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(71) Applicant: **Sumitomo Heavy Industries, Ltd.**
Tokyo 141-6025 (JP)

(72) Inventor: **MORIE, Takaaki**
Yokosuka-shi Kanagawa 237-8555 (JP)

(74) Representative: **Louis Pöhlau Lohrentz**
Patentanwälte
Postfach 30 55
90014 Nürnberg (DE)

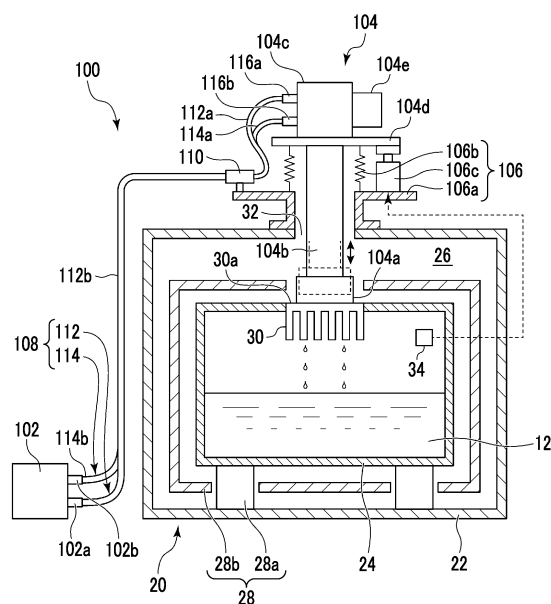
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(54) **CRYOGENIC REFRIGERATOR**

(57) A cryogenic refrigerator (100) includes a cold head (104) that is mountable on a vacuum container (20), a cold head mount (106) configured to couple the cold head (104) with the vacuum container (20) to allow movement of the cold head (104) with respect to the vacuum

container (20), a flexible line (108) that is connected to the cold head (104) outside the vacuum container (20), and a flexible line holder (110) configured to hold the flexible line (108) in a fixed manner with respect to the vacuum container (20).

FIG. 1



Description

Technical Field

[0001] The present invention relates to a cryogenic refrigerator.

Background Art

[0002] Cryogenic refrigerators represented by Gifford-McMahon (GM) cryocooler are often used to provide cryogenic cooling to various cooling targets, for example, to cool superconductivity equipment or to condense cryogenic liquid such as liquid helium. In the related art, it is known that a thermal switch that thermally connects a cryogenic refrigerator to a cooling target in a cryostat or disconnects the cryogenic refrigerator from the cooling target in the cryostat by installing the cryogenic refrigerator in the cryostat via a bellows and by using upward or downward movement of the cryogenic refrigerator accompanying expansion or contraction of the bellows.

Citation List

Patent Literature

[0003] [PTL 1] Japanese Unexamined Patent Publication No. 2016-211803

Summary of Invention

Technical Problem

[0004] When the thermal switch of the above-described type is turned on (that is, when the cryogenic refrigerator is thermally connected to the cooling target), the cryogenic refrigerator can be rigidly fixed to the cryostat. Contrary to this, when the thermal switch is turned off (that is, when the cryogenic refrigerator is temporarily disconnected from the cooling target), the cryogenic refrigerator is likely to be supported by the cryostat having low rigidity, for example, because of flexibility of the bellows.

[0005] When the cryogenic refrigerator is operated at a site, various pipes and wires such as a flexible hose for supplying and collecting a working gas and a cable for supplying power are connected to the cryogenic refrigerator and extend around the cryogenic refrigerator. One of the risks assumed in a general setup of such a cryogenic refrigerator is that there is a possibility that an unexpected large external force may act on the cryogenic refrigerator from the pipes, for example, as in a case where a worker passing near the cryogenic refrigerator hooks his or her foot on the pipes and stumbles. Such an unexpected external force may cause a problem, particularly when the thermal switch is off. A position and posture of the cryogenic refrigerator may be disturbed by

the external force, and the cryogenic refrigerator may interfere with or collide with a surrounding structure. In the worst case, the cryogenic refrigerator or a support structure of the cryogenic refrigerator may be damaged.

[0006] One of exemplary objects of a certain aspect of the present invention is to protect a cryogenic refrigerator from an unexpected external force.

Solution to Problem

[0007] According to a certain aspect of the present invention, a cryogenic refrigerator includes a cold head that is mountable on a vacuum container, a cold head mount configured to couple the cold head with the vacuum container to allow movement of the cold head with respect to the vacuum container, a flexible line that is connected to the cold head outside the vacuum container, and a flexible line holder configured to hold the flexible line in a fixed manner with respect to the vacuum container.

Advantageous Effects of Invention

[0008] According to the present invention, it is possible to protect a cryogenic refrigerator from an unexpected external force.

Brief Description of Drawings

[0009]

Fig. 1 is a view schematically showing a cryogenic device according to an embodiment.

Fig. 2 is a view schematically showing a working gas line of a cryogenic refrigerator according to a comparative example.

Fig. 3 is a view schematically showing exemplary electrical connection applicable to a cryogenic refrigerator shown in Fig. 1.

Fig. 4 is a view schematically showing an exemplary drive source applicable to the cryogenic refrigerator shown in Fig. 1.

Description of Embodiments

[0010] Embodiments of the present invention will be described in detail below with reference to the drawings. The same or equivalent components, members, and processing in the description and the drawings will be denoted by the same reference numerals and repeated description thereof will be appropriately omitted. A scale and shape of each part to be shown are conveniently set to facilitate the description, and are not limitedly interpreted as long as not particularly mentioned. The embodiments are exemplary and do not limit the scope of the present invention in any way. All features or combinations thereof described in the embodiments are not necessarily essential to the invention.

[0011] Fig. 1 is a view schematically showing a cryogenic device 10 according to an embodiment. In the embodiment, the cryogenic device 10 can be used as a storage device for cryogenic liquid. Here, the cryogenic device 10 includes a vacuum container 20 for storing cryogenic liquid 12 such as liquid hydrogen or another liquid and a cryogenic refrigerator 100 for cooling the cryogenic liquid 12, which is stored, to a cryogenic temperature equal to or lower than a liquefaction temperature of the cryogenic liquid 12 (approximately -253°C (20 K) in a case of liquid hydrogen).

[0012] The vacuum container 20 includes an outer tank 22 and an inner tank 24. A vacuum heat insulation layer 26 is formed between the outer tank 22 and the inner tank 24. The outer tank 22 is configured to separate the vacuum heat insulation layer 26 from an ambient environment (for example, a room temperature atmospheric pressure environment) of the cryogenic device 10. In addition, the inner tank 24 is configured to separate an internal volume of the inner tank 24 from the vacuum heat insulation layer 26. The cryogenic liquid 12 is accommodated in the inner tank 24. The outer tank 22 and the inner tank 24 are formed of a metal material such as stainless steel or another suitable high-strength material to withstand a pressure difference between an inside and an outside.

[0013] A heat insulation structure 28 including a heat insulation support 28a and a heat insulation layer 28b may be disposed in the vacuum heat insulation layer 26. The heat insulation support 28a is formed of, for example, a hard material having heat insulation properties such as fiber-reinforced plastic, and is configured to support the inner tank 24 in the outer tank 22. The heat insulation layer 28b may include a multilayer insulation (MLI). Together with the heat insulation layer 28b or instead of the heat insulation layer 28b, the heat insulation structure 28 may include a granular or other-shaped heat insulation material (for example, granular perlite) filled in the vacuum heat insulation layer 26.

[0014] The inner tank 24 includes a recondensing unit 30 provided on a tank wall of the inner tank 24. The recondensing unit 30 is cooled from the outside of the inner tank 24 by the cryogenic refrigerator 100. The recondensing unit 30 includes a heat transfer surface 30a that is exposed to the outside of the inner tank 24 and comes into contact with the cryogenic refrigerator 100. The recondensing unit 30 may have a fin-shaped protrusion or a recess and protrusion inside the inner tank 24 in order to increase a surface area in contact with the cryogenic liquid 12 or the vaporized cryogenic liquid 12. The recondensing unit 30 is formed of, for example, pure copper (for example, oxygen-free copper, tough pitch copper, or the like), or other high thermal conductivity metal.

[0015] The cryogenic refrigerator 100 includes a compressor 102, a cold head 104 that is mountable on the vacuum container 20, and a cold head mount 106 configured to couple the cold head 104 with the vacuum

container 20 to allow movement of the cold head 104 with respect to the vacuum container 20.

[0016] The compressor 102 is configured to recover a working gas of the cryogenic refrigerator 100 from the cold head 104, increase a pressure of the recovered working gas, and supply the working gas to the cold head 104 again. The cold head 104 is also referred to as an expander or a cryocooler. The compressor 102 and the cold head 104 configure a refrigeration cycle of the cryogenic refrigerator 100, and thereby the cryogenic refrigerator 100 provides cryogenic cooling. The working gas is also referred to as a refrigerant gas and is typically a helium gas, but other suitable gases may be used.

[0017] The cryogenic refrigerator 100 is a single-stage GM cryocooler in the embodiment. Therefore, the cold head 104 includes a cooling stage 104a, a cylinder 104b, a drive unit 104c, and a cold head flange 104d. The cooling stage 104a is formed of, for example, pure copper (for example, oxygen-free copper, tough pitch copper, or the like), or other high thermal conductivity metal. During driving of the cryogenic refrigerator 100, the cooling stage 104a is cooled to a desired cryogenic temperature, for example, to a temperature range equal to or lower than the liquefaction temperature of the cryogenic liquid 12. In a case where the cryogenic liquid 12 is liquid hydrogen, the cooling stage 104a is cooled to a cooling temperature included in, for example, a temperature range of 10 K to 30 K (for example, a cooling temperature near 20 K, such as $20\text{ K} \pm 1\text{ K}$, $20\text{ K} \pm 2\text{ K}$, or $20\text{ K} \pm 5\text{ K}$).

[0018] The cylinder 104b connects the cooling stage 104a to the cold head flange 104d. A displacer (not shown) for controlling a volume of an expansion space of the working gas adjacent to the cooling stage 104a is disposed in the cylinder 104b to be movable in an axial direction (an up-down direction in Fig. 1) of the cylinder 104b. The cylinder 104b and the cold head flange 104d are typically formed of an appropriate metal material such as stainless steel. The drive unit 104c is attached to the cold head flange 104d on a side opposite to the cylinder 104b. The drive unit 104c is provided with a cold head drive motor 104e such as an electric motor for driving the displacer in the cylinder 104b, and a pressure control mechanism (not shown) such as a rotary valve for controlling a working gas pressure of the expansion space in the cylinder 104b.

[0019] As shown in Fig. 1, a mounting port 32 for mounting the cold head 104 to the vacuum container 20 is provided in the outer tank 22 of the vacuum container 20. During mounting, the cold head 104 is inserted into the vacuum container 20 from the mounting port 32, and is detachably attached to the mounting port 32 via the cold head mount 106. The cold head 104 is mounted on the vacuum container 20 such that the cooling stage 104a is disposed in the vacuum heat insulation layer 26 in the vacuum container 20 and the drive unit 104c is disposed outside the vacuum container 20.

[0020] As an example, the mounting port 32 is formed in a top plate or an upper portion of the vacuum container

20. The cold head 104 is installed in the vacuum container 20 such that a center axis of the cold head 104 coincides with a vertical direction. However, a position of the mounting port 32 and an attachment posture of the cold head 104 are not limited thereto. For example, the mounting port 32 may be formed in a bottom plate or a lower portion of the vacuum container 20. The cold head 104 can be installed in a desired posture, and may be installed in the vacuum container 20 such that the center axis coincides with an oblique direction or a horizontal direction.

[0021] The cold head mount 106 includes an attachment flange 106a attachable to the vacuum container 20, and an expandable and contractible airtight partition wall 106b that connects the cold head 104 to the attachment flange 106a. The attachment flange 106a is fixed to the mounting port 32 of the vacuum container 20 by using, for example, a fastening member such as a bolt, or other appropriate fixing means. The attachment flange 106a may be fixed to the vacuum container 20 via a connection member instead of being directly fixed to the vacuum container 20 as shown. The expandable and contractible airtight partition wall 106b is, for example, a bellows, and connects the cold head flange 104d to the attachment flange 106a. Therefore, the mounting port 32 is closed by the attachment flange 106a, the airtight partition wall 106b, and the cold head flange 104d, and airtightness of the vacuum container 20 is maintained.

[0022] The attachment flange 106a has an opening at a center portion, and the expandable and contractible airtight partition wall 106b is formed in a tubular shape. The cylinder 104b of the cold head 104 extends into the vacuum container 20 from the cold head flange 104d through an inside of the expandable and contractible airtight partition wall 106b and the opening of the attachment flange 106a.

[0023] In addition, the cold head mount 106 includes a drive source 106c mounted on the cold head mount 106 and configured to move the cold head 104 with respect to the vacuum container 20. The drive source 106c may be configured to move the cold head 104 by using appropriate motive power such as a pneumatic pressure, a hydraulic pressure, an electric motor, or an electromagnet, or may be operable to move the cold head 104 manually.

[0024] The drive source 106c is installed on the attachment flange 106a, and is connected to the cold head flange 104d to move the cold head flange 104d in an expansion and contraction direction of the airtight partition wall 106b. Therefore, by operating the drive source 106c, the cold head flange 104d can be moved with respect to the attachment flange 106a while the airtight partition wall 106b is expanded and contracted. In an example shown in Fig. 1, the drive source 106c can raise and lower the cold head flange 104d with respect to the attachment flange 106a (that is, the cold head 104 with respect to the vacuum container 20) upward and downward.

[0025] In this way, the cold head mount 106 can operate as a thermal switch that thermally connects the cold head 104 to the inner tank 24 of the vacuum container 20 or disconnects the cold head 104 from the inner tank 24 of the vacuum container 20, which is a storage tank for the cryogenic liquid 12. Fig. 1 shows an on-state of the thermal switch with a solid line, and shows an off-state of the thermal switch with a broken line. When the thermal switch is turned on, the cooling stage 104a of the cold head 104 comes into contact with the heat transfer surface 30a of the recondensing unit 30 of the inner tank 24. In this manner, the cooling stage 104a can cool the recondensing unit 30 to the liquefaction temperature of the cryogenic liquid 12, can hold the cryogenic liquid 12 in the inner tank 24, and can recondense the vaporized cryogenic liquid 12. On the other hand, when the cold head 104 is lifted by the operation of the drive source 106c, the cooling stage 104a is separated from the heat transfer surface 30a of the recondensing unit 30. Since the cooling stage 104a is disposed in the vacuum heat insulation layer 26, thermal contact between the cooling stage 104a and the recondensing unit 30 is released. In this case, the cold head 104 does not cool the inner tank 24.

[0026] Such a thermal switch is advantageous for improving an energy saving property of the cryogenic device 10. As exemplary running of the cryogenic refrigerator 100, it is conceivable to stop the cooling driving of the cryogenic refrigerator 100 in a state where the vacuum container 20 is sufficiently cooled. In this case, when the cold head 104 is in contact with the inner tank 24 of the vacuum container 20, the cold head 104 becomes a heat transfer path from the ambient environment of the cryogenic device 10 to the inner tank 24, and undesirable heat intrusion to the cryogenic liquid 12 may occur. On the other hand, when the cryogenic refrigerator 100 is stopped, the cold head 104 is separated from the inner tank 24 by using the thermal switch. In this manner, intrusion heat can be blocked.

[0027] In order to switch the thermal switch, the cryogenic device 10 may be provided with a sensor 34 that measures a physical quantity of the cryogenic liquid 12. The drive source 106c may be configured to receive an output signal from the sensor 34 indicating the measured physical quantity of the cryogenic liquid 12 and to move the cold head 104 based on the measured physical quantity of the cryogenic liquid 12.

[0028] For example, the sensor 34 may be disposed in the inner tank 24 of the vacuum container 20 and may be configured to measure an internal pressure of the inner tank 24. A vapor pressure of the cryogenic liquid 12 in the inner tank 24 is measured by the sensor 34. The drive source 106c may compare the measured pressure with a pressure threshold value, turn on the thermal switch in a case where the measured pressure exceeds the pressure threshold value, and turn off the thermal switch in a case where the measured pressure falls below the pressure threshold value. In this way, the internal pressure of

the inner tank 24 can be maintained at an appropriate pressure corresponding to the pressure threshold value.

[0029] Alternatively, the sensor 34 may be configured to measure a temperature of the cryogenic liquid 12. In this case, the sensor 34 may be disposed in the inner tank 24 or may be installed in the recondensing unit 30 of the inner tank 24. The drive source 106c may compare the measured temperature with a temperature threshold value, turn on the thermal switch in a case where the measured temperature exceeds the temperature threshold value, and turn off the thermal switch in a case where the measured temperature falls below the temperature threshold value. In this way, the cryogenic liquid 12 can be maintained at an appropriate temperature corresponding to the temperature threshold value.

[0030] In addition, the cryogenic refrigerator 100 includes a flexible line 108 that is connected to the cold head 104 outside the vacuum container 20, and a flexible line holder 110 configured to hold the flexible line 108 in a fixed manner with respect to the vacuum container 20. The flexible line 108 connects the drive unit 104c of the cold head 104 to an external element (for example, the compressor 102) disposed outside the vacuum container 20. The flexible line holder 110 is fixed to the attachment flange 106a of the cold head mount 106, and holds the flexible line 108 in the middle of a path from the cold head 104 to an external element. In other words, the flexible line holder 110 corresponds to a connection point at which the flexible line 108 is fixed to the vacuum container 20.

[0031] The compressor 102 may be disposed in a position remote from the cold head 104 and the vacuum container 20, for example, the compressor 102 may be installed in a room or section in which the cold head 104 and the vacuum container 20 is installed or in another room or section. The length of the flexible line 108 may be 10 m or more. The flexible line holder 110 is fixed to the attachment flange 106a. Accordingly, the flexible line holder 110 holds the flexible line 108 at an end portion (for example, an end portion of the flexible line 108 having a length of 10% or less or 5% or less of the total length of the flexible line 108) of the flexible line 108 on a cold head 104 side.

[0032] In the embodiment, the flexible line 108 includes a working gas line for supplying the working gas to the cold head 104 or collecting the working gas from the cold head 104, more specifically, a gas supply line 112 and a gas recovery line 114. The gas supply line 112 connects a working gas discharge port 102a of the compressor 102 to a high-pressure port 116a of the cold head 104, and the gas recovery line 114 connects a working gas suction port 102b of the compressor 102 to a low-pressure port 116b of the cold head 104.

[0033] Therefore, the working gas of the cryogenic refrigerator 100 is supplied from the compressor 102 to the cold head 104 through the gas supply line 112, and is recovered from the cold head 104 to the compressor 102 through the gas recovery line 114. As is well known, a

pressure of the working gas in the gas supply line 112 and a pressure of the working gas in the gas recovery line 114 are both considerably higher than an atmospheric pressure, and can be referred to as a first high pressure and a second high pressure, respectively. For convenience of description, the first high pressure and the second high pressure are also simply referred to as a high pressure and a low pressure, respectively. Typically, the high pressure is, for example, 2 to 3 MPa. The low pressure is, for example, 0.5 to 1.5 MPa and is, for example, about 0.8 MPa.

[0034] The flexible line holder 110 may include a working gas line holder that holds the working gas line. The flexible line holder 110 may include a first holder that holds the gas supply line 112 and a second holder that holds the gas recovery line 114, and the two holders may be fixed to the attachment flange 106a. The flexible line holder 110 can be rigidly fixed to the attachment flange 106a by using, for example, screwing, welding, or other appropriate fixing means.

[0035] The two holders may be disposed side by side on the attachment flange 106a, may be disposed to interpose the drive unit 104c on the attachment flange 106a, or may be disposed at any other optional location on the attachment flange 106a. In the example shown in Fig. 1, the flexible line holder 110 is attached to an upper surface of the attachment flange 106a, but may be attached to a lower surface of the attachment flange 106a or another part.

[0036] The gas supply line 112 includes a first part 112a extending from the high-pressure port 116a of the cold head 104 and a second part 112b extending from the working gas discharge port 102a of the compressor 102. The flexible line holder 110 may be configured as an intermediate coupling including an internal flow path through which the working gas of the cryogenic refrigerator 100 can flow. For example, the first holder may be a first intermediate coupling including a first internal flow path. In this case, the first part 112a of the gas supply line 112 is connected to the first holder at one end and is connected to the high-pressure port 116a at the other end. The second part 112b of the gas supply line 112 is connected to the first holder at one end and is connected to the working gas discharge port 102a at the other end. In this way, the high-pressure working gas discharged from the working gas discharge port 102a flows into the cold head 104 through the second part 112b, the first holder, and the first part 112a.

[0037] Similarly, the gas recovery line 114 includes a first part 114a extending from the low-pressure port 116b of the cold head 104 and a second part 114b extending from the working gas suction port 102b of the compressor 102. The flexible line holder 110 may be configured as the intermediate coupling including the internal flow path through which the working gas of the cryogenic refrigerator 100 can flow. For example, the second holder may be a second intermediate coupling including a second internal flow path. In this case, the first part 114a of the

gas recovery line 114 is connected to the second holder at one end and is connected to the low-pressure port 116b at the other end. The second part 114b of the gas recovery line 114 is connected to the second holder at one end and is connected to the working gas suction port 102b at the other end. In this way, the low-pressure working gas flowing out from the low-pressure port 116b of the cold head 104 is recovered to the compressor 102 through the first part 114a, the second holder, and the second part 114b.

[0038] The gas supply line 112 and the gas recovery line 114 may be, for example, a pipe having flexibility such as a flexible hose. In addition, the gas supply line 112 and the gas recovery line 114 may be attachable to and detachable from the compressor 102, the cold head 104, and the flexible line 108, for example, to be convenient for replacement due to wear.

[0039] Fig. 2 is a view schematically showing a working gas line of a cryogenic refrigerator according to a comparative example. As shown, a cryogenic refrigerator 200 includes a compressor 202 and a cold head 204. The compressor 202 and the cold head 204 are connected to each other by a flexible hose 206. The cold head 204 is mounted on the vacuum container 20 such that the cold head 204 can be moved (raised and lowered) with respect to the vacuum container 20. The cold head 204 can operate as a thermal switch that thermally connects the cold head 204 to an object 208 to be cooled or disconnects the cold head 204 from the object 208 to be cooled by raising and lowering the cold head 204. In Fig. 2, a case where the thermal switch is off, that is, a state where the cold head 204 is separated from the object 208 to be cooled is shown.

[0040] A worker passing near the cryogenic refrigerator 200 may hook his or her foot 210 on the flexible hose 206 and stumble. In this case, the flexible hose 206 may be instantly strongly pulled by the hooked foot 210, and a strong lateral load 212 may act on the cold head 204. When the thermal switch is off, the cold head 204 is supported to the vacuum container 20 by a support structure having low rigidity such as a bellows. Therefore, the lateral load 212 may disturb a position and posture of the cryogenic refrigerator 200 as shown by a black arrow 214 and a broken line in Fig. 2, and may cause the cryogenic refrigerator 200 to collide with a surrounding structure such as the vacuum container 20, the object 208 to be cooled, or the like in some cases. As a result, the cryogenic refrigerator 200 or the surrounding structure may be damaged.

[0041] On the other hand, according to the embodiment, the flexible line 108 is held by the flexible line holder 110 in a fixed manner with respect to the vacuum container 20. For a second part (for example, 112b and 114b) of the flexible line 108 on a side far from the cold head 104, a risk that a worker may hook his or her foot on the second part and stumble can still be assumed. However, even if such a situation occurs, a tension force acting on the second part is merely received by the attachment flange

106a and the vacuum container 20 to which the flexible line holder 110 is fixed. The tension force is not directly transmitted to the cold head 104, and it is expected that a position and posture of the cold head 104 can be held even when the thermal switch is off. In this way, the cryogenic refrigerator 100 can be protected from an unexpected external force.

[0042] Fig. 3 is a view schematically showing exemplary electrical connection applicable to the cryogenic refrigerator 100 shown in Fig. 1. The flexible line 108 may be a power supply cable for supplying power to the cold head 104. The power supply cable connects a power supply 118 disposed outside the vacuum container 20 to the drive unit 104c (for example, the cold head drive motor 104e shown in Fig. 1) of the cold head 104. In an exemplary configuration, the compressor 102 may be used as the power supply 118.

[0043] The flexible line holder 110 may be a cable holder that is fixed to the attachment flange 106a and holds the power supply cable. In the shown example, the flexible line holder 110 is attached to the attachment flange 106a such that the flexible line holder 110 penetrates the attachment flange 106a. Accordingly, the power supply cable can be guided from one surface of the attachment flange 106a (for example, the upper surface) to a surface on a side opposite thereto (for example, the lower surface). A degree of freedom in the disposition of the power supply cable can be increased as compared to a case where the power supply cable is routed only on an upper surface side of the attachment flange 106a.

[0044] Even in this way, the cryogenic refrigerator 100 can be protected from an unexpected external force as in the embodiment described with reference to Figs. 1 and 2. That is, even when an unexpected external force acts on the second part of the flexible line 108 extending from the flexible line holder 110 to the power supply 118, the attachment flange 106a and the vacuum container 20 to which the flexible line holder 110 is fixed can receive the external force. It is possible to reduce an adverse effect on the cold head 104 caused by the external force.

[0045] In addition, the flexible line holder 110 of a type that penetrates the attachment flange 106a as described above may be used as the holder for the working gas line described with reference to Fig. 1.

[0046] Fig. 4 is a view schematically showing an exemplary drive source applicable to the cryogenic refrigerator 100 shown in Fig. 1. The drive source 106c is attached to a plate-shaped support body 120 disposed above the cold head 104. The drive source 106c includes a movable piston 122 that penetrates the support body 120 and protrudes downward. A plurality of (for example, four) guide rods 124 are erected on the attachment flange 106a to surround the cold head 104, and the support body 120 is fixed to distal ends of the guide rods 124. The guide rods 124 penetrate the cold head flange 104d in the up-down direction, and the cold head flange 104d is movable in the up-down direction along the guide rods 124.

[0047] In addition, a movable frame 126 including

support columns 126a and a movable plate 126b is installed on the cold head flange 104d. The support columns 126a are erected on the cold head flange 104d, and the movable plate 126b is fixed to the support columns 126a to bridge distal ends of the support columns 126a. A lower end of the movable piston 122 is fixed to the movable plate 126b.

[0048] Therefore, when the movable piston 122 advances and retreats up and down by the operation of the drive source 106c, the cold head flange 104d can also move up and down via the movable frame 126. In this case, the cold head flange 104d moves up and down along the guide rods 124, accompanying expansion and contraction of the airtight partition wall 106b. In this way, the drive source 106c can provide the movement of the cold head 104 with respect to the vacuum container 20.

[0049] The cryogenic refrigerator 100 may include an additional flexible line 128 connected to the drive source 106c, and an additional flexible line holder 130 configured to hold the additional flexible line 128 in a fixed manner with respect to the vacuum container 20. The drive source 106c may be, for example, an air cylinder. In this case, the flexible line 128 may be a compressed-air line for supplying compressed air to the drive source 106c and collecting compressed air from the drive source 106c. The flexible line holder 130 may be a holder that is fixed to the attachment flange 106a and holds the compressed-air line.

[0050] Even in this way, the cryogenic refrigerator 100 can be protected from an unexpected external force. That is, even when an unexpected external force acts on the second part of the flexible line 128 extending from the flexible line holder 130 to a compressed-air source 132, the attachment flange 106a and the vacuum container 20 to which the flexible line holder 130 is fixed can receive the external force. It is possible to reduce an adverse effect on the cold head 104 caused by the external force.

[0051] The present invention has been described above based on the examples. It will be understood by those skilled in the art that the present invention is not limited to the above embodiments, various design changes can be made, various modification examples are possible, and such modification examples are also within the scope of the present invention. Various features described in relation to an embodiment are also applicable to other embodiments. New embodiments resulting from combinations have the effect of each of embodiments which are combined.

[0052] Although the above-described embodiment has been described as an example in which the working gas line holder is an intermediate coupling, other configurations are also possible. For example, the working gas line holder may be an appropriate fixing tool such as a hose clamp that holds the working gas line, and the fixing tool may be fixed to the attachment flange 106a. In this case, the working gas line does not need to be divided by the holder (the working gas line need not be divided into the first part and the second part, and may be a single flexible

hose).

[0053] Although the above-described embodiment has been described as an example in which the flexible line holder 110 is fixed to the attachment flange 106a of the cold head mount 106, other configurations are also possible. For example, the flexible line holder 110 may be directly fixed to the vacuum container 20. For example, the flexible line holder 110 may be fixed to a wall surface of the vacuum container 20 to which the attachment flange 106a is attached (that is, on which the mounting port 32 is provided), or to another part of the vacuum container 20.

[0054] Although the above-described embodiment has been described as an example in which the cryogenic refrigerator 100 is a single-stage GM cryocooler, other configurations are also possible. For example, the cryogenic refrigerator 100 may be a two-stage GM cryocooler. In this case, the cryogenic refrigerator 100 may provide cryogenic cooling of about 4 K or lower, and the cryogenic liquid 12 may be liquid helium. The cryogenic refrigerator 100 may be a pulse tube cryocooler, a Stirling cryocooler, or another type of cryogenic refrigerator.

[0055] Although the above-described embodiment describes a case where the cryogenic device 10 is a storage device for the cryogenic liquid 12 as an example, other configurations are also possible. For example, the cryogenic device 10 may be superconductivity equipment, and the cryogenic refrigerator 100 may be used to cool a superconducting coil disposed in the vacuum container 20.

[0056] The present invention has been described using specific terms and phrases, based on the embodiments. However, the embodiments show only one aspect of the principles and applications of the present invention, and in the embodiments, many modification examples or disposition changes are permitted within a scope which does not depart from the ideas of the present invention defined in the claims.

Industrial Applicability

[0057] The present invention can be used in the field of cryogenic refrigerators.

Reference Signs List

[0058]

20	vacuum container
100	cryogenic refrigerator
104	cold head
106	cold head mount
106a	attachment flange
106b	airtight partition wall
106c	drive source
108	flexible line
110	flexible line holder

Claims**1.** A cryogenic refrigerator comprising:

a cold head that is mountable on a vacuum container; 5
 a cold head mount configured to couple the cold head with the vacuum container to allow movement of the cold head with respect to the vacuum container; 10
 a flexible line that is connected to the cold head outside the vacuum container; and
 a flexible line holder configured to hold the flexible line in a fixed manner with respect to the vacuum container. 15

2. The cryogenic refrigerator according to claim 1, wherein the flexible line holder holds the flexible line at an end portion of the flexible line on a cold head side. 20**3.** The cryogenic refrigerator according to claim 1 or 2,

wherein the flexible line includes a working gas line for supplying a working gas to the cold head or collecting the working gas from the cold head, and 25
 the flexible line holder includes a working gas line holder that holds the working gas line. 30

4. The cryogenic refrigerator according to claim 3,

wherein the working gas line holder includes an intermediate coupling including an internal flow path through which the working gas is capable of flowing, and 35
 the working gas line includes a first part that connects the cold head to the intermediate coupling and a second part that is connected to the intermediate coupling. 40

5. The cryogenic refrigerator according to claim 3,

wherein the cold head mount includes an attachment flange attachable to the vacuum container, 45
 and an expandable and contractible airtight partition wall that connects the cold head to the attachment flange, and
 the working gas line holder is fixed to the attachment flange. 50

6. The cryogenic refrigerator according to claim 1 or 2,

wherein the flexible line includes a power supply cable for supplying power to the cold head, and 55
 the flexible line holder includes a cable holder that holds the power supply cable.

7. The cryogenic refrigerator according to claim 6,

wherein the cold head mount includes an attachment flange attachable to the vacuum container, and an expandable and contractible airtight partition wall that connects the cold head to the attachment flange, and
 the cable holder is fixed to the attachment flange.

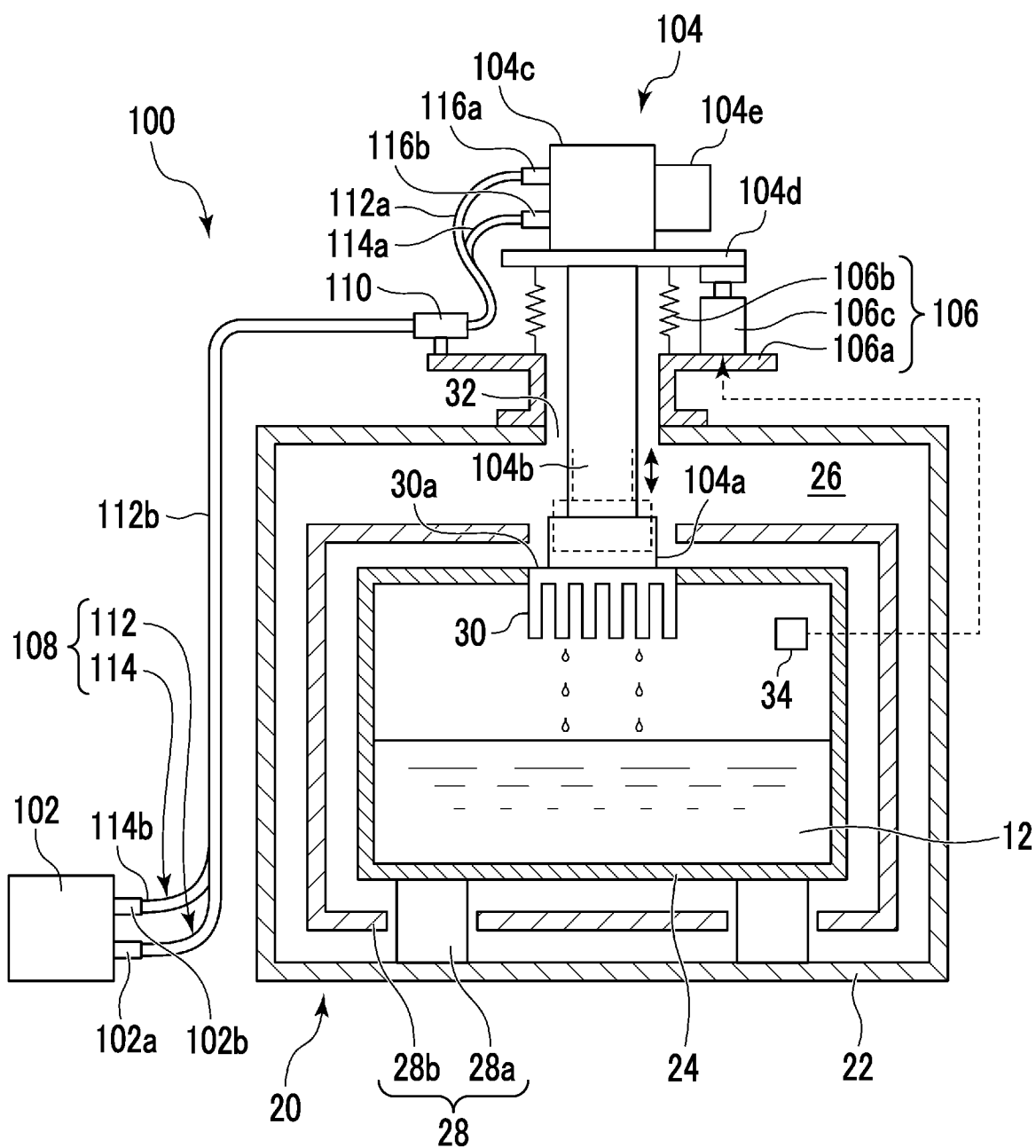
8. The cryogenic refrigerator according to any one of claims 1 to 7, further comprising:

a drive source mounted on the cold head mount and configured to move the cold head with respect to the vacuum container;
 an additional flexible line that is connected to the drive source; and
 an additional flexible line holder configured to hold the additional flexible line in a fixed manner with respect to the vacuum container.

9. The cryogenic refrigerator according to claim 8,

wherein the cold head mount includes an attachment flange attachable to the vacuum container, and an expandable and contractible airtight partition wall that connects the cold head to the attachment flange, and
 the additional flexible line holder is fixed to the attachment flange.

FIG. 1



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FIG. 2

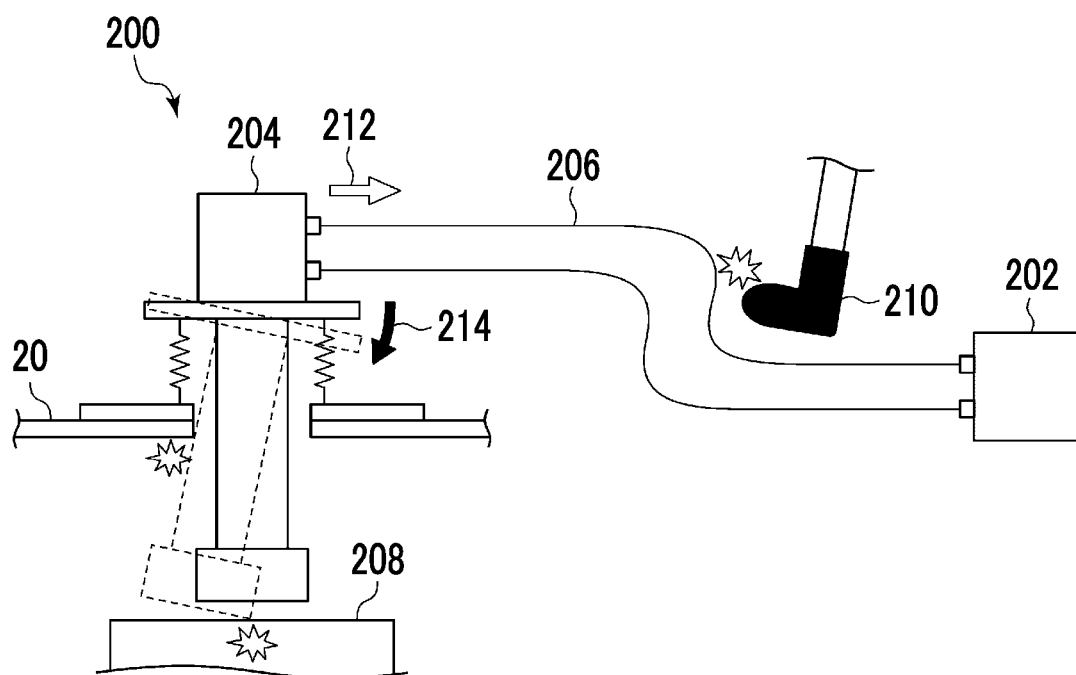


FIG. 3

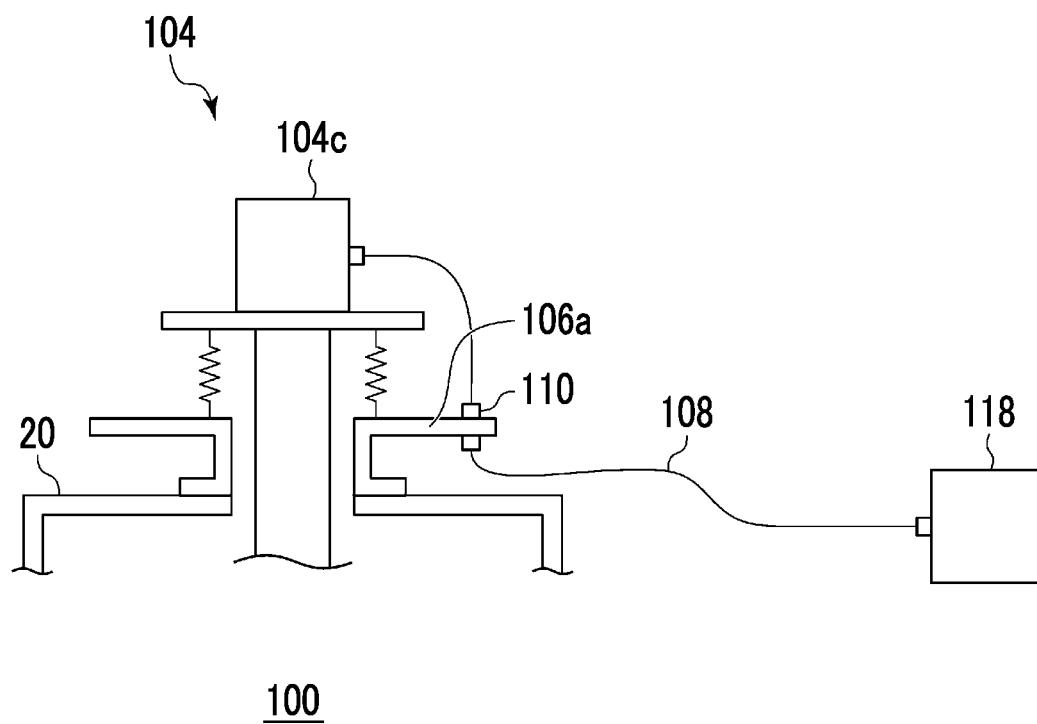
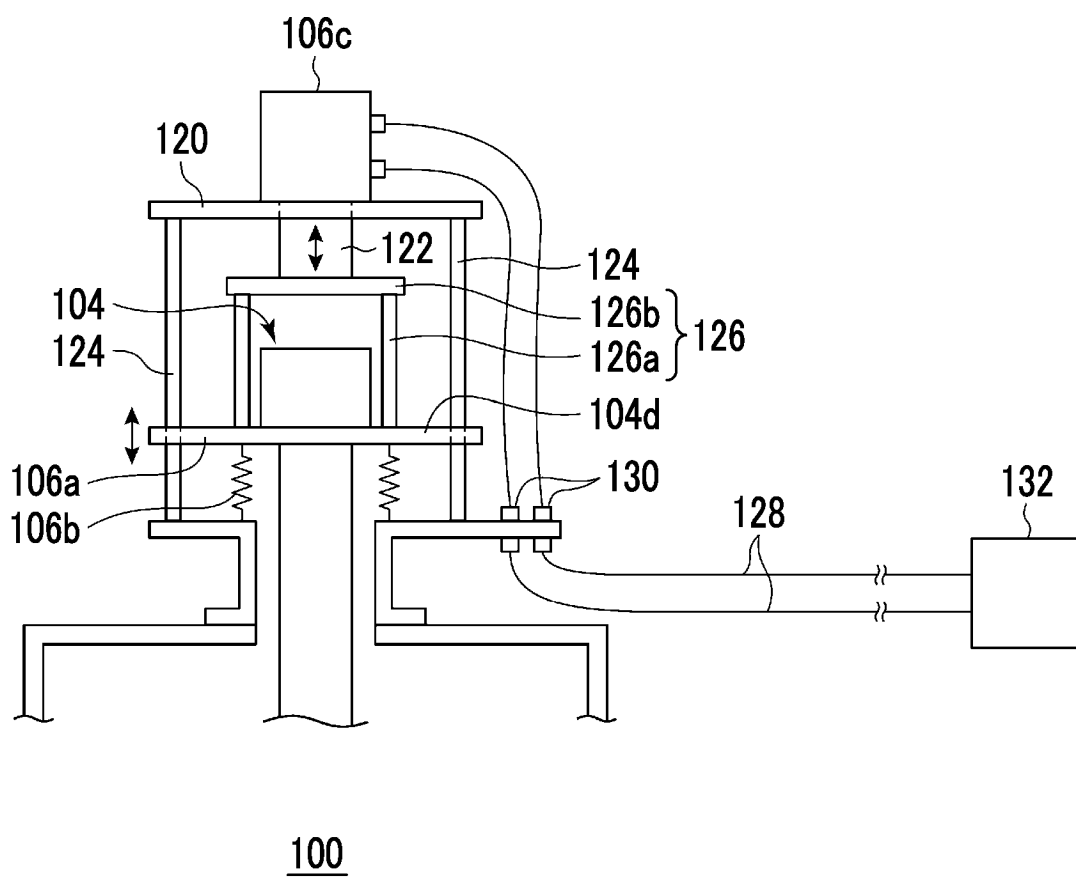


FIG. 4



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2023/018540

A. CLASSIFICATION OF SUBJECT MATTER**F25B 9/00**(2006.01)i

FI: F25B9/00 B; 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)

F25B9/00-9/14

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 1971-2023

Registered utility model specifications of Japan 1996-2023

Published registered utility model applications of Japan 1994-2023

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 11-512512 A (SIEMENS AKTIENGESELLSCHAFT) 26 October 1999 (1999-10-26) p. 6, line 17 to p. 10, line 18, fig. 1-3	1
Y		2-4, 6, 8
A		5, 7, 9
Y	JP 2020-134006 A (SUMITOMO HEAVY INDUSTRIES) 31 August 2020 (2020-08-31) paragraph [0020]	2-4, 6, 8
A	paragraph [0032], fig. 1	5, 7, 9
A	JP 9-287837 A (KOBE STEEL LTD) 04 November 1997 (1997-11-04) paragraphs [0013]-[0015], fig. 1-2	1, 8
P, A	JP 2022-113132 A (SUMITOMO HEAVY INDUSTRIES) 03 August 2022 (2022-08-03) paragraphs [0015], [0042]-[0046], fig. 1, 3	1

☐ 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

12 July 2023

Date of mailing of the international search report

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Name and mailing address of the ISA/JP

Japan Patent Office (ISA/JP)

3-4-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8915

Japan

Authorized officer

Telephone No.

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2023/018540

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JP 11-512512 A	26 October 1999	US 5934082 A column 3, line 6 to column 6, line 17, fig. 1-3 WO 1997/010469 A1 DE 19533555 A1	
JP 2020-134006 A	31 August 2020	US 2020/0262013 A1 paragraphs [0031], [0043], fig. 1 EP 3699516 A2 CN 111571517 A	
JP 9-287837 A	04 November 1997	(Family: none)	
JP 2022-113132 A	03 August 2022	(Family: none)	

REFERENCES CITED IN THE DESCRIPTION

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