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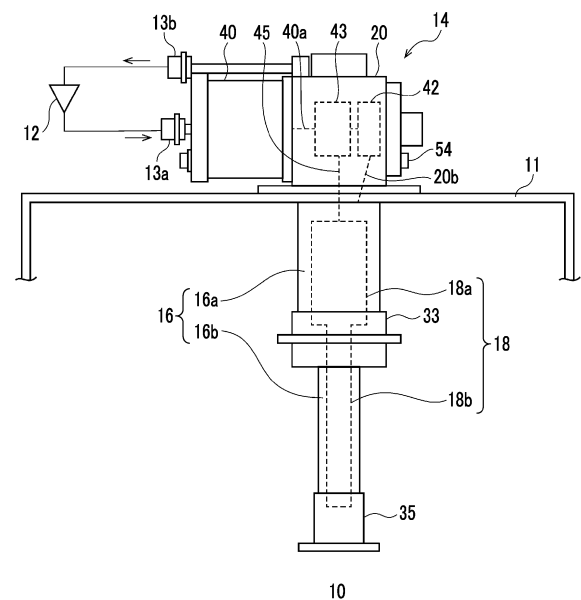
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(54) **GAS REPLACEMENT METHOD FOR EXPANDER OF CRYOCOOLER, CRYOCOOLER, AND GAS REPLACEMENT PIPE**

(57) There is provided a gas replacement technique for an expander (14) of a cryocooler (10) for avoiding contact between electrical equipment in the expander (14) and a flammable gas. A gas replacement method for an expander (14) of a cryocooler (10) is provided. The expander (14) includes an expander cylinder (16), a pressure switching valve (42) that switches a pressure inside the expander cylinder (16), a connection flow path (20b) from the pressure switching valve (42) to the expander cylinder (16), and an expander motor (40) that drives the pressure switching valve (42). The method includes connecting a nonflammable gas source (60) to the connection flow path (20b) or the expander cylinder (16), and purging a residual gas in the expander cylinder (16) with a nonflammable gas from the nonflammable gas source (60) while the expander motor (40) is stopped.

FIG. 1



Description

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The present invention relates to a gas replacement method for an expander of a cryocooler and a cryocooler. In addition, the present invention relates to a gas replacement pipe that can be used in such a gas replacement method.

Description of Related Art

[0002] For example, a cryocooler such as a Gifford-McMahon (GM) cryocooler is mounted in a storage container for a liquefied gas and used for recondensing the gas as one of applications thereof (for example, Japanese Unexamined Patent Publication No. 2001-241796).

SUMMARY OF THE INVENTION

[0003] In a case where the gas to be recondensed by the cryocooler contains, for example, a flammable gas such as hydrogen, an atmosphere surrounding the cryocooler may contain the flammable gas. The present inventor has noticed that the flammable gas may be taken into an expander of the cryocooler during maintenance work that is performed by interrupting an operation of the cryocooler. The maintenance work involves disassembling and reassembling the expander to inspect or replace an internal component. Therefore, in a case where the maintenance work is performed at a site where the expander is installed, an ambient gas, that is, a gas that may contain the flammable gas, may be taken into the expander. As a result, electrical equipment in the expander, such as a motor, and the flammable gas may come into contact with each other. Operating the electrical equipment in a state of being in contact with the flammable gas may cause a risk of ignition.

[0004] An exemplary object of one aspect of the present invention is to provide a gas replacement technique for an expander of a cryocooler for avoiding contact between electrical equipment in the expander and a flammable gas.

[0005] According to one aspect of the present invention, there is provided a gas replacement method for an expander of a cryocooler. The expander includes an expander cylinder, a pressure switching valve that switches a pressure inside the expander cylinder, a connection flow path from the pressure switching valve to the expander cylinder, and an expander motor that drives the pressure switching valve. The method includes connecting a nonflammable gas source to the connection flow path or the expander cylinder, and purging a residual gas in the expander cylinder with a nonflammable gas from the nonflammable gas source while the expander motor is stopped.

[0006] According to another aspect of the present invention, there is provided a cryocooler including an expander cylinder, a pressure switching valve that switches a pressure inside the expander cylinder, a high pressure port and a low pressure port connected to the expander cylinder via the pressure switching valve, a connection flow path from the pressure switching valve to the expander cylinder, and a gas receiving port that is different from the high pressure port and the low pressure port and is connected to the connection flow path to allow a gas to flow into the connection flow path.

[0007] According to still another aspect of the present invention, there is provided a gas replacement pipe used for gas replacement of an expander of a cryocooler. The gas replacement pipe includes a main pipe that is connectable to a nonflammable gas source, a first branch pipe that branches from the main pipe and is connectable to a gas receiving port of the expander, a second branch pipe that branches from the main pipe and is connectable to a high pressure port of the expander, and a third branch pipe that branches from the main pipe and is connectable to a low pressure port of the expander.

[0008] According to the present invention, it is possible to provide a gas replacement technique for an expander of a cryocooler for avoiding contact between electrical equipment in the expander and a flammable gas.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009]

Fig. 1 is a diagram schematically showing a cryocooler according to an embodiment.

Fig. 2 is a diagram schematically showing the cryocooler according to the embodiment.

Fig. 3 is a diagram schematically showing the cryocooler according to the embodiment.

Fig. 4 is a diagram schematically showing a disassembled perspective view of a main part of a motion conversion mechanism of a cold head according to the embodiment.

Fig. 5 is a flowchart showing a gas replacement method for an expander of the cryocooler according to the embodiment.

Fig. 6 is a schematic view showing the expander of the cryocooler in the gas replacement method according to the embodiment.

Fig. 7 is a schematic view showing the expander of the cryocooler in the gas replacement method according to the embodiment.

Fig. 8 is a diagram schematically showing the cryocooler according to the embodiment.

DETAILED DESCRIPTION OF THE INVENTION

[0010] Hereinafter, an embodiment for carrying out the present invention will be described in detail with reference to the drawings. In the description and the drawings,

the same or equivalent components, members, and processes are denoted by the same reference numerals, and overlapping description is omitted as appropriate. The scale and the shape of each of parts shown in the drawings are set for convenience to make the description easy to understand, and are not to be interpreted as limiting unless stated otherwise. The embodiment is merely an example and does not limit the scope of the present invention. All features described in the embodiment or combinations thereof are not necessarily essential to the present invention.

[0011] Figs. 1 to 3 are diagrams schematically showing a cryocooler 10 according to the embodiment. Fig. 1 shows an appearance of a cold head of the cryocooler 10, and Fig. 2 shows an internal structure of a low-temperature section of the cold head. Fig. 3 shows an internal structure of a drive unit of the cold head. The cryocooler 10 is usually installed in a vacuum chamber (not shown) such that the low-temperature section is disposed inside the vacuum chamber and the drive unit is disposed in a surrounding environment (for example, a room temperature atmospheric pressure environment) outside the vacuum chamber. As an example, the cryocooler 10 is a two-stage Gifford-McMahon (GM) cryocooler.

[0012] As an example of applications, the cryocooler 10 may be mounted in a cryogenic liquid storage tank that stores a cryogenic liquid. The cryocooler 10 may be used for recondensing a vaporized cryogenic liquid. The cryogenic liquid may be a refrigerant having a boiling point lower than a boiling point of nitrogen (about 77 K) in the embodiment, and may be, for example, liquid hydrogen, liquid helium, or liquid neon.

[0013] The cryocooler 10 includes a compressor 12 and an expander 14. The compressor 12 is configured to collect a working gas of the cryocooler 10 from the expander 14, to pressurize the collected working gas, and to supply the working gas to the expander 14 again. The compressor 12 and the expander 14 constitute a refrigeration cycle of the cryocooler 10, whereby the cryocooler 10 can provide desired cryogenic cooling. The expander 14 is also often referred to as a cold head. The working gas is also referred to as a refrigerant gas, and other suitable gases may be used although a helium gas is typically used. For the sake of understanding, a flow direction of the working gas is shown by an arrow in Fig. 1.

[0014] In general, both a pressure of a working gas supplied from the compressor 12 to the expander 14 and a pressure of a working gas collected from the expander 14 to the compressor 12 are considerably higher than the atmospheric pressure, and can be called 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 called 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. For the sake of understanding,

a flow direction of the working gas is shown by an arrow.

[0015] The expander 14 includes an expander cylinder 16, a displacer assembly (hereinafter, also referred to as a displacer) 18, and an expander housing (hereinafter, also referred to as a housing) 20. The expander cylinder 16 guides linear reciprocation of the displacer 18, and forms an expansion chamber (32, 34) as an expansion space for the working gas in a space with the displacer 18. The expander cylinder 16 is fixed to the expander housing 20, whereby a casing of the expander 14 is configured, and an airtight space for accommodating the displacer 18 is formed inside the expander cylinder 16.

[0016] In addition, the expander 14 includes a high pressure port 13a and a low pressure port 13b. The high pressure port 13a is provided in the expander housing 20 as an inlet for the working gas to the expander 14, and the low pressure port 13b is provided in the expander housing 20 as an outlet for the working gas from the expander 14. Therefore, the high pressure port 13a is connected to a high pressure side of the compressor 12 by a high pressure side pipe, and the low pressure port 13b is connected to a low pressure side of the compressor 12 by a low pressure side pipe. Accordingly, the high pressure working gas is supplied from the high pressure side of the compressor 12 to the expander 14 through the high pressure port 13a. In addition, the low pressure working gas is collected from the expander 14 to the low pressure side of the compressor 12 through the low pressure port 13b.

[0017] In the present specification, in order to describe a positional relationship between the components of the cryocooler 10, for convenience, a side close to a top dead center of the axial reciprocation of the displacer is described as "upper", and a side close to a bottom dead center is described as "lower". The top dead center is a position of the displacer where a volume of an expansion space is maximized, and the bottom dead center is the position of the displacer where the volume of the expansion space is minimized. Since a temperature gradient is generated in which a temperature drops from the upper side to the lower side in the axial direction during the operation of the cryocooler 10, the upper side can be referred to as a high temperature side and the lower side can be referred to as a low temperature side.

[0018] The expander cylinder 16 includes a first cylinder 16a and a second cylinder 16b. As an example, the first cylinder 16a and the second cylinder 16b are members having a cylindrical shape, and the second cylinder 16b has a smaller diameter than the first cylinder 16a. The first cylinder 16a and the second cylinder 16b are coaxially disposed, and a lower end of the first cylinder 16a is rigidly connected to an upper end of the second cylinder 16b.

[0019] The displacer assembly 18 includes a first displacer 18a and a second displacer 18b, which are connected to each other, and these move integrally. As an example, the first displacer 18a and the second displacer 18b are members having a cylindrical shape, and the

second displacer 18b has a smaller diameter than the first displacer 18a. The first displacer 18a and the second displacer 18b are coaxially disposed.

[0020] The first displacer 18a is accommodated in the first cylinder 16a, and the second displacer 18b is accommodated in the second cylinder 16b. The first displacer 18a can reciprocate in an axial direction along the first cylinder 16a, and the second displacer 18b can reciprocate in the axial direction along the second cylinder 16b.

[0021] As shown in Fig. 2, the first displacer 18a accommodates a first regenerator 26. The first regenerator 26 is formed by filling a tubular main body of the first displacer 18a with a wire mesh such as copper or other appropriate first regenerator material. An upper lid portion and a lower lid portion of the first displacer 18a may be provided as separate members from the main body of the first displacer 18a, and the upper lid portion and the lower lid portion of the first displacer 18a may be fixed to the main body by appropriate means such as fastening or welding, whereby the first regenerator material may be accommodated in the first displacer 18a.

[0022] Similarly, the second displacer 18b accommodates a second regenerator 28. The second regenerator 28 is formed by filling a tubular main body of the second displacer 18b with a non-magnetic regenerator material such as bismuth, a magnetic regenerator material such as HoCu_2 , or other appropriate second regenerator material. The second regenerator material may be formed in a granular shape. The upper lid portion and the lower lid portion of the second displacer 18b may be provided as separate members from the main body of the second displacer 18b, and the lower lid portion and the upper lid portion of the second displacer 18b may be fixed to the main body by appropriate means such as fastening or welding, whereby the second regenerator material may be accommodated in the second displacer 18b.

[0023] The displacer 18 forms an upper chamber 30, a first expansion chamber 32, and a second expansion chamber 34 inside the expander cylinder 16. The expander 14 includes a first cooling stage 33 and a second cooling stage 35 for heat exchange with a desired object or medium to be cooled by the cryocooler 10. The upper chamber 30 is formed between the upper lid portion of the first displacer 18a and the upper portion of the first cylinder 16a. The first expansion chamber 32 is formed between the lower lid portion of the first displacer 18a and the first cooling stage 33. The second expansion chamber 34 is formed between the lower lid portion of the second displacer 18b and the second cooling stage 35. The first cooling stage 33 is fixed to the lower portion of the first cylinder 16a to surround the first expansion chamber 32, and the second cooling stage 35 is fixed to the lower portion of the second cylinder 16b to surround the second expansion chamber 34.

[0024] The first regenerator 26 is connected to the upper chamber 30 through a working gas flow path 36a formed in the upper lid portion of the first displacer

18a, and is connected to the first expansion chamber 32 through a working gas flow path 36b formed in the lower lid portion of the first displacer 18a. The second regenerator 28 is connected to the first regenerator 26 through a working gas flow path 36c formed from the lower lid portion of the first displacer 18a to the upper lid portion of the second displacer 18b. In addition, the second regenerator 28 is connected to the second expansion chamber 34 through a working gas flow path 36d formed in the lower lid portion of the second displacer 18b.

[0025] A first seal 38a and a second seal 38b may be provided so that the working gas flow between the first expansion chamber 32, the second expansion chamber 34 and the upper chamber 30 is guided to the first regenerator 26 and the second regenerator 28 rather than to the clearance between the expander cylinder 16 and the displacer 18. The first seal 38a may be mounted to the upper lid portion of the first displacer 18a to be disposed between the first displacer 18a and the first cylinder 16a. The second seal 38b may be mounted to the upper lid portion of the second displacer 18b to be disposed between the second displacer 18b and the second cylinder 16b.

[0026] As shown in Fig. 3, the expander housing 20 includes a housing main body 22 having a lower opening 21 and a lower cover 24 that closes the lower opening 21. The lower opening 21 is formed on a lower surface of the housing main body 22. As shown in the figure, a housing internal volume 20a formed by the housing main body 22 and the lower cover 24 may be connected to a low pressure side of the compressor 12 and maintained at a low pressure.

[0027] The lower cover 24 partitions the housing internal volume 20a and a displacer accommodation space (upper chamber 30) in the expander cylinder 16. The lower cover 24 has a disk shape as a whole, and more specifically, has an upper large-diameter portion and a lower small-diameter portion. A first sealing member 25a is provided between the lower cover 24 and the expander cylinder 16 in order to maintain airtightness of an internal volume of the expander cylinder 16, and a second sealing member 25b is provided between the lower cover 24 and the housing main body 22 in order to maintain airtightness of the housing internal volume 20a. As shown in the figure, the first sealing member 25a may be mounted to the small-diameter portion of the lower cover 24, and the second sealing member 25b may be mounted to the large-diameter portion of the lower cover 24.

[0028] The lower cover 24 is removably fitted into the lower opening 21, and an upper flange portion of the expander cylinder 16 is fastened to the housing main body 22 with a fastening member such as a bolt. In this way, the lower cover 24 is interposed between the housing main body 22 and the upper flange portion of the expander cylinder 16. The lower cover 24 is not fixed to the housing main body 22 through fastening. Note that a structure may be adopted in which the housing main body 22 and the lower cover 24 are fastened to each other with

a fastening member such as a bolt.

[0029] In addition, the expander 14 includes an expander motor 40, a pressure switching valve 42, and a motion conversion mechanism 43. The expander motor 40 is attached to the expander housing 20, more specifically, to a side surface of the housing main body 22. In order to maintain the airtightness of the housing internal volume 20a, a sealing member (not shown) may be provided on an attachment surface between the expander motor 40 and the housing main body 22. The pressure switching valve 42 and the motion conversion mechanism 43 are accommodated in the expander housing 20.

[0030] The expander motor 40 is provided in the expander 14 as a drive source for the displacer 18 and the pressure switching valve 42. The expander motor 40 may be an appropriate electric motor, and may be configured to rotate a motor rotary shaft 40a at a constant rotational speed, or may be capable of variably controlling the rotational speed of the motor rotary shaft 40a.

[0031] The pressure switching valve 42 connects the high pressure port 13a and the low pressure port 13b to the expander cylinder 16 (that is, the upper chamber 30, the first expansion chamber 32, and the second expansion chamber 34). The pressure switching valve 42 is configured to alternately connect the high pressure port 13a and the low pressure port 13b to the expander cylinder 16 and to periodically switch between the intake and the exhaust of the expander cylinder 16.

[0032] In addition, the pressure switching valve 42 may be configured to temporarily block the connection between both the high pressure port 13a and the low pressure port 13b and the expander cylinder 16 when switching the connection between the high pressure port 13a and the low pressure port 13b. In this case, the pressure switching valve 42 does not instantaneously switch the connection between the high pressure port 13a and the low pressure port 13b, but has a period in which the expander cylinder 16 is connected to neither the high pressure port 13a nor the low pressure port 13b.

[0033] The pressure switching valve 42 is a rotary valve type in the embodiment. Therefore, the pressure switching valve 42 includes a valve rotor 42a and a valve stator 42b, and the valve rotor 42a is in contact with the valve stator 42b so as to rotate while sliding with respect to the valve stator 42b. The valve rotor 42a is supported to be rotatable with respect to the housing main body 22, and the valve stator 42b is supported to be unrotatable with respect to the housing main body 22. An elastic body such as a spring for pressing the valve stator 42b toward the valve rotor 42a in a direction of a rotation axis of the valve rotor 42a may be interposed between the valve stator 42b and the housing main body 22.

[0034] A connection flow path 20b from the pressure switching valve 42 to the expander cylinder 16 is formed in the expander housing 20. The connection flow path 20b connects the pressure switching valve 42 to the upper chamber 30. The valve rotor 42a and the valve stator 42b of the pressure switching valve 42 are formed

with a valve internal flow path to alternately connect the connection flow path 20b to the high pressure port 13a and the housing internal volume 20a (that is, the low pressure port 13b). Various known forms can be adopted as the valve internal flow path, and details thereof will not be described herein.

[0035] The motion conversion mechanism 43 is configured to connect the expander motor 40 to the pressure switching valve 42 and the displacer 18 so as to transmit the rotation of the motor rotary shaft 40a to the pressure switching valve 42 and convert the rotation into the linear reciprocation of the displacer 18. An example of the motion conversion mechanism 43 will be described below. One rotation of the motor rotary shaft 40a causes one reciprocation of the displacer 18 via the motion conversion mechanism 43, thereby periodically changing the volume of the expansion space for the working gas. Simultaneously, one rotation of the motor rotary shaft 40a causes one rotation of the pressure switching valve 42 via the motion conversion mechanism 43, whereby the high pressure port 13a and the low pressure port 13b are alternately connected to the expander cylinder 16 via the pressure switching valve 42, and the pressure of the expansion space for the working gas periodically changes.

[0036] In this way, the synchronized volume fluctuation and pressure fluctuation are generated in the expansion space to configure the refrigeration cycle of the cryocooler 10, whereby the cryocooler 10 can provide desired cryogenic cooling. The first cooling stage 33 can be cooled to a first cooling temperature, and the second cooling stage 35 can be cooled to a second cooling temperature lower than the first cooling temperature. The first cooling temperature may be, for example, in a range of about 10 K to about 100 K or in a range of about 20 K to about 40 K. The second cooling temperature may be, for example, about 20 K or lower, or about 10 K or lower, or in a range of about 1 K to about 4 K. In a case where the cryocooler 10 is used for recondensing the vaporized cryogenic liquid, a cooling temperature of the cryocooler 10 (for example, the second cooling temperature) may be a temperature equal to or lower than a boiling point of the cryogenic liquid.

[0037] The expander 14 of the cryocooler 10 may be installed in a hermetic container 11 as illustrated in Fig. 1. The hermetic container 11 may be, for example, a vacuum chamber such as a cryostat. In a case where the cryocooler 10 is used for recondensing the vaporized cryogenic liquid, the hermetic container 11 may configure a cryogenic liquid storage tank that stores the cryogenic liquid. The expander 14 may be inserted into the hermetic container 11 from an opening portion of a wall surface of the hermetic container 11, and the expander housing 20 may be fixed to the hermetic container 11 at the opening portion. The expander housing 20 is exposed to ambient environment (for example, room temperature atmospheric pressure environment) of the hermetic container 11, and the first cooling stage 33 and the second cooling

stage 35 are disposed inside the hermetic container 11. The expander 14 may be vertically installed in the hermetic container 11 such that the expander housing 20 faces upward and the first cooling stage 33 and the second cooling stage 35 face downward.

[0038] Fig. 4 is a diagram schematically showing a disassembled perspective view of a main part of the motion conversion mechanism 43 of the cold head according to the embodiment. An exemplary form of the motion conversion mechanism 43 will be described with reference to Figs. 3 and 4.

[0039] The motion conversion mechanism 43 is a scotch yoke in this embodiment, and includes a crank 44 having a crank pin 44a, a scotch yoke shaft 45, and a crank pin bearing 46. The scotch yoke shaft 45 includes a scotch yoke plate 45a, an upper rod 45b, and a lower rod 45c. The scotch yoke shaft 45 may be formed of a metal material such as stainless steel.

[0040] The crank 44 is fixed to the motor rotary shaft 40a. The crank pin 44a extends parallel to the motor rotary shaft 40a at a position eccentric from the motor rotary shaft 40a. The crank pin 44a extends from the crank 44 toward a side opposite to the motor rotary shaft 40a with respect to the crank 44.

[0041] The scotch yoke plate 45a is a rectangular plate-shaped member having a horizontally elongated window 47. The horizontally elongated window 47 extends in the axial direction and in a direction perpendicular to the motor rotary shaft 40a. The crank pin bearing 46 is reliably disposed in the horizontally elongated window 47. The crank pin bearing 46 may be, for example, a roller bearing. An engagement hole 46a that engages with the crank pin 44a is formed at the center of the crank pin bearing 46, and the crank pin 44a penetrates the engagement hole 46a.

[0042] On a side opposite to the crank 44 with respect to the scotch yoke plate 45a, the valve rotor 42a of the pressure switching valve 42 is disposed such that a center axis thereof coincides with the motor rotary shaft 40a, and a tip of the crank pin 44a penetrating the engagement hole 46a is fixed to the valve rotor 42a.

[0043] The upper rod 45b extends upward from the center of an upper frame of the scotch yoke plate 45a, the lower rod 45c extends downward from the center of a lower frame of the scotch yoke plate 45a, and the rods are coaxially disposed. The scotch yoke plate 45a and the upper rod 45b are accommodated in the expander housing 20, and the lower rod 45c extends out of the expander housing 20 by penetrating the lower cover 24. A tip of the lower rod 45c is connected to the displacer 18 inside the expander cylinder 16.

[0044] A first sliding bearing 48a is provided between the upper rod 45b and the housing main body 22, and a second sliding bearing 48b is provided between the lower rod 45c and the lower cover 24. The housing main body 22 has a recessed portion for receiving the upper rod 45b in an upper portion thereof, and the first sliding bearing 48a is disposed in the recessed portion to slidably sup-

port the upper rod 45b in the axial direction. The lower cover 24 has a through-hole in a center portion thereof, and the second sliding bearing 48b is disposed in the through-hole to slidably support the lower rod 45c in the axial direction. The second sliding bearing 48b is provided with a seal portion such as a slipper seal or a clearance seal, and is configured to be airtight. Therefore, the housing internal volume 20a is isolated from the upper chamber 30. There is no direct gas flow between the housing internal volume 20a and the upper chamber 30.

[0045] A collar portion 50 is fixed to the tip of the lower rod 45c connected to the displacer 18 by a fixing pin 49. The collar portion 50 is a short tubular member into which a tip of the displacer assembly 18 is inserted. A through-hole is formed in the tip of the lower rod 45c and the collar portion 50 in a direction perpendicular to the axial direction, and the collar portion 50 is fixed to the lower rod 45c by fitting the fixing pin 49 into the through-hole.

[0046] The first displacer 18a has a lid portion 52a and a main body 52b. The lid portion 52a is an upper lid of the first displacer 18a, and has a disk shape. The lid portion 52a is formed of a metal material such as an alumite-treated aluminum alloy, or other material. The main body 52b has a cylindrical shape, and includes a regenerator therein. The main body 52b is formed of a synthetic resin material or other material, and may be formed of, for example, a phenolic resin such as Bakelite. The above-described working gas flow path 36a is formed by penetrating the lid portion 52a and an upper end portion of the main body 52b in the axial direction. The above-described first seal 38a may be interposed between outermost peripheral portions of the lid portion 52a and the main body 52b. The lid portion 52a and the main body 52b are fixed to each other by using, for example, a fastening member such as a bolt, or by using, for example, other methods such as adhesion.

[0047] A through-hole for receiving the tip of the lower rod 45c and the collar portion 50 is formed in a center portion of the lid portion 52a. The collar portion 50 has a flange portion that expands outward in a radial direction at a lower end portion thereof, and the flange portion is interposed between the lid portion 52a and the main body 52b of the first displacer 18a, so that the lower rod 45c and the collar portion 50 are connected to the first displacer 18a. In this way, the displacer 18 is attached to the scotch yoke shaft 45.

[0048] Therefore, when the expander motor 40 is driven and the motor rotary shaft 40a is rotated, the crank pin bearing 46 engaged with the crank pin 44a rotates in a circular motion. In this case, the crank pin bearing 46 reciprocates in the horizontally elongated window 47 of the scotch yoke plate 45a, and the scotch yoke shaft 45 and the displacer 18 reciprocate in the axial direction. In this way, the expander motor 40 drives the axial movement of the scotch yoke shaft 45.

[0049] In the embodiment, as shown in Figs. 1 and 3, the expander 14 includes a gas receiving port 54 different

from the high pressure port 13a and the low pressure port 13b. The gas receiving port 54 is provided in the expander housing 20 and is connected to the connection flow path 20b to allow a gas to flow into the connection flow path 20b. Therefore, the gas receiving port 54 is provided not on the compressor 12 side (that is, on the high pressure port 13a and low pressure port 13b side) but on the expander cylinder 16 side with respect to the pressure switching valve 42.

[0050] The gas receiving port 54 is not used in a normal operation of the cryocooler 10 for cryogenic cooling and is closed. As will be described below, the gas receiving port 54 is used in an open state in a gas replacement method for the expander 14 to return the cryocooler 10 from the maintenance work to the normal operation.

[0051] The gas receiving port 54 is provided in the expander housing 20 and is therefore disposed outside the hermetic container 11. Therefore, in a state where the expander 14 is attached to the hermetic container 11, a worker can access the gas receiving port 54 from outside the hermetic container 11 and easily open and close the gas receiving port 54.

[0052] As with the high pressure port 13a and the low pressure port 13b, the gas receiving port 54 may be a detachable coupling such as a self-sealing coupling. Accordingly, the pipe can be easily attached to and detached from the gas receiving port 54 for the gas replacement work of the expander 14.

[0053] The gas receiving port 54 may have a size different from that of the high pressure port 13a and the low pressure port 13b, for example, a size smaller than that of the high pressure port 13a and the low pressure port 13b. For example, the gas receiving port 54 may be a coupling having a size (for example, a nominal diameter) smaller than that of a coupling configuring the high pressure port 13a (or the low pressure port 13b). In this way, the gas receiving port 54 is easily identified by making the gas receiving port 54 different in size from other ports. This is helpful to prevent misconnection of the pipe between the gas receiving port 54 and other ports.

[0054] A flow path cross-sectional area of the gas receiving port 54 may be smaller than a flow path cross-sectional area of the connection flow path 20b. Here, the flow path cross-sectional area means a flow path cross-sectional area in a direction perpendicular to a flow direction of the working gas. The gas receiving port 54 (and a flow path volume from the gas receiving port 54 to the connection flow path 20b) is not used in the normal operation of the cryocooler 10, and thus can be a dead volume that can reduce a cooling capacity of the cryocooler 10. Therefore, such a dead volume can be reduced and the adverse effect on the cooling capacity of the cryocooler 10 can be reduced by making the flow path cross-sectional area of the gas receiving port 54 smaller than the flow path cross-sectional area of the connection flow path 20b.

[0055] Fig. 5 is a flowchart showing the gas replace-

ment method for the expander 14 of the cryocooler 10 according to the embodiment. Fig. 6 is a schematic view showing the expander 14 of the cryocooler 10 in the gas replacement method according to the embodiment.

[0056] This gas replacement method can be executed while the operation of the cryocooler 10 is stopped, for example, before the normal operation of the cryocooler 10 is resumed after the maintenance work on the cryocooler 10 is performed. In the maintenance work, for example, the expander 14 may be disassembled and reassembled in order to inspect or replace an internal component of the expander 14, such as the displacer assembly 18. In a case where the cryocooler 10 is mounted in a storage container for the cryogenic liquid and is used for recondensing the vaporized cryogenic liquid, when the maintenance work is performed at the site, the environmental atmosphere surrounding the cryocooler 10 may contain the vaporized cryogenic liquid. The gas can be taken into the expander 14 during the maintenance work. In a case where the cryogenic liquid is liquid hydrogen, hydrogen is a flammable gas. Therefore, a residual gas taken into the expander 14 may contain the flammable gas. Resuming the operation of the cryocooler 10 in this state (that is, starting the drive of the expander motor 40) cannot be said to avoid contact between the electrical equipment (that is, the expander motor 40) in the expander 14 and the flammable gas in that an internal volume of the expander 14 is not guaranteed to be filled only with the nonflammable gas.

[0057] The gas replacement method for the expander 14 according to the embodiment includes connecting the nonflammable gas source 60 to the connection flow path 20b (S10), and purging the residual gas in the expander cylinder 16 with the nonflammable gas from the nonflammable gas source 60 while the expander motor 40 is stopped (that is, in a state where energization to the expander motor 40 is stopped) (S20). In addition, in this method, when the purging of the residual gas is completed, the connection between the nonflammable gas source 60 and the connection flow path 20b is released, and the operation of the cryocooler 10 is resumed.

[0058] Here, it is convenient to use the working gas of the cryocooler 10, which is typically, for example, helium gas, as the nonflammable gas. In this way, the internal volume of the expander cylinder 16 can be filled with the working gas of the cryocooler 10 after the purging of the residual gas is completed, and the operation of the cryocooler 10 can be immediately resumed.

[0059] In S10, the nonflammable gas source 60 is connected to the gas receiving port 54 of the connection flow path 20b via a gas replacement pipe 56. Fig. 6 shows an example of the connection between the expander 14 of the cryocooler 10 and the nonflammable gas source 60.

[0060] The gas replacement pipe 56 includes a gas supply valve 57. The gas supply valve 57 is provided in a main pipe 56a of the gas replacement pipe 56. The nonflammable gas source 60 is connected to one end

of the main pipe 56a, a coupling that is attachable to and detachable from the gas receiving port 54 of the expander 14 is provided at the other end of the main pipe 56a, and the main pipe 56a is connected to the gas receiving port 54 by the coupling. By opening the gas supply valve 57, the nonflammable gas is supplied from the nonflammable gas source 60 to the gas receiving port 54, and by closing the gas supply valve 57, the supply of the nonflammable gas is stopped. The nonflammable gas source 60 may be, for example, a gas cylinder filled with the nonflammable gas (for example, an inert gas such as helium gas) at a high pressure.

[0061] In addition, the gas replacement pipe 56 includes a gas outlet port 58 branched from the main pipe 56a. The gas outlet port 58 may be, for example, an on-off valve. By opening the gas outlet port 58, the gas can be exhausted to the outside from the gas replacement pipe 56, and by closing the gas outlet port 58, the gas exhaust from the gas replacement pipe 56 is stopped.

[0062] In S20, the nonflammable gas from the nonflammable gas source 60 is supplied to the expander cylinder 16 from the gas replacement pipe 56 through the gas receiving port 54. In addition, the residual gas in the expander cylinder 16 is exhausted from the gas outlet port 58 of the gas replacement pipe 56. In other words, the residual gas in the expander cylinder 16 is diluted by the supply of the nonflammable gas, and this diluted gas is exhausted from the expander cylinder 16. The supply of the nonflammable gas and the exhaust of the residual gas are performed while the expander motor 40 is stopped.

[0063] The supply of the nonflammable gas and the exhaust of the residual gas may be simultaneously performed. In this case, the gas supply valve 57 and the gas outlet port 58 are simultaneously opened. Alternatively, the supply of the nonflammable gas and the exhaust of the residual gas may be alternately performed. In this case, a supply state in which the gas supply valve 57 is opened and the gas outlet port 58 is closed and an exhaust state in which the gas supply valve 57 is closed and the gas outlet port 58 is opened may be alternately repeated.

[0064] When the cryocooler 10 is stopped, the pressure switching valve 42 can take any of a first state in which the high pressure port 13a is connected to the expander cylinder 16, a second state in which the low pressure port 13b is connected to the expander cylinder 16, and a third state in which the expander cylinder 16 is connected to neither the high pressure port 13a nor the low pressure port 13b. Therefore, in the existing cryocooler in which the gas receiving port 54 is not provided, even when the nonflammable gas source is connected to the high pressure port 13a or the low pressure port 13b and the nonflammable gas is supplied from the port, it is not guaranteed that the purging of the residual gas in the expander cylinder 16 is realized. For example, in the third state, since both the high pressure port 13a and the low pressure port 13b are blocked from the expander cylinder

16 by the pressure switching valve 42, the nonflammable gas is not supplied into the expander cylinder 16.

[0065] On the other hand, according to the embodiment, since the gas receiving port 54 is connected to the connection flow path 20b from the pressure switching valve 42 to the expander cylinder 16, the nonflammable gas source 60 can be connected to the expander cylinder 16 via the gas replacement pipe 56 so as to be parallel to the pressure switching valve 42. Therefore, regardless of the state of the pressure switching valve 42, the residual gas in the expander cylinder 16 can be purged with the nonflammable gas from the nonflammable gas source 60, and the internal volume of the expander cylinder 16 can be reliably replaced with the nonflammable gas (for example, helium gas). Thereafter, when the operation of the cryocooler 10 is resumed, it is guaranteed that the residual gas, which may contain the flammable gas, does not exist in the expander 14 and the expander 14 is filled with the nonflammable gas. Therefore, the cryocooler 10 can be returned from the maintenance work to the normal operation in a state of avoiding the contact between the electrical equipment in the expander 14 and the flammable gas.

[0066] In addition, in S20, the nonflammable gas may be supplied to the expander 14 from the high pressure port 13a and the low pressure port 13b. This may be performed simultaneously with the supply of the nonflammable gas from the gas receiving port 54 to the expander cylinder 16. Alternatively, the supply from the gas receiving port 54, the supply from the high pressure port 13a, and the supply from the low pressure port 13b may be performed in any order, and may be performed in this order. In order to supply the nonflammable gas from the high pressure port 13a to the expander 14, the nonflammable gas source 60 may be connected to the high pressure port 13a by using the above-described gas replacement pipe 56. Similarly, in order to supply the nonflammable gas from the low pressure port 13b to the expander 14, the nonflammable gas source 60 may be connected to the low pressure port 13b by using the above-described gas replacement pipe 56. In this way, the residual gas can be replaced with the nonflammable gas in the internal volume of the expander 14 connected to the high pressure port 13a and the low pressure port 13b.

[0067] Fig. 7 is a schematic view showing the expander 14 of the cryocooler 10 in the gas replacement method according to the embodiment. As shown in the figure, a three-pronged gas replacement pipe 56 may be used. The gas replacement pipe 56 may include a main pipe 56a that is connectable to the nonflammable gas source 60, a first branch pipe 56b that branches from the main pipe 56a and is connectable to the gas receiving port 54 of the expander 14, a second branch pipe 56c that branches from the main pipe 56a and is connectable to the high pressure port 13a of the expander 14, and a third branch pipe 56d that branches from the main pipe 56a and is connectable to the low pressure port 13b of the expander

14. By using such a gas replacement pipe 56, it is possible to supply the nonflammable gas to the expander 14 at once from three ports (the gas receiving port 54, the high pressure port 13a, and the low pressure port 13b) of the expander 14, and to purge the residual gas, which is convenient.

[0068] As in the above embodiment, the gas replacement pipe 56 may include the gas supply valve 57 in the main pipe 56a. The gas replacement pipe 56 may include the gas outlet port 58 branched from the main pipe 56a. Instead of or together with the gas outlet port 58 branched from the main pipe 56a, the gas outlet port 59 may be provided in the expander 14 (for example, the expander housing 20). In addition, the gas replacement pipe 56 may include a pressure sensor 62 that measures the pressure of the gas supplied from the nonflammable gas source 60.

[0069] Fig. 8 is a diagram schematically showing the cryocooler 10 according to the embodiment. Fig. 8 shows an internal structure of a drive unit of the cold head. As shown in the figure, a so-called gas assist type cryocooler 10 is known in which a gas assist chamber 64, which is a hermetic space, is formed between the upper rod 45b of the scotch yoke shaft 45 and the expander housing 20. The gas assist chamber 64 is connected to the high pressure port 13a and the low pressure port 13b via the pressure switching valve 42, similarly to the expander cylinder 16. Therefore, a second connection flow path 20c that connects the pressure switching valve 42 to the gas assist chamber 64 is formed in the expander housing 20. The pressure switching valve 42 is configured to alternately connect the high pressure port 13a and the low pressure port 13b to the gas assist chamber 64. As a result, a differential pressure that periodically acts between the gas assist chamber 64 and the internal volume of the expander housing 20 can assist the axial reciprocation of the scotch yoke shaft 45, that is, the displacer 18.

[0070] The expander 14 including such a gas assist chamber 64 may include a second gas receiving port 55 connected to the second connection flow path 20c in addition to a first gas receiving port 54 connected to the first connection flow path 20b. The gas replacement method according to the embodiment may be applied to the gas assist chamber 64 through the second gas receiving port 55. In this way, the residual gas in the gas assist chamber 64 can be purged with the nonflammable gas. For the gas replacement for the expander 14 including the gas assist chamber 64, a four-pronged gas replacement pipe may be used in which a fourth branch pipe that branches from the main pipe 56a and is connectable to the gas assist chamber 64 of the expander 14 is added to the gas replacement pipe 56 shown in Fig. 7.

[0071] 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-described embodiment, various design changes are possible, various modification exam-

ples are possible, and such modification examples are also within the scope of the present invention. Various characteristics described in relation to one embodiment are also applicable to other embodiments. A new embodiment generated through combination also has the effects of each of the combined embodiments.

[0072] In the above embodiment, a case where the nonflammable gas source 60 is connected to the connection flow path 20b through the gas receiving port 54 by using the gas replacement pipe 56 has been described as an example, but other connection configurations are also possible. In a certain embodiment, the nonflammable gas source 60 may be connected to the expander cylinder 16 instead of the connection flow path 20b. In this case, the gas receiving port 54 may be provided in the expander cylinder 16. The gas replacement pipe 56 may be provided to penetrate a wall of the hermetic container 11 in order to connect the gas receiving port 54 disposed inside the hermetic container 11 to the nonflammable gas source 60 disposed outside the hermetic container 11.

[0073] In the above embodiment, a case where the cryocooler 10 is a two-stage GM cryocooler has been described as an example, but the cryocooler 10 according to the embodiment may be, for example, a single-stage GM cryocooler (providing cryogenic cooling of, for example, 20 K to 80 K), or any other cryocooler including a pressure switching valve in an expander. Even in such a case, the gas replacement method according to the embodiment can be similarly applied.

[0074] 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-described embodiment, various design changes are possible, various modification examples are possible, and such modification examples are also within the scope of the present invention.

Brief Description of the Reference Symbols

[0075]

- 10 cryocooler
- 13a high pressure port
- 13b low pressure port
- 14 expander
- 16 expander cylinder
- 20 expander housing
- 20b connection flow path
- 40 expander motor
- 42 pressure switching valve
- 54 gas receiving port
- 56 gas replacement pipe
- 58 gas outlet port
- 60 nonflammable gas source

Claims

1. A gas replacement method for an expander (14) of a cryocooler (10), the expander (14) including an expander cylinder (16), a pressure switching valve (42) that switches a pressure inside the expander cylinder (16), a connection flow path (20b) from the pressure switching valve (42) to the expander cylinder (16), and an expander motor (40) that drives the pressure switching valve (42), the gas replacement method comprising:
 - connecting a nonflammable gas source (60) to the connection flow path (20b) or the expander cylinder (16); and
 - purging a residual gas in the expander cylinder (16) with a nonflammable gas from the nonflammable gas source (60) while the expander motor (40) is stopped.
2. The gas replacement method according to claim 1,
 - wherein the connection includes connecting the nonflammable gas source (60) to a gas receiving port (54) of the connection flow path (20b) via a gas replacement pipe (56), and
 - the purging includes supplying the nonflammable gas from the nonflammable gas source (60) to the expander cylinder (16) from the gas replacement pipe (56) through the gas receiving port (54) and exhausting the residual gas from the gas replacement pipe (56) or a gas outlet port (58) of the expander (14).
3. The gas replacement method according to claim 2,
 - wherein the expander (14) includes a high pressure port (13a) and a low pressure port (13b) connected to the expander cylinder (16) via the pressure switching valve (42), and
 - the purging includes supplying the nonflammable gas to the expander (14) from the high pressure port (13a) and the low pressure port (13b).
4. The gas replacement method according to any one of claims 1 to 3,
 - wherein the nonflammable gas is a working gas of the cryocooler (10).
5. A cryocooler (10) comprising:
 - an expander cylinder (16);
 - a pressure switching valve (42) that switches a pressure inside the expander cylinder (16);
 - a high pressure port (13a) and a low pressure port (13b) connected to the expander cylinder (16) via the pressure switching valve (42);
 - a connection flow path (20b) from the pressure switching valve (42) to the expander cylinder (16); and
 - a gas receiving port (54) that is different from the high pressure port (13a) and the low pressure port (13b) and is connected to the connection flow path (20b) to allow a gas to flow into the connection flow path (20b).
6. The cryocooler (10) according to claim 5, further comprising:
 - an expander housing (20) that is coupled to the expander cylinder (16) and accommodates the pressure switching valve (42), wherein the gas receiving port (54) is provided in the expander housing (20).
7. The cryocooler (10) according to claim 6, wherein a gas outlet port (58) is provided in the expander housing (20) in addition to the high pressure port (13a), the low pressure port (13b), and the gas receiving port (54).
8. The cryocooler (10) according to claim 5, wherein the gas receiving port (54) has a size different from sizes of the high pressure port (13a) and the low pressure port (13b).
9. The cryocooler (10) according to any one of claims 5 to 8, wherein a flow path cross-sectional area of the gas receiving port (54) is smaller than a flow path cross-sectional area of the connection flow path (20b).
10. A gas replacement pipe (56) used for gas replacement of an expander (14) of a cryocooler (10), the gas replacement pipe (56) comprising:
 - a main pipe (56a) that is connectable to a nonflammable gas source (60);
 - a first branch pipe (56b) that branches from the main pipe (56a) and is connectable to a gas receiving port (54) of the expander (14);
 - a second branch pipe (56c) that branches from the main pipe (56a) and is connectable to a high pressure port (13a) of the expander (14); and
 - a third branch pipe (56d) that branches from the main pipe (56a) and is connectable to a low pressure port (13b) of the expander (14).

FIG. 1

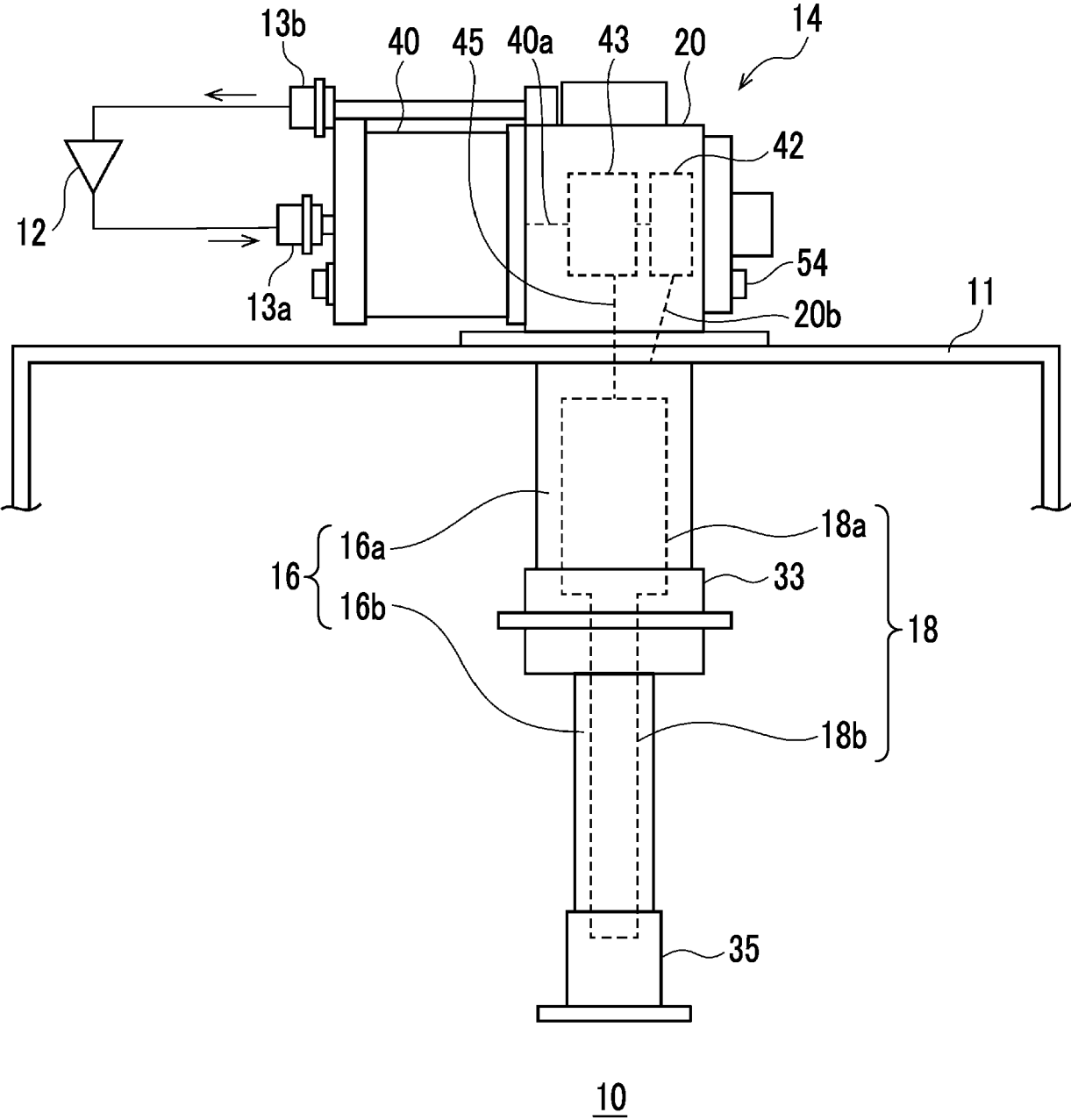


FIG. 2

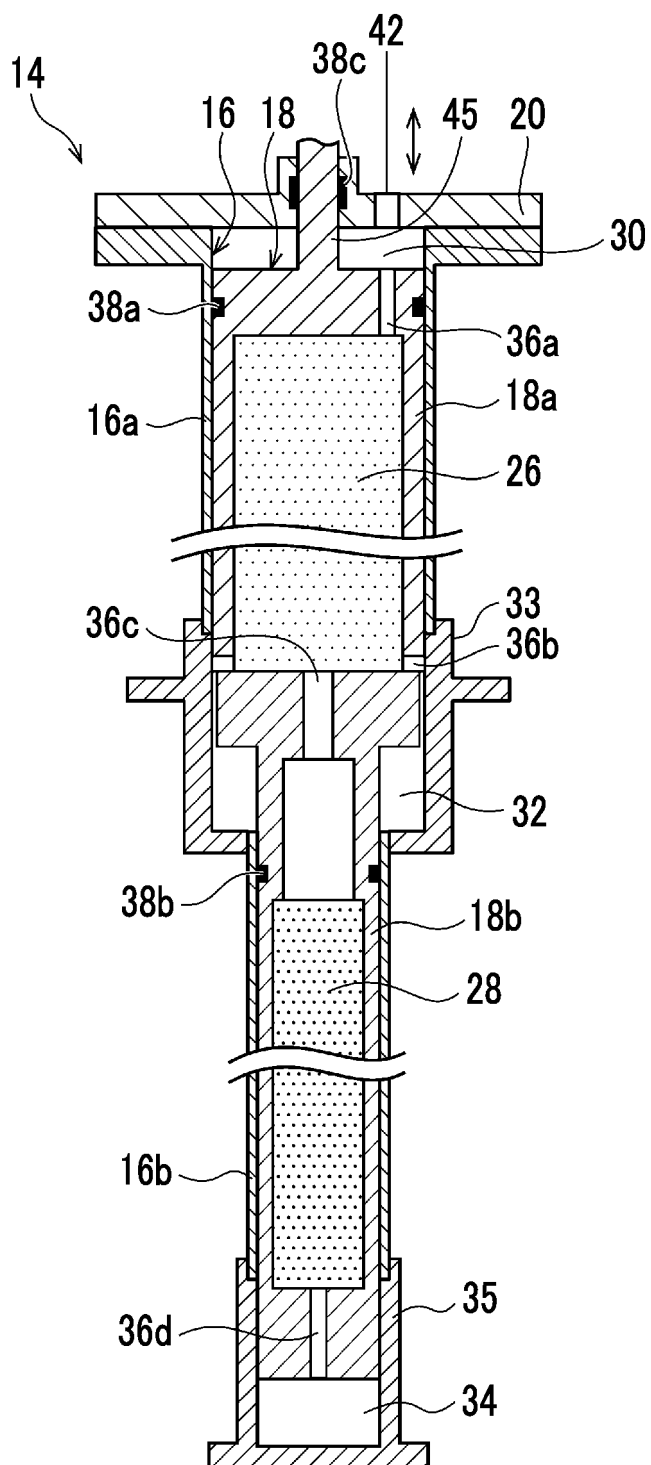


FIG. 3

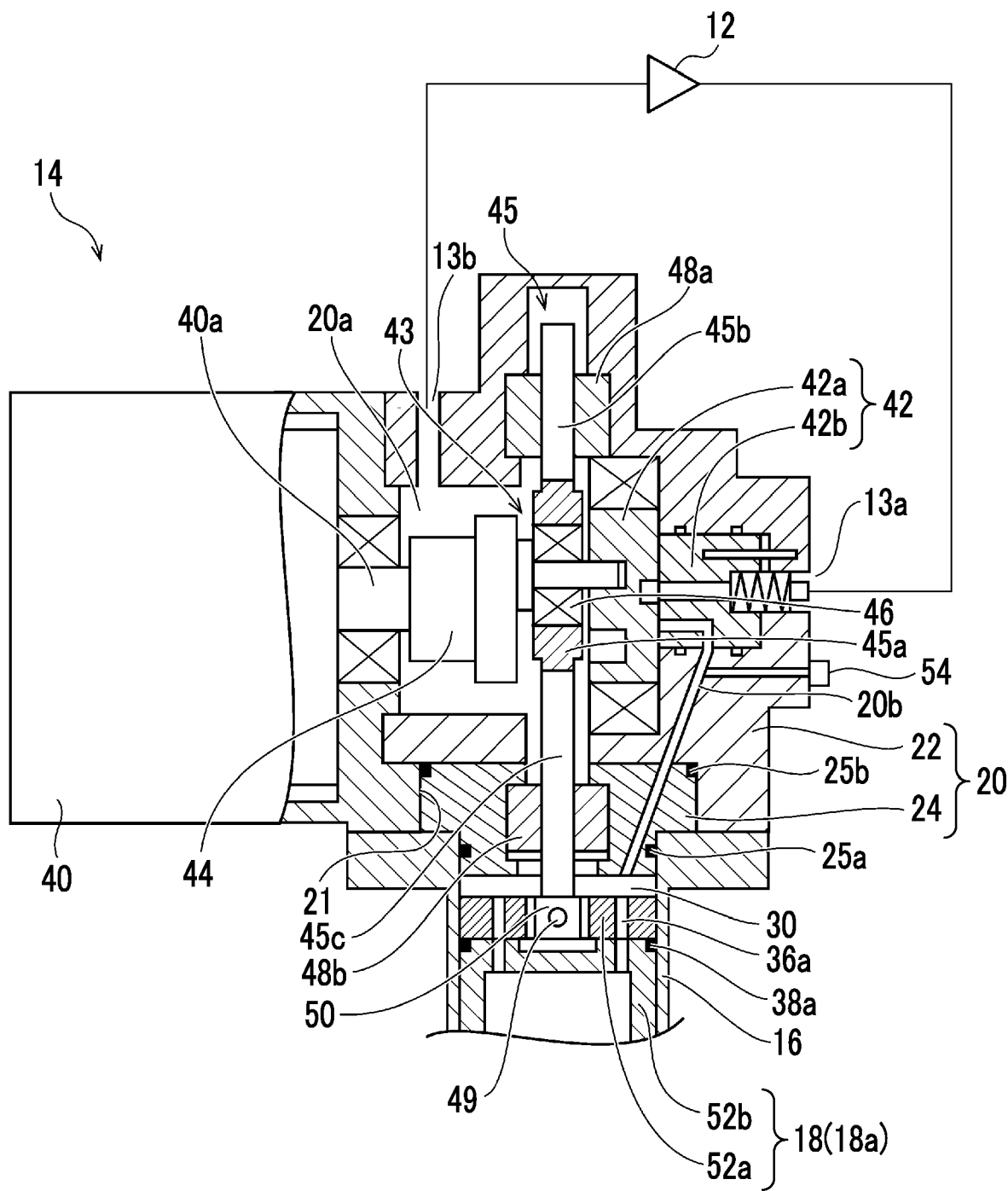


FIG. 4

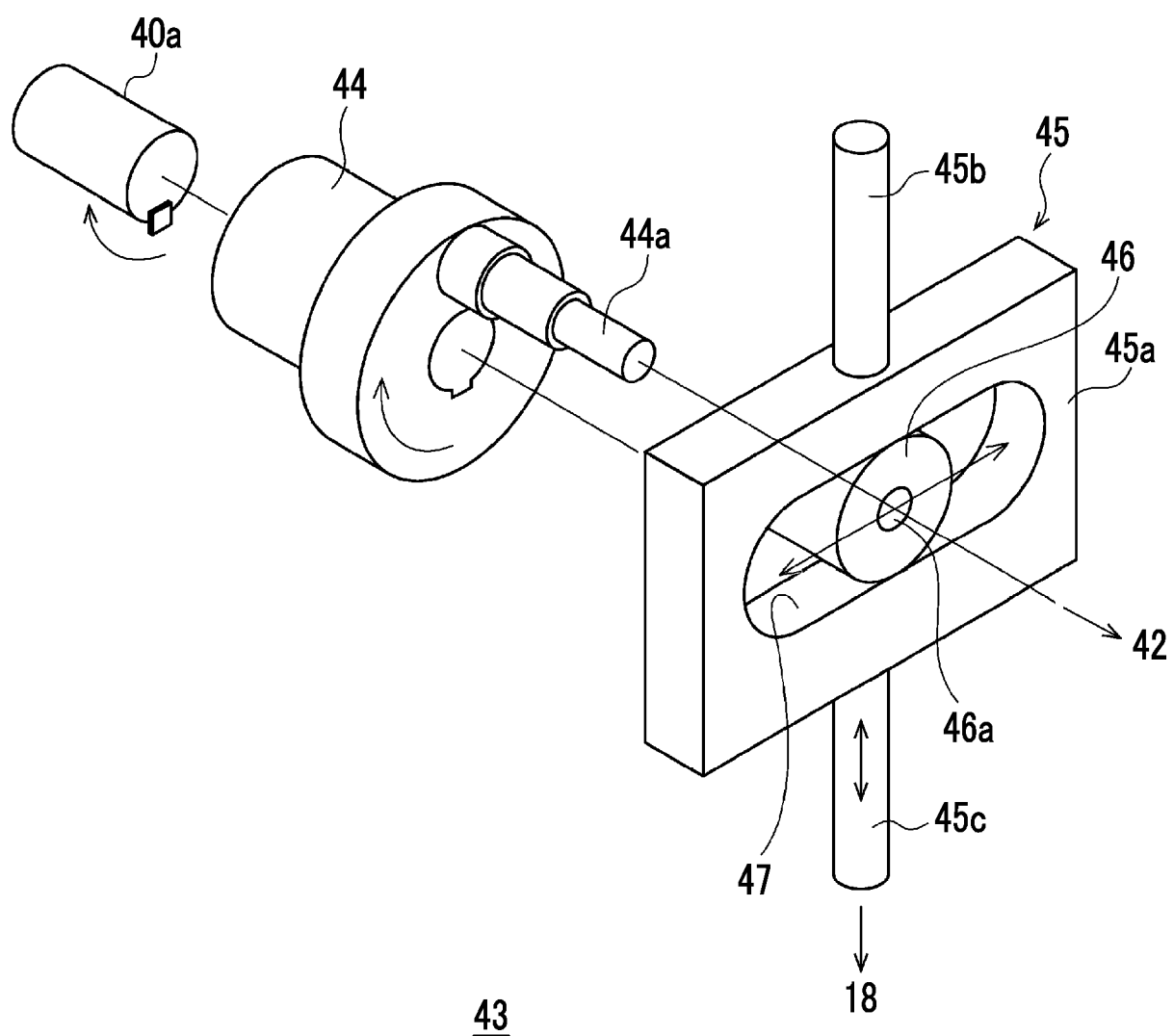


FIG. 5

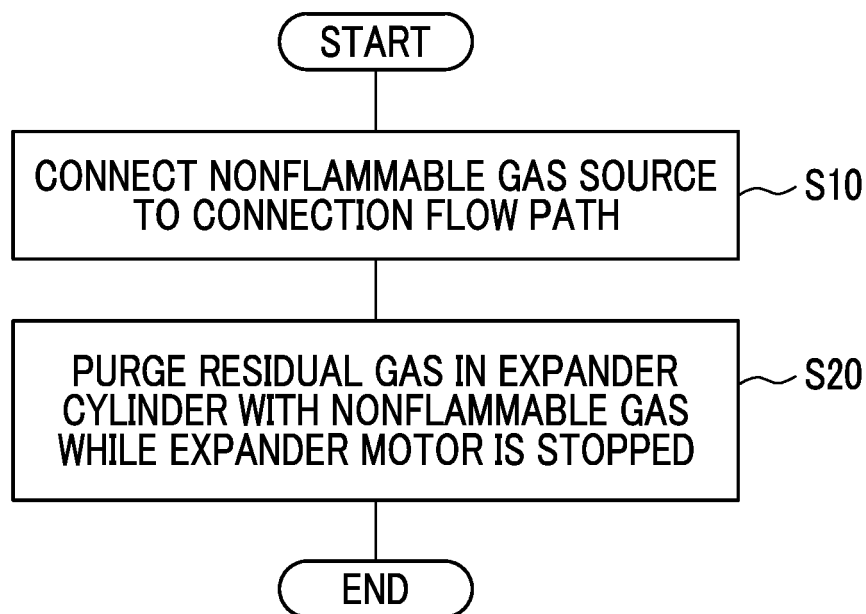


FIG. 6

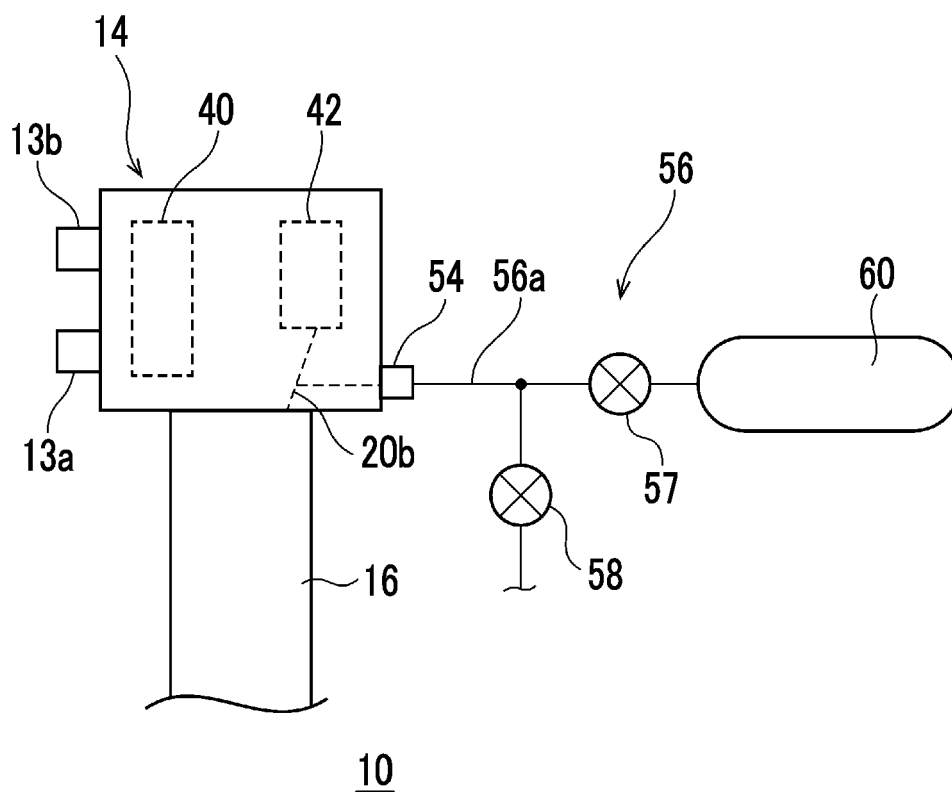


FIG. 7

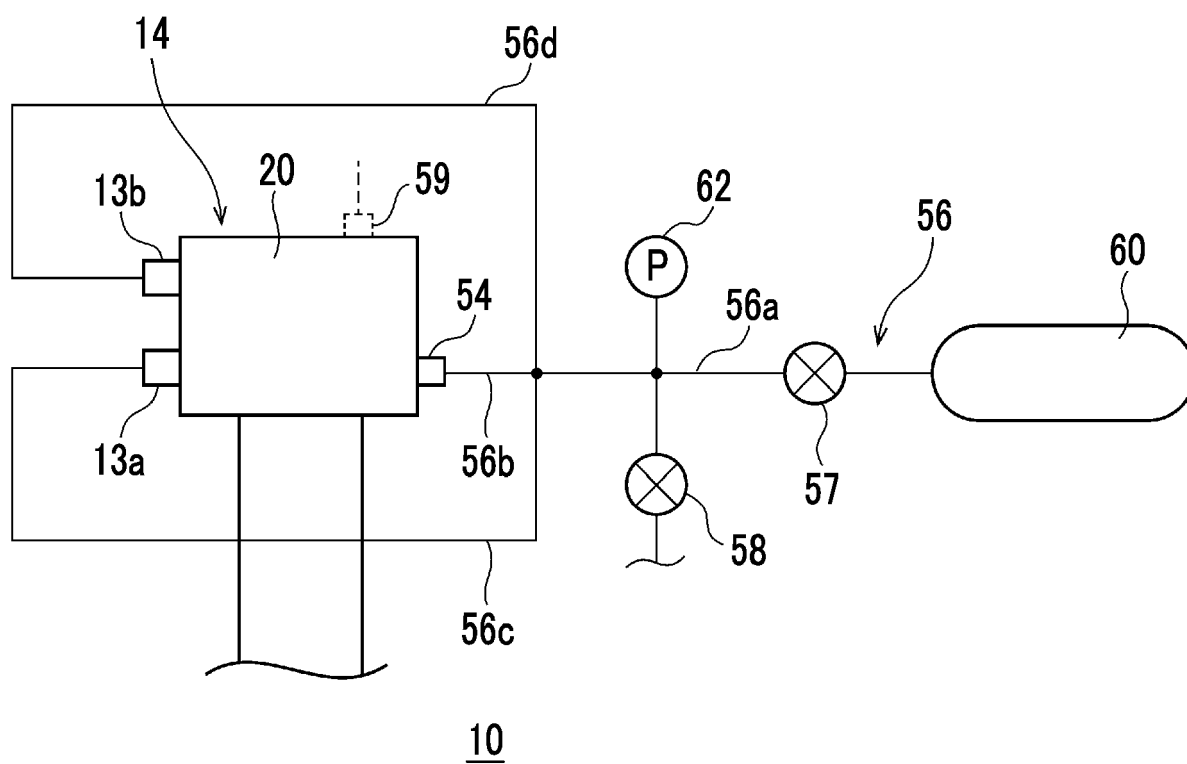
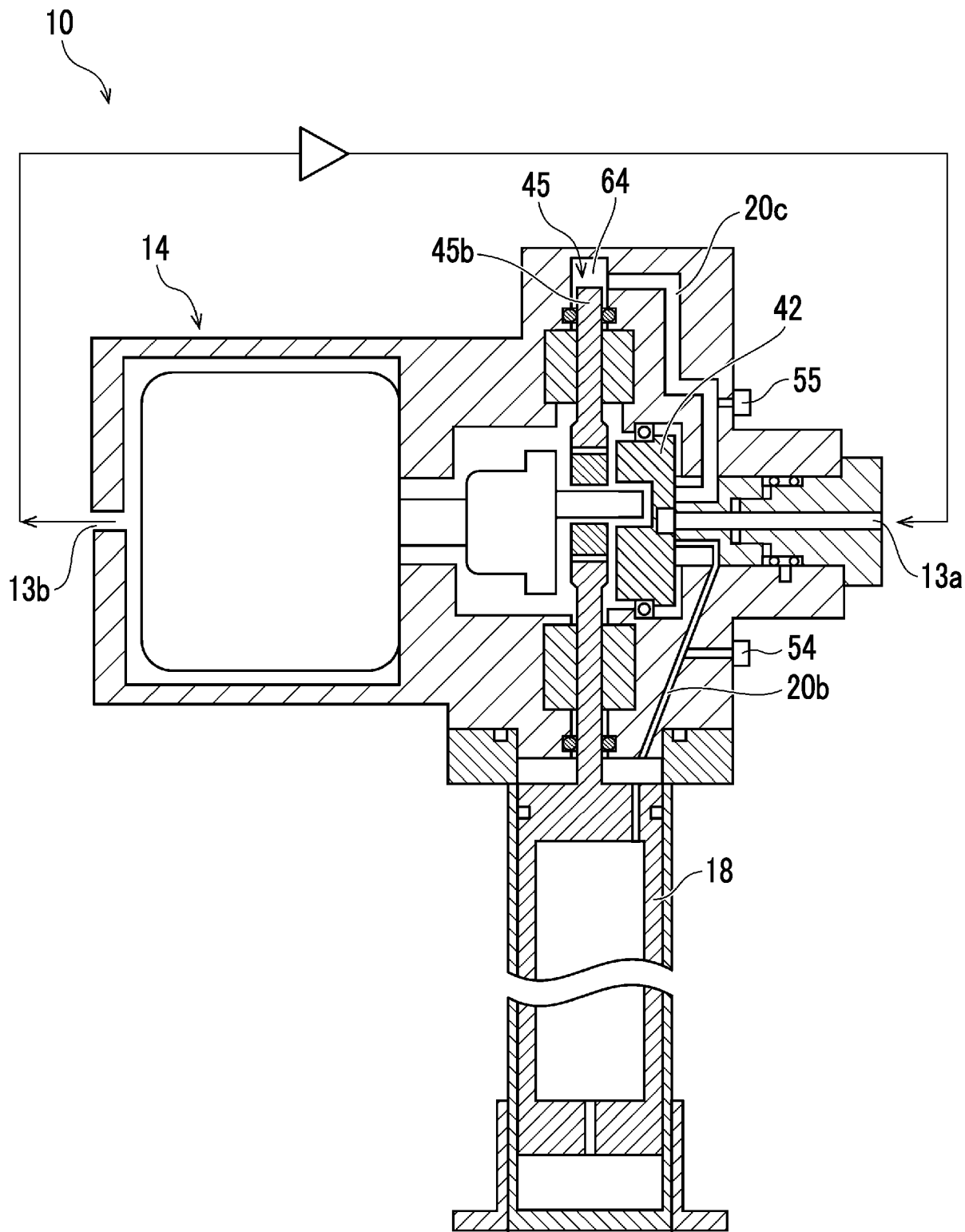


FIG. 8





EUROPEAN SEARCH REPORT

Application Number

EP 24 17 8659

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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A	* & associated description; figures 1-4 *	2-4	F25B45/00
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			F25B
The present search report has been drawn up for all claims			
Place of search		Date of completion of the search	Examiner
Munich		17 October 2024	Gaspar, Ralf
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17-10-2024

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