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(54) LIQUID SUPPLY SYSTEM

(57) There is provided a liquid supply system that can be cooled efficiently. The liquid supply system 10 includes a container 130 having an inlet 131b and an outlet 131c for liquid and provided with a pump chamber P1, P2 inside it, an outlet pipe 320 through which liquid discharged from the outlet 131c is brought to outside, a fluid channel through which liquid flows, the fluid channel leading out of the inlet 131b, passing through the pump chamber P1, P2, and extending vertically downward from the pump chamber P1, P2 to the outlet 131c, and a gas vent pipe 602 connecting a first orifice 601 and a second orifice 604, the first orifice 601 being disposed in the fluid channel and the second orifice 604 being disposed in the fluid channel downstream of the first orifice 601. The second orifice 604 is located at vertically higher level than the first orifice 601.

[Fig. 1]

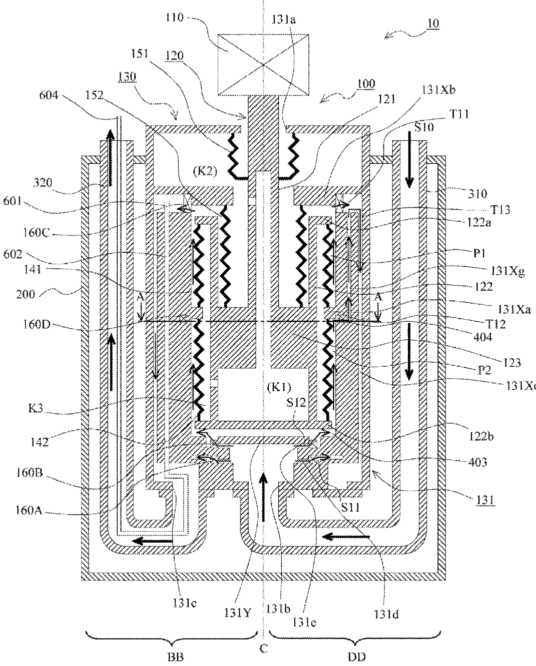

Fig.1

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Description

[Technical Field]

[0001] The present invention relates to a liquid supply system used to supply liquid.

[Background Art]

[0002] A liquid supply system using a bellows pump including pump chambers formed by bellows is known as a system used to cause a liquid to flow in a circulation fluid passage (see Patent Literature 1 in the citation list below). This system has two pump chambers arranged one above the other along the vertical direction. The bellows that forms each pump chamber is fixedly attached to a shaft that is driven by an actuator to move upward and downward. The bellows expands and contracts with the upward and downward motion of the shaft.

[0003] The pump apparatus is housed in a vacuum container for heat insulation, above which the actuator is disposed. For the purpose of helping heat insulation, an inlet pipe for supplying liquid to the pump apparatus from outside and an outlet pipe for discharging liquid from the pump apparatus to outside may be connected to the pump apparatus at locations as remote as possible from the outside air. For this reason, the inlet pipe and the outlet pipe are arranged to enter into the vacuum container from above, extend to a location lower than the pump apparatus, then turn in a U-shape, and be connected to openings provided on the bottom of the pump apparatus. This shape of the pipes connected to the pump apparatus provides insulation against heat coming from outside. The bellows pump structured as above can be suitably used for the purpose of supplying a cryogenic liquid such as liquid nitrogen or liquid helium to an apparatus to be cooled, such as a superconducting device.

[0004] When a bellows pump assembled or maintained in an ordinary temperature environment is used to supply low temperature liquid, it is necessary to cool the components of the pump apparatus from the ordinary temperature to the temperature of the low temperature liquid. If the temperature of the components is high, the low temperature liquid will evaporate in a bellows chamber to be in a mixed state of gas and liquid, impairing the operation of the pump. One method of cooling the pump apparatus is causing low temperature liquid to flow in the pump apparatus to cause heat exchange between the components of the pump apparatus and the low temperature liquid, thereby gradually lowering the temperature of the components. In the process of this method, the low temperature liquid flowing into the pump apparatus from its bottom fills the interior of the pump chamber; specifically the liquid firstly fills the lower bellows pump chamber and then the upper bellows pump chamber, as the level of the low temperature liquid increases. However, cooling the bellows pump to an operable temperature by this cooling method takes a long time.

[0005] One reason for this is that when the level of the low temperature liquid in the pump apparatus is low, the contact area of the components of the pump and the low temperature liquid is small, and the efficiency of cooling is low in the early stage of the cooling process. Another reason is that when the temperature of the components of the pump is high, the low temperature liquid evaporates to create gas staying in the pump chambers, which blocks the entrance of the low temperature liquid. Moreover, since the two bellows pump chambers are arranged one (the first pump chamber) above the other (the second pump chamber), the liquid supplied into the pump apparatus flows out through the discharge port of the second (or lower) pump chamber, and the liquid level is slow to rise above the height of the discharge port of the second pump chamber. Therefore, if the first pump chamber is located above the discharge port of the second pump chamber, cooling of the first pump chamber takes a long time. Moreover, the components of the pump are made of a metal material(s) having high rigidity in order to allow high discharge pressure, and when low temperature liquid comes in contact with the surface of the metal, which has high heat conductivity, the surface of the metal is covered with gas produced by evaporation of the low temperature liquid. This phenomenon is called film boiling. The gas layer produced on the metal surface in this way functions as a heat insulation layer to block heat transfer between the low temperature liquid and the components of the pump.

[Citation List]

[Patent Literature]

[0006] [PTL 1]
WO 2016/006648

[Summary of Invention]

[Technical Problem]

[0007] An object of the present invention is to provide a liquid supply system that can be cooled efficiently.

[Solution to Problem]

[0008] To achieve the above object, the following features are adopted.

[0009] An aspect of the present invention is a liquid supply system comprises:

a container having an inlet and an outlet for liquid and provided with a pump chamber inside it;
an outlet pipe through which liquid discharged from the outlet is brought to outside;
a fluid channel through which liquid flows, the fluid channel leading out of the inlet, passing through the pump chamber, and extending vertically downward

from the pump chamber to the outlet; and

a gas vent pipe having a first orifice disposed in the fluid channel and a second orifice disposed in the fluid channel downstream of the first orifice,

wherein the second orifice is located at vertically higher level than the first orifice.

[0010] The liquid supply system has a fluid channel in which liquid flows vertically downward from the pump chamber. Liquid staying in a lower portion in such system may prevent gas generated in the container from being discharged from the container. Such a situation may occur, for example, when liquid supplied to the liquid supply system for the purpose of cooling evaporates in the container during a cooling process for making the liquid supply system in an ordinary temperature environment operable for the purpose of circulation of a cryogenic liquid.

[0011] When gas is present in the container of the liquid supply system, namely when gas is present in the fluid passage passing through the pump chamber, the gas can be discharged out of the container through the gas vent pipe. Thus the system can prevent gas from staying in the container. If gas stays in the container, the gas may hamper feeding of low temperature liquid during a cooling process of the system, leading to an increase in the time taken to cool the system. The present invention can prevent gas from staying in the container, thus the time needed for cooling can be reduced. Hence, the liquid supply system can be cooled efficiently by supplying low temperature liquid into it. Thus, the present invention can suppress an increase in the man-hour in setting-up and maintenance of the system through reducing the time taken to cool the liquid supply system in an ordinary temperature environment. Moreover, the consumption of low temperature liquid in the cooling process can be reduced.

[0012] The second orifice may be disposed in the outlet pipe.

[0013] This enables gas staying in the upper portion of the pump chamber to be discharged to the outlet pipe. Thus, if the outlet pipe or a liquid supply target is provided with a gas vent system, it can be shared, This reduces portions in which liquid comes in contact with the outside environment from a viewpoint of the whole system, thereby heat exchange can be reduced, leading to reduction in the consumption of low temperature liquid.

[0014] Another aspect of the present invention is a liquid supply system having bellows pumps. Specifically, the liquid supply system may comprise:

a shaft member that moves vertically upward and downward in the container; and

a first bellows and a second bellows disposed one above the other along the vertical direction, each of which expands and contracts with upward and downward motion of the shaft member;

wherein the pump chamber may include a first pump chamber formed by a space surrounding the outer circumference of the first bellows and a second pump chamber formed by a space surrounding the outer circumference of the second bellows,

the fluid channel may include a first fluid channel through which liquid flows from the inlet to the outlet via the first pump chamber and a second fluid channel through which liquid flows from the inlet to the outlet via the second pump chamber, and

the gas vent pipe may be provided in at least one of the first and second fluid channels.

[0015] Although gas tends to stay in the upper pump chamber in this liquid supply system, the gas vent pipe provided in at least one of the first and second fluid channels can easily discharge the gas staying in the fluid channel passing through the upper pump chamber to the outside. Thus, the first and second pump chambers can be cooled efficiently by supplying low temperature liquid into them.

[0016] The first pump chamber may be disposed above the second pump chamber, and the first orifice may be located above the outlet of the first pump chamber.

[0017] Although gas tends to stay in a region near the outlet of the upper first pump chamber in this liquid supply system, the first orifice of the gas vent pipe located above the outlet of the first pump chamber enables gas in the container to be easily discharged.

[0018] The above-described features may be adopted in any feasible combination.

[Advantageous Effects of Invention]

[0019] The liquid supply system according to the present invention can be cooled efficiently.

[Brief Description of Drawings]

[0020]

[Fig. 1]
Fig. 1 is a diagram illustrating the general configuration of a liquid supply system in an embodiment.
[Fig. 2]
Fig. 2 is a diagram illustrating the general configuration of the liquid supply system in the embodiment.
[Fig. 3]
Fig. 3 is a schematic cross sectional view of the liquid supply system in the embodiment.

[Description of Embodiments]

[0021] In the following, modes for carrying out the present invention will be described specifically on the basis of a specific embodiment with reference to the drawings. The dimensions, materials, shapes, relative arrangements, and other features of the components that will be described in connection with the embodiment are not intended to limit the technical scope of the present invention only to them, unless particularly stated.

Embodiment

[0022] A liquid supply system in an embodiment will be described with reference to Figs. 1 to 3. The liquid supply system is suitably used for the purpose of, for example, maintaining a superconducting device in a ultra-low temperature state. Superconducting devices require perpetual cooling of components such as superconducting coils. Thus, a cooled device including a superconducting coil and other components is perpetually cooled by continuous supply of a cryogenic liquid (such as liquid nitrogen or liquid helium) to the cooled device. Specifically, a circulation fluid passage passing through the cooled device is provided, and the liquid supply system is connected to the circulation fluid passage to cause the cryogenic liquid to circulate, thereby enabling perpetual cooling of the device to be cooled.

<Overall Configuration of the Liquid Supply System>

[0023] Figs. 1 and 2 are schematic diagrams illustrating the overall configuration of the liquid supply system, where the overall configuration of the liquid supply system is illustrated in cross sections. Figs. 1 and 2 illustrate the general configuration of the liquid supply system in cross sections in planes containing the center axis. In each of Figs. 1 and 2, cross sections of the cylindrical liquid supply system in different circumferential phases are illustrated in a single drawing. Specifically, the left side of the center axis in Figs. 1 and 2 illustrates a cross section in a phase in which a gas vent pipe is clearly seen (the phase indicated by line B-B in Fig. 3), the right side of the center axis in Fig. 1 illustrates a cross section in a phase in which a second fluid passage passing through a second pump chamber is clearly seen (the phase indicated by line D-D in Fig. 3), and the right side of the center axis in Fig. 2 illustrates a cross section in a phase in which a first fluid passage passing through a first pump chamber is clearly seen (the phase indicated by line C-C in Fig. 3).

[0024] The liquid supply system 10 includes a main unit of the liquid supply system (which will be referred to as the "main system unit 100" hereinafter), a vacuum container 200 in which the main system unit 100 is housed, and pipes (including an inlet pipe 310 and an outlet pipe 320). The inlet pipe 310 and the outlet pipe 320 both extend into the interior of the vacuum container 200 from outside the vacuum container 200 and are connected to the main system unit 100. The interior of the vacuum container 200 is a hermetically sealed space. The interior space of the vacuum container 200 outside the main system unit 100, the inlet pipe 310, and the outlet pipe 320 is kept in a vacuum state. Thus, this space provides heat insulation. The liquid supply system 10 is normally installed on a horizontal surface. In the installed state, the upward direction of the liquid supply system 10 in Figs. 1 and 2 is the vertically upward direction and the downward direction in Figs. 1 and 2 is the vertically downward direction.

[0025] The main system unit 100 includes a linear actuator 110 serving as a driving source, a shaft member 120 that is moved in vertically upward and downward directions by the linear actuator 110, and a container 130. The linear actuator 110 is fixed on something suitable, which may be the container 130 or something that is not shown in the drawings. The container 130 includes a casing 131. The shaft member 120 extends from outside the container 130 into the inside through an opening 131a provided in the ceiling portion of the casing 131. The casing 131 has an inlet 131b and an outlet 131c for liquid on its bottom. The inlet pipe 310 is connected to the inlet 131b and the outlet pipe 320 is connected to the outlet 131c.

[0026] Inside the casing 131 are provided a plurality of structural components that compart the interior space into a plurality of spaces, which constitute a plurality of pump chambers, passages for liquid, and vacuum chambers providing heat insulation. In the following, the structure inside the casing 131 will be described in further detail.

[0027] The shaft member 120 has a main shaft portion 121 having a cavity in it, a cylindrical portion 122 surrounding the outer circumference of the main shaft portion 121, and a connecting portion 123 that connects the main shaft portion 121 and the cylindrical portion 122. The cylindrical portion 122 is provided with an upper outward flange 122a at its upper end and a lower outward flange 122b at its lower end.

[0028] The casing 131 has a substantially cylindrical body portion 131X and a bottom plate 131Y. The body portion 131X has a first inward flange 131Xa provided near its vertical center and a second inward flange 131Xb provided on its upper portion.

[0029] Inside the body portion 131X, there are a plurality of first fluid passages 131Xc that extend in the axial direction below the first inward flange 131Xa and are spaced apart from one another along the circumferential direction. The first fluid passages 131Xc connect a fluid passage 131d and an inlet 401 of a first pump chamber P1. Inside the body portion 131X, there also are a plurality of third fluid passages 131Xg that extend in the axial direction above the first inward flange 131Xa and are spaced apart from one another along the circumferential direction. The third fluid passages 131Xg are joined with an outlet 404 of a second pump chamber P2. Inside the body portion 131X, there also is a second fluid passage 131Xd, which is an axially extending cylindrical space provided radially outside the region in which the first fluid passages 131Xc are provided. The second fluid passage 131Xd is joined with an outlet 402 of the first pump chamber P1 and extends to the level of the outlet 402 of the first pump chamber P1. The bottom portion of the casing 131 is provided with the fluid passage 131d that extends circumferentially and radially outwardly to join to the first fluid passages 131Xc. Furthermore, the bottom plate 131Y of the casing 131 is provided with a fluid passage 131e that extends circumferentially and radially outwardly. The fluid passage 131e is joined with an inlet 403 of the second pump chamber P2. These fluid passages 131d and 131e extend uniformly all along the circumferential direction to allow liquid to flow radially outwardly in all directions, namely 360 degrees about the center axis. The fluid passage 131d, the first fluid passages 131Xc, and the second fluid passage 131Xd constitute a fluid channel passing through the first pump chamber P1. The fluid passage 131e, the third fluid passages 131Xg, and the second fluid passage 131Xd constitute a fluid channel passing through the second pump chamber P2.

[0030] Inside the container 130, there are provided a first bellows 141 and a second bellows 142, which expand and contract with the up and down motion of the shaft member 120. The first bellows 141 and the second bellows 142 are arranged one above the other along the vertical direction. The upper end of the first bellows 141 is fixedly attached to the upper outward flange 122a of the cylindrical portion 122 of the shaft member 120 and the lower end of the first bellows 141 is fixedly attached to the first inward flange 131Xa of the casing 131. The upper end of the second bellows 142 is fixedly attached to the first inward flange 131Xa of the casing 131 and the lower end of the second bellows 142 is fixedly attached to the lower outward flange 122b of the cylindrical portion 122 of the shaft member 120. The space surrounding the outer circumference of the first bellows 141 forms the first pump chamber P1, and the space surrounding the outer circumference of the second bellows 142 forms the second pump chamber P2.

[0031] Inside the container 130, there also are provided a third bellows 151 and a fourth bellows 152, which expand and contract with the up and down motion of the shaft member 120. The upper end of the third bellows 151 is fixedly attached to the ceiling portion of the casing 131 and the lower end of the third bellows 151 is fixedly attached to the shaft member 120. Thus, the opening 131a of the casing 131 is closed. The upper end of the fourth bellows 152 is fixedly attached to the second inward flange 131Xb provided on the casing 131 and the lower end of the fourth bellows 152 is fixedly attached to the connecting portion 123 of the shaft member 120. A first space K1 is formed by the cavity in the main shaft portion 121 of the shaft member 120. A second space K2 is formed outside the third bellows 151 and inside the fourth bellows 152. A third space K3 is formed inside the first bellows 141 and the second bellows 142 and outside the cylindrical portion 122. The first space K1, the second space K2, and the third space K3 are in communication with each other. The space constituted by the first to third spaces K1, K2, and K3 is hermetically sealed. This space is kept in a vacuum condition to provide heat insulation.

[0032] There are four check valves 160 including a first check valve 160A, a second check valve 160B, a third check valve 160C, and a fourth check valve 160D, which are provided at different locations inside the container 130. The first check valve 160A and the second check valve 160B are disposed on the opposite side (lower side) of the linear actuator 110 with respect to the first pump chamber P1 and the second pump chamber P2. The third check valve 160C and the fourth check valve 160D are arranged above the first check valve 160A and the second check valve 160B.

[0033] The first check valve 160A and the third check valve 160C are provided in the fluid channel passing through the first pump chamber P1. The first check valve 160A and the third check valve 160C block backflow of liquid pumped by the pumping effect of the first pump chamber P1. Specifically, the first check valve 160A is provided on the upstream side of the first pump chamber P1 and the third check valve 160C is provided on the downstream side of the first pump chamber P1. The first check valve 160A is provided in the fluid passage 131d provided in the bottom portion of the casing 131. The third check valve 160C is provided in the fluid passage formed in the vicinity of the second inward flange 131Xb provided on the casing 131. Specifically, the third check valve 160C is provided in the upper portion of the first pump chamber P1. The upper portion of the pump chamber refers to the portion of the region that functions as the pump chamber that is higher than its vertical center. In other words, the third check valve 160C is provided at a position at which it allows gas in the first pump chamber P1 to be discharged from it and allows the first pump chamber P1 to be filled with liquid.

[0034] The second check valve 160B and the fourth check valve 160D are provided in the fluid channel passing through the second pump chamber P2. The second check valve 160B and the fourth check valve 160D block backflow of liquid pumped by the pumping effect of the second pump chamber P2. Specifically, the second check valve 160B is provided on the upstream side of the second pump chamber P2 and the fourth check valve 160D is provided on the downstream side of the second pump chamber P2. The second check valve 160B is provided in the fluid passage 131e provided in the bottom plate 131Y of the casing 131. The fourth check valve 160D is provided in the fluid passage formed in the vicinity of the first inward flange 131Xa of the casing 131. Specifically, the fourth check valve 160D is provided in the upper portion of the second pump chamber P2. The upper portion of the pump chamber refers to the portion of the region that functions as the pump chamber that is higher than its vertical center. In other words, the fourth check valve 160D is provided at a position at which it allows gas in the second pump chamber P2 to be discharged from it and allows the second pump chamber P2 to be filled with liquid. The exit from the third fluid passage 131Xg is provided at a location of the same height as the location at which liquid flows out of the third check valve 160C.

<Description of the Overall Operation of the Liquid Supply System>

[0035] The overall operation of the liquid supply system will be described. When the shaft member 120 is lowered by the linear actuator 110, the first bellows 141 contracts and the second bellows 142 expands. Consequently, the fluid pressure in the first pump chamber P1 decreases. Then, the first check valve 160A is opened and the third check valve 160C is closed. In consequence, liquid supplied from outside the liquid supply system 10 through the inlet pipe 310 (indicated by arrow S10) is taken into the interior of the container 130 through the inlet 131b and passes through the first check valve 160A (indicated by arrow S11). Then, the liquid having passed through the first check valve 160A is pumped into the first pump chamber P1 through the first fluid passages 131Xc in the body portion 131X of the casing 131. On the other hand, the fluid pressure in the second pump chamber P2 increases. Then, the second check valve 160B is closed and the fourth check valve 160D is opened. In consequence, the liquid in the second pump chamber P2 is pumped into the third fluid passages 131Xg and the second fluid passage 131Xd through the fourth check valve 160D (see arrow T12). Then, the liquid passes through the outlet 131c and is brought to the outside of the liquid supply system 10 through the outlet pipe 320.

[0036] When the shaft member 120 is raised by the linear actuator 110, the first bellows 141 expands and the second bellows 142 contracts. Consequently, the fluid pressure in the first pump chamber P1 increases. Then, the first check valve 160A is closed, and the third check valve 160C is opened. In consequence, the liquid in the first pump chamber P1 is pumped into the second fluid passage 131Xd provided in the body portion 131X through the third check valve 160C (indicated by arrow T11). Then, the liquid passes through the outlet 131c and is brought to the outside of the liquid supply system 10 through the outlet pipe 320. On the other hand, the fluid pressure in the second pump chamber P2 decreases. Then, the second check valve 160B is opened and the fourth check valve 160D is closed. In consequence, liquid supplied from outside the liquid supply system 10 through the inlet pipe 310 (indicated by arrow S10) is taken into the interior of the container 130 through the inlet 131b and passes through the second check valve 160B (indicated by arrow S12). Then, the liquid having passed through the second check valve 160B is pumped into the second pump chamber P2.

[0037] As above, the liquid supply system 10 can cause liquid to flow from the inlet pipe 310 to the outlet pipe 320 both when the shaft member 120 moves downward and when the shaft member 120 moves upward. Hence, the phenomenon called pulsation can be reduced.

[0038] The fluid passage through which the cryogenic liquid flows from the inlet 131b to the outlet 131c via the first pump chamber P1 will be hereinafter referred to as a first fluid channel. The fluid passage through which the cryogenic liquid flows from the inlet 131b to the outlet 131c via the second pump chamber P2 will be hereinafter referred to as a second fluid channel. The first fluid channel is the passage of the cryogenic liquid that enters from the inlet 130b, and then flows in the direction indicated by arrow S11, and then flows in the direction indicated by arrow T11, and then flows to the outlet 131c. The second fluid channel is the passage of the cryogenic liquid that enters from the inlet 131b, and then flows in the direction indicated by arrow S12, and then flows in the directions indicated by arrows T12 and T13, and then flows to the outlet 131c.

[0039] The height of the location at which the direction of the liquid flow in the first fluid channel changes from the vertically upward direction to the downward direction (see arrow T11) and the height of the location at which the direction of the liquid flow in the second fluid channel changes from the vertically upward direction to the downward direction (see arrow T13) are the same.

[0040] The flow of liquid in the liquid supply system 10 during its operation is summarized as below. When the shaft member 120 moves downward, the liquid flows in the first fluid channel upstream of the first pump chamber P1 but does not flow in the first fluid channel downstream of the first pump chamber P1. The liquid flows in the second fluid channel downstream of the second pump chamber P2 but does not flow in the second fluid channel upstream of the second pump chamber P2. When the shaft member 120 moves upward, the liquid flows in the first fluid channel downstream of the first pump chamber P1 but does not flow in the first fluid channel upstream of the first pump chamber P1. The liquid flows in the second fluid channel upstream of the second pump chamber P2 but does not flow in the second fluid channel downstream of the second pump chamber P2.

<Gas Vent Pipe>

[0041] A gas vent pipe provided in the liquid supply system will be described with reference to Figs. 1 to 3. Fig. 3 schematically illustrates the cross section taken along line A-A in Figs. 1 and 2.

[0042] As illustrated in Fig. 3, radially outside the second pump chamber P2, gas vent pipes 602, the third fluid passages 131Xg connected to the outlet 404 of the second pump chamber P2, the first fluid passages 131Xc connected to the inlet 401 of the first pump chamber P1, and bolts 603 that fasten components together are disposed at uniform circumferential intervals.

[0043] As illustrated in Figs. 1 and 2, the gas vent pipe 602 has a first orifice 601 disposed in the space near the check valve 160C provided at the outlet 402 of the first pump chamber P1 and extends in the container 130 vertically downward to reach the outlet 131C. The gas vent pipe 602 passes through the outlet 131c, extends inside the outlet pipe 320, and has a second orifice 604 located at a position higher than the first orifice 601, as illustrated in Fig. 1. Thus, gas staying in the vicinity of the outlet in the fluid channel passing through the first pump chamber P1 is discharged through the gas vent pipe 602 to the outside at a position higher than the first orifice 601. The gas vent pipe 602 may be connected to a gas discharge system outside the liquid supply system 10. Thus, gas is efficiently discharged out of the container 130.

<Cooling of the Liquid Supply System>

[0044] When the liquid supply system 10 is used for circulation of a cryogenic liquid such as liquid nitrogen or liquid helium, it is necessary, before operation, to cool the liquid supply system 10 in an ordinary temperature environment to a temperature as low as a low temperature liquid used as a working liquid. The liquid used to cool the system is the same as the low temperature liquid that is caused to flow by the liquid supply system when it is operating. The liquid used to cool the system may be different from the low temperature liquid that is caused to flow by the liquid supply system when it is operating.

[0045] Cooling of the system is performed by supplying low temperature liquid through the inlet pipe 310 to let heat exchange between the components of the liquid supply system 10 including the casing 131 and the low temperature liquid occur thereby gradually lowering the temperature of the components. Since the inlet 131b and the outlet 131c are provided on the bottom of the container 100, the low temperature liquid supplied in the cooling process gradually fills the interior of the system, as the level of the low temperature liquid rises. Specifically, the low temperature liquid fills the second pump chamber P2 firstly and then the first pump chamber P1. As the level of the low temperature liquid rises, components that exchange heat with the low temperature liquid increase. Thus, cooling progresses from the lower portion to the upper portion of the system.

<Advantages of the Liquid Supply System>

[0046] When cooling of the liquid supply system 10 is performed before using it for the purpose of circulation of low temperature liquid, the low temperature liquid evaporates in the container in the early stage of the cooling process, thus the gas generated stays in the upper portion of the container to create a mixed state of gas and liquid. The gas firstly stays in the space near the outlet 402 of the first pump chamber P1. The gas may stay even in the first pump chamber P1 and the second pump chamber P2 when its amount increases. The gas may block the entrance of the low temperature liquid supplied through the inlet pipe 310 in order to cool the system, making it harder for the level of the low temperature liquid in the container to rise. This may cause the cooling of the system not to progress efficiently because the cooling of the system performed by supplying the low temperature liquid progresses as a result of heat exchange occurring between the components of the system and the low temperature liquid that come in contact with each other.

[0047] The liquid supply system 10 can discharge the gas staying in the container to the outside through the gas vent pipes 602. Thus, the liquid supply system 10 can eliminate or reduce the gas staying in the upper portion of the container in the early stage of the cooling process so that the entrance of the low temperature liquid for cooling into the container tends not to be blocked. In consequence, the rise of the level of the low temperature liquid in the container is not prevented or slowed down, and the heat exchange between the low temperature liquid and the components of the system progresses with improved efficiency. Thus, the cooling of the liquid supply system 10 by supplying the low temperature liquid can be carried out efficiently. This can lead to a reduction in time taken to cool the liquid supply system in an ordinary temperature environment in order to make it operable, thereby preventing an increase in the man-hour in setting-up and maintenance of the system. Moreover, the consumption of low temperature liquid in the cooling process can be reduced.

Others

[0048] While in the embodiment, the first orifice 601 of the gas vent pipe 602 is arranged in the space near the outlet 402 of the first pump chamber P1, the location of the orifice of the gas vent pipe may be set appropriately depending on the structure of the liquid supply system. The orifice of the gas vent pipe may be located at or in the vicinity of the vertically highest location in the fluid channel passing through the pump chamber. This ensures discharging of the gas remaining in the upper portion of the container and prevents the liquid in the container to flow into the gas vent pipe, even when the liquid level in the container rises. Since the gas vent pipe is disposed inside the outlet pipe 320, the gas vent pipe may be provided with heat insulation that prevents or reduces the influence of the temperature of the liquid flowing in the outlet pipe 320 on interior space of the gas vent pipe, thereby preventing the gas flowing into the gas vent pipe from being liquefied in it. The above-described advantages of the embodiment can be enjoyed when the present invention is applied to liquid supply systems having a fluid passage leading out of the outlet of a pump chamber, extending vertically downward on the downstream side, and then turning at a further downstream location to extend vertically upward. The liquid supply system has the outlet pipe 320 connected to the outlet 131c for liquid provided on the bottom of the container, which is an example of the fluid passage that extends vertically downward from the outlet of a pump chamber and then upward. Inside this outlet pipe, the gas vent pipe is disposed in the embodiment. However, the configuration of the fluid passage that extends vertically downward from the outlet of a pump chamber and then upward is not limited to this. The present invention can also be applied to, for example, a liquid supply system having a fluid passage that turns in a U-shape in the interior of the container.

[0049] While we have described a case where the present invention is applied to a liquid supply system provided with a bellows pump including two pump chambers formed around the outer circumference of bellows that are arranged one above the other along the vertical direction (or the direction of expansion and contraction of the bellows), liquid supply systems to which the present invention can be applied are not limited to this type. The present invention can be applied to pumps in general that take in and discharge liquid and provides the above-described advantageous effects when applied to liquid supply systems configured to discharge liquid from the bottom of a container in which a pump chamber is housed and bring it to a location higher than the bottom. Liquid supply systems configured in this way discharge liquid out of the container using a U-shaped pipe. In such liquid supply systems, it is not easy to discharge gas staying in the container. If the present invention is applied, gas staying in the container can readily be discharged to the outside.

[0050] The interior space of the vacuum container 200 outside the main system unit 100, the intake pipe 310, and the outlet pipe 320 is kept in a vacuum state to provide heat insulation. The hermetically sealed space constituted by the first to third spaces K1, K2, and K3 is kept in a vacuum state to provide heat insulation. Alternatively, these spaces may also be supplied with cryogenic liquid to keep the temperature of liquid flowing in a circulation fluid passage low.

[Reference Signs List]

[0051]

10: liquid supply system
100: main system unit
110: linear actuator
120: shaft member
121: main shaft portion
122: cylindrical portion
122a: upper outward flange
122b: lower outward flange
123: connecting portion
130: container
131: casing
131a: opening
131b: inlet
131c: outlet
131d: fluid passage
131e: fluid passage
131X: body portion
131Xa: first inward flange
131Xb: second inward flange
131Xc: first fluid passage
131Xd: second fluid passage
131Xg: third fluid passage
131Y: bottom plate
141: first bellows
142: second bellows
151: third bellows
152: fourth bellows
160: check valve
160A: first check valve
160B: second check valve
160C: third check valve
160D: fourth check valve
200: vacuum container
310: inlet pipe
320: outlet pipe
401: inlet of first pump chamber
402: outlet of first pump chamber
403: inlet of second pump chamber
404: outlet of second pump chamber
601: first orifice
602: gas vent pipe
603: bolt
604: second orifice
P1: first pump chamber
P2: second pump chamber

Claims

1. A liquid supply system comprising:

a container having an inlet and an outlet for liquid and provided with a pump chamber inside it;
an outlet pipe through which liquid discharged from the outlet is brought to outside;
a fluid channel through which liquid flows, the fluid channel leading out of the inlet, passing through the pump chamber, and extending vertically downward from the pump chamber to the outlet; and
a gas vent pipe having a first orifice disposed in the fluid channel and a second orifice disposed in the fluid channel downstream of the first orifice,
wherein the second orifice is located at vertically higher level than the first orifice.

2. A liquid supply system according to claim 1, wherein the second orifice is disposed in the outlet pipe.

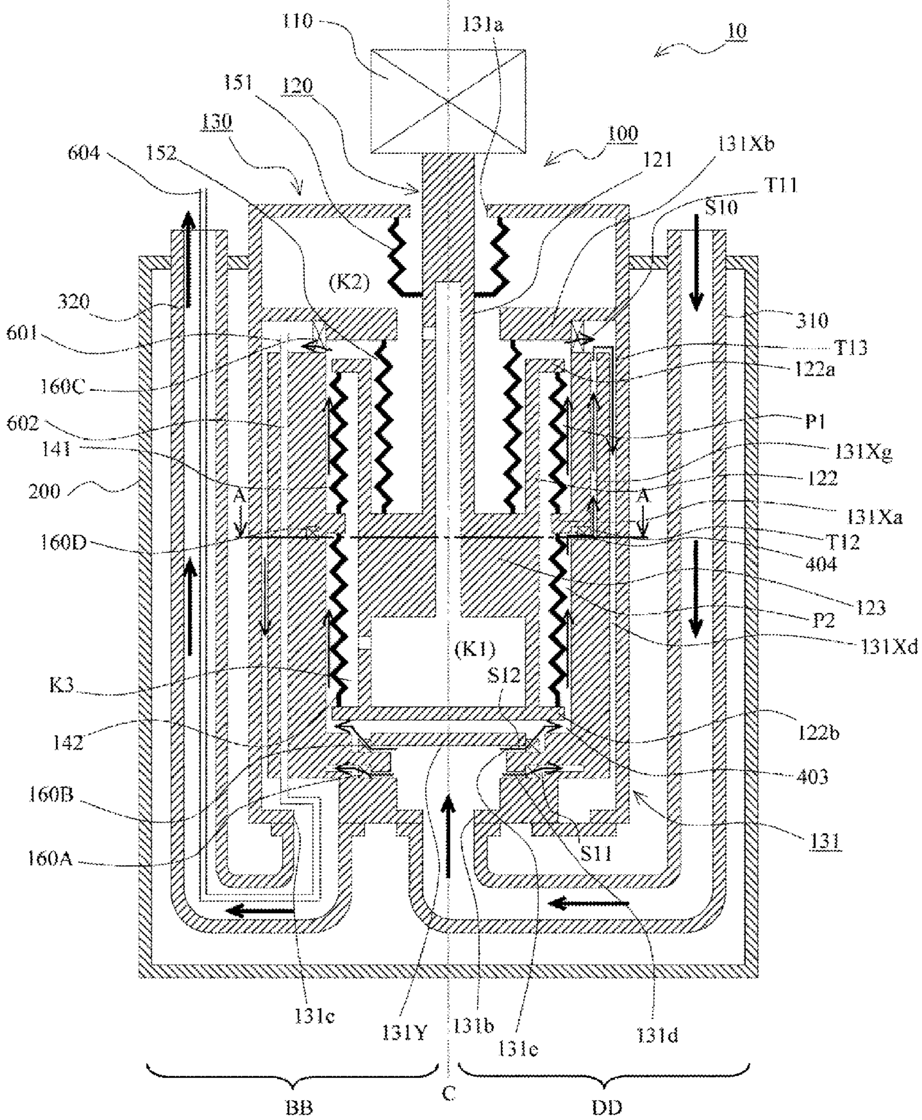
3. A liquid supply system comprising:

a shaft member that moves vertically upward and downward in the container; and
a first bellows and a second bellows disposed one above the other along the vertical direction, each of which expands and contracts with upward and downward motion of the shaft member;
wherein the pump chamber includes a first pump chamber formed by a space surrounding the outer circumference of the first bellows and a second pump chamber formed by a space sur-

rounding the outer circumference of the second bellows,
the fluid channel includes a first fluid channel through which liquid flows from the inlet to the outlet via the first pump chamber and a second fluid channel through which liquid flows from the inlet to the outlet via the second pump chamber, and
the gas vent pipe is provided in at least one of the first and second fluid channels.

4. A liquid supply system according to claim 3, wherein the first pump chamber is disposed above the second pump chamber and the first orifice is located above the outlet of the first pump chamber.

[Fig. 1]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131a
10
151
120
130
100
604
152
131Xb
121
T11
S10
(K2)
320
310
601
T13
160C
122a
602
P1
141
131Xg
200
122
A
A
131Xa
160D
T12
404
123
P2
131Xd
(K1)
K3
S12
122b
142
403
160B
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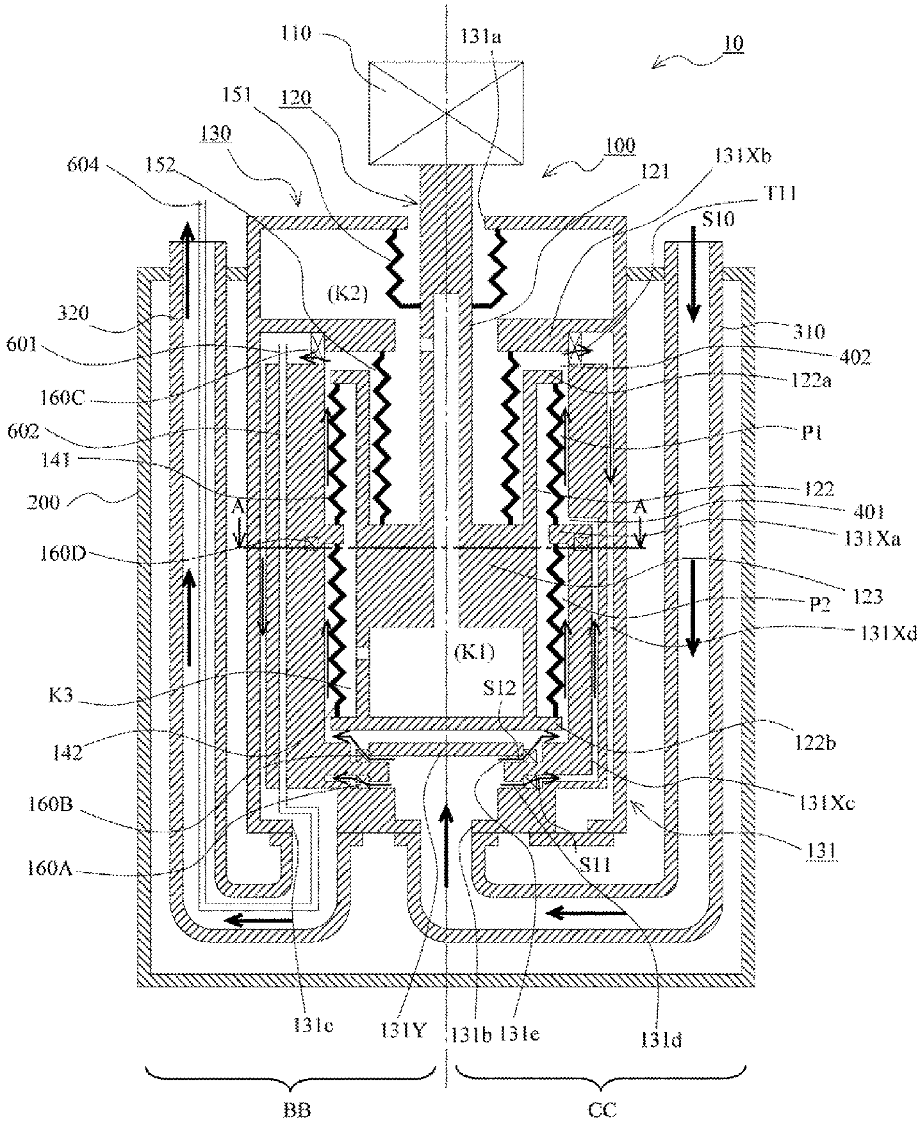
160A
S11
131c
131Y
131b
131e
131d
BB
C
DD

Fig.1

[Fig. 2]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121
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S10
(K2)
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310
601
402
160C
122a
602
P1
141
122
200
A
A
401
131Xa
160D
123
P2
131Xd
(K1)
S12
K3
122b
142
131Xc
160B
131
S11
160A
131c
131Y
131b
131e
131d
BB
CC

Fig.2

[Fig. 3]

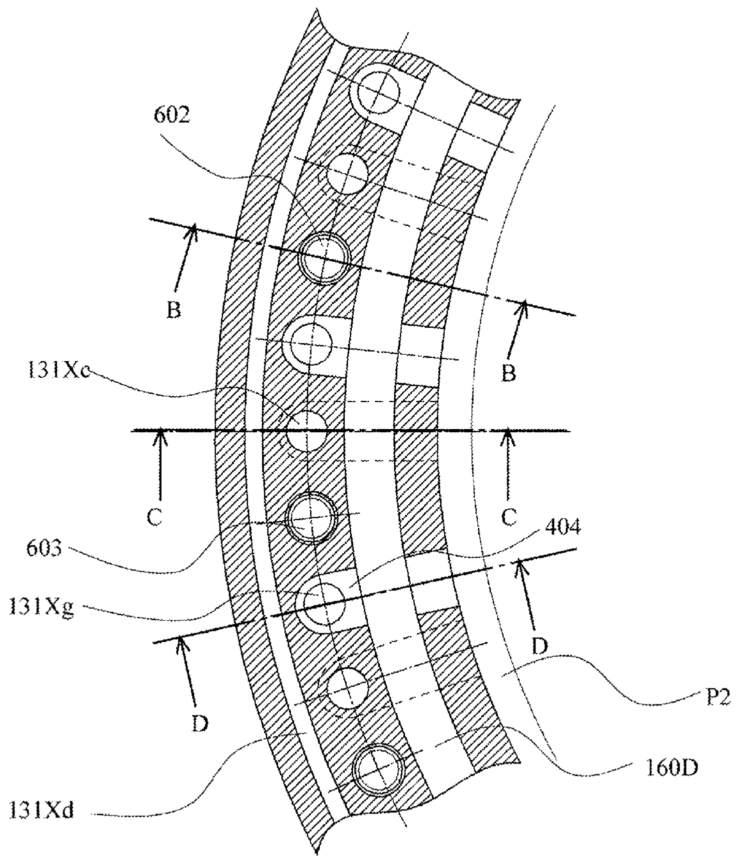

Fig.3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2018/003632

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl. F04B43/08(2006.01)i, F04B15/08(2006.01)i, F04B53/06(2006.01)i, F25B9/00(2006.01)n

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
Int.Cl. F04B43/08, F04B15/08, F04B53/06, F25B9/00

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

Published examined utility model applications of Japan	1922-1996
Published unexamined utility model applications of Japan	1971-2018
Registered utility model specifications of Japan	1996-2018
Published registered utility model applications of Japan	1994-2018

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.
A	JP 2005-113858 A (NIPPON PILLARPACKING CO., LTD.) 28 April 2005, paragraphs [0014]-[0029], fig. 5 (Family: none)	1-2
A	JP 2012-107559 A (NIPPON PILLARPACKING CO., LTD.) 07 June 2012, paragraphs [0013]-[0037], fig. 1 (Family: none)	1-2
A	WO 2016/006648 A1 (EAGLE INDUSTRY CO., LTD.) 14 January 2016, paragraphs [0020]-[0041], fig. 1 & US 2017/0167475 A1, paragraphs [0024]-[0045], fig. 1 & EP 3168550 A1 & KR 10-2017-0010399 A & CN 106662372 A	3-4

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

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"&" document member of the same patent family

Date of the actual completion of the international search
06 April 2018 (06.04.2018)

Date of mailing of the international search report
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Name and mailing address of the ISA/
Japan Patent Office
3-4-3, Kasumigaseki, Chiyoda-ku,
Tokyo 100-8915, Japan

Authorized officer

Telephone No.

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

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- WO 2016006648 A **[0006]**