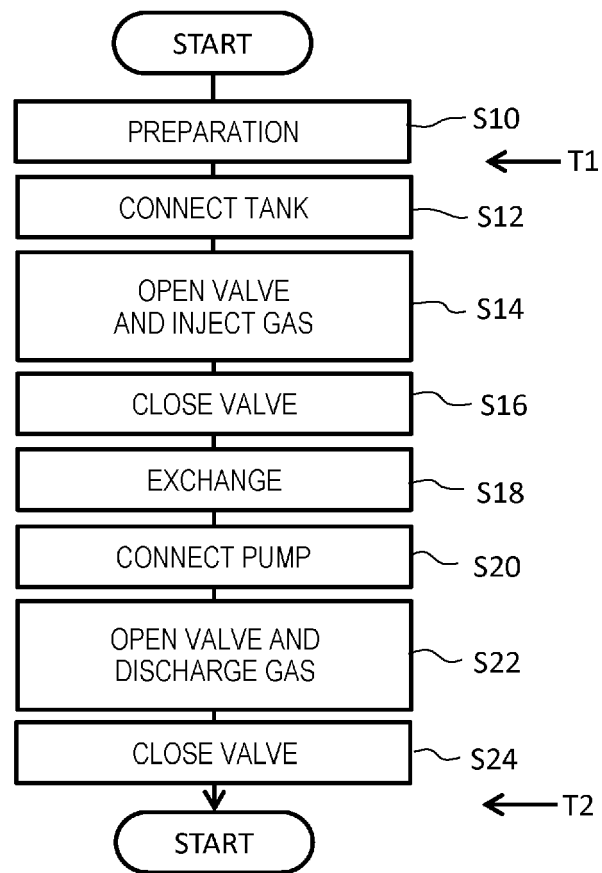
[FIG. 6]



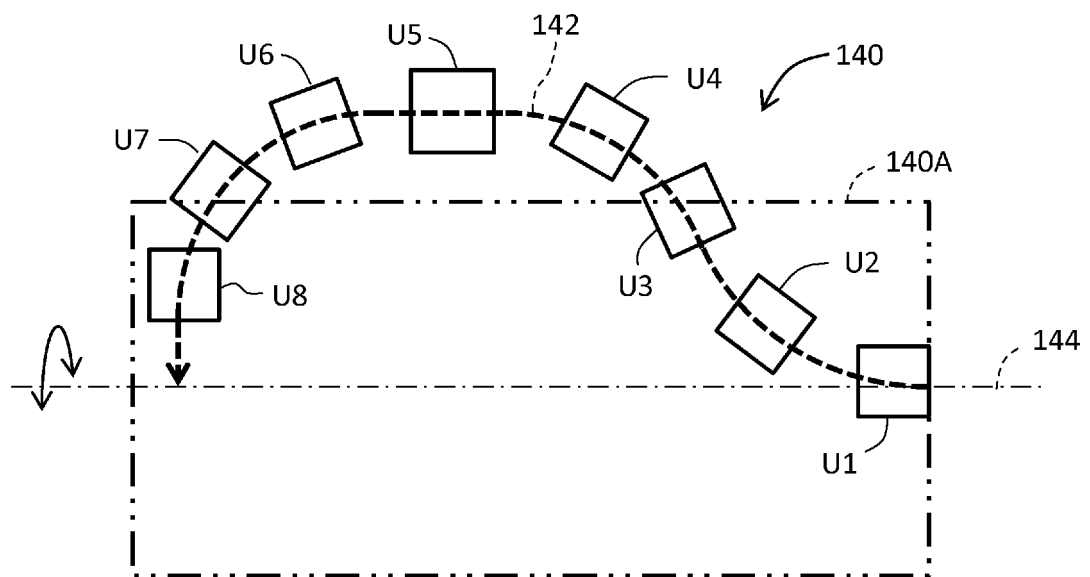


[FIG. 7]

[FIG. 8]



[FIG. 9]



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2021/005482

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl. F25B9/00 (2006.01) i

FI: F25B9/00 H

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Int. Cl. F25B9/00

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

Published examined utility model applications of Japan 1922-1996

Published unexamined utility model applications of Japan 1971-2021

Registered utility model specifications of Japan 1996-2021

Published registered utility model applications of Japan 1994-2021

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2014-157011 A (KOBE STEEL, LTD.) 28 August	1-3, 7-9
Y	2014, paragraphs [0002]-[0005], [0024]-[0073], fig. 1-6	4-6
Y	JP 2016-211803 A (TOSHIBA CORP.) 15 December 2016, paragraphs [0020]-[0085], fig. 1-8	4-6
Y	CN 109632150 A (HEFEI CAS ION MEDICAL AND TECHNICAL DEVICES CO., LTD.) 16 April 2019, paragraphs [0037], [0038]	4-6

☐ Further documents are listed in the continuation of Box C.
 ☒ See patent family annex.

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Date of the actual completion of the international search

23.03.2021

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Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/JP2021/005482

Patent Documents referred to in the Report	Publication Date	Patent Family	Publication Date
JP 2014-157011 A	28.08.2014	US 2015/0338151 A1 paragraphs [0002]- [0005], [0017]- [0072], fig. 1-6 WO 2014/112343 A1 EP 2947403 A1 CN 104919258 A	
JP 2016-211803 A	15.12.2016	(Family: none)	
CN 109632150 A	16.04.2019	(Family: none)	

Form PCT/ISA/210 (patent family annex) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

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