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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 having an inlet 131b and an outlet 131c for liquid and provided with pump chambers P1, P2 inside it, supply passages 131e, 131Xc through which the liquid flowing in through the inlet 131b is supplied to the pump chambers P1, P2, and a discharge passage 131Xd through which the liquid discharged from the pump chambers P1, P2 is brought to the outlet 131c. Portions 180, 181 of an inner surface of the liquid supply system 10 that are in contact with the liquid are each provided with an increased surface structure 400 having an increased liquid contact area and extending along the direction L1, L2 of flow of the liquid.

[Fig. 2]

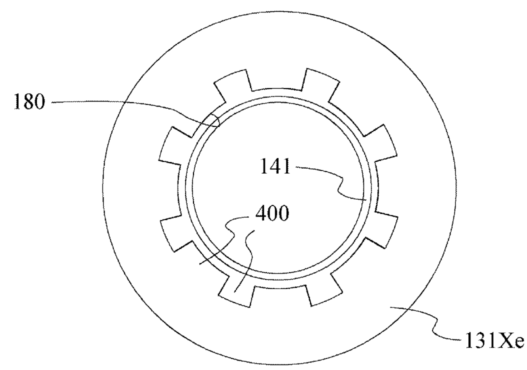

Fig.2

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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, and 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 a 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;
a supply passage through which the liquid flowing in through the inlet is supplied to the pump chamber; and
a discharge passage through which the liquid discharged from the pump chamber is brought to the

outlet,

wherein a portion of an inner surface of the liquid supply system that is in contact with the liquid is provided with an increased surface structure having an increased liquid contact area and extending along the direction of flow of the liquid.

[0010] The inner surface provided with the increased surface structure has a larger liquid contact area (i.e. an area that is in contact with liquid) than inner surfaces that are not provided with the increased surface structure. The increased surface structure is provided on a portion of the inner surface of the liquid supply system that is in contact with liquid. Hence, when low temperature liquid flows into the liquid supply system, heat exchange between the low temperature liquid and structural components of the liquid supply system progresses more efficiently than that in conventional liquid supply systems that are not provided with the increased surface structure. In consequence, the liquid supply system can be cooled efficiently by supplying low temperature liquid into it. Time taken to cool the liquid supply system in a ordinary temperature environment can be reduced, 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.

[0011] The increased surface structure may include depressions and projections. Thus, the increased surface structure can be implemented as a simple structure.

[0012] The increased surface structure may be provided in the pump chamber. The inner surface of the pump chamber provided with the increased surface structure has a larger area that is in contact with the liquid flowing in the pump chamber than the inner surface not provided with the increased surface structure. Hence, when low temperature liquid flows into the pump chamber, heat exchange between the low temperature liquid and structural components of the pump chamber progresses more efficiently than that in conventional liquid supply systems that are not provided with the increased surface structure. In consequence, the pump chamber can be cooled efficiently by supplying low temperature liquid into it. The pump chamber can be cooled efficiently, and therefore situations in which gas generated by vaporization of low temperature liquid stays in the pump chamber can be eliminated early. Thus, the time taken to make the liquid supply system operable by cooling can be reduced.

[0013] The pump chamber may have a substantially axisymmetric shape, a pump inlet with which the supply passage is joined may be provided on one axial side of the pump chamber, a pump outlet with which the discharge passage is joined may be provided on the other axial side of the pump chamber, and the increased surface structure may be provided uniformly along the axial direction in the pump chamber.

[0014] If the above feature is adopted, the liquid flowing into the pump chamber through the pump inlet and discharged through the pump outlet flows substantially along the axial direction of the pump chamber. Since the increased surface structure is provided in the pump chamber uniformly along the axial direction, it does not interfere with the flow of liquid in the pump chamber.

[0015] The increased surface structure may be provided in the supply passage and the discharge passage. This enables more efficient cooling of the components of the liquid supply system.

[0016] 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 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 surrounding the outer circumference of the second bellows, and the increased surface structure includes depressions and projections that are provided on an inner surface of a wall that defines the space surrounding the outer circumference of the first bellows in the first pump chamber and extend parallel to the direction of expansion and contraction of the first bellows and depressions and projections that are provided on an inner surface of a wall that defines the space surrounding the outer circumference of the second bellows in the second pump chamber and extend parallel to the direction of expansion and contraction of the second bellows.

[0017] In the liquid supply system having the above structure, the liquid flows in the first pump chamber and the second pump chamber respectively along the direction of expansion and contraction of the first bellows and the direction of expansion and contraction of the second bellows. The increased surface structures are provided in the first pump chamber and the second pump chamber and include depressions and projections extending parallel to the direction of expansion and contraction of the first bellows and the direction of expansion and contraction of the second bellows respectively. Therefore, the increased surface structures do not interfere with the flow of liquid in the first pump chamber and the second pump chamber. The first pump chamber and the second pump chamber of this liquid supply system can be cooled efficiently by supplying low temperature liquid to the first pump chamber and the second pump chamber.

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

[Advantageous Effects of Invention]

[0019] As above, 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 schematic cross sectional view of an example of an increased surface structure 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 and 2. 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 cooled device.

<Overall Configuration of the Liquid Supply System>

[0023] Fig. 1 is a schematic diagram illustrating the overall configuration of the liquid supply system, where the overall configuration of the liquid supply system is illustrated in a cross section. 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 Fig. 1 is the vertically upward direction, and the downward direction in Fig. 1 is the vertically downward direction.

[0024] 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 aforementioned inlet pipe 310 is connected to the inlet 131b and the outlet pipe 320 is connected to the outlet 131c.

[0025] 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.

[0026] 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.

[0027] 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.

[0028] 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. 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 bottom portion of the casing 131 is provided with a 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. 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.

[0029] 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 a first pump chamber P1, and the space surrounding the outer circumference of the second bellows 142 forms a second pump chamber P2.

[0030] 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.

[0031] 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.

[0032] The first check valve 160A and the third check valve 160C are provided in the fluid passage 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. More specifically, 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.

[0033] The second check valve 160B and the fourth check valve 160D are provided in the fluid passage 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. More specifically, 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.

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

[0034] 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 second fluid passage 131Xd provided in the body portion 131X 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.

[0035] 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.

[0036] 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.

<Cooling of the Liquid Supply System>

[0037] 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 a 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 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.

[0038] 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 increases, the components that exchange heat with the low temperature liquid increases. Thus, cooling progresses from the lower portion to the upper portion of the system.

<Increased Surface Area Structure>

[0039] An increased surface structure will be described with reference to Figs. 1 and 2. Fig. 2 schematically illustrates a cross section taken along line A-A in Fig. 1. For the sake of simplicity, Fig. 2 illustrates the cross sections of only the first bellows 141 and a wall 131Xe of the first pump chamber P1 and does not illustrate the cross sections of the fourth bellows 152, the cylindrical portion 122, and the main shaft portion 121, which actually exist radially inside the illustrated components.

[0040] The first pump chamber P1 is a space formed between the outer circumferential surface of the first bellows 141 and the inner surface 180 of the wall 131Xe opposed to the first bellows 141. The wall 131Xe is in contact with the liquid flowing in the first pump chamber P1. The wall 131Xe is a part of the casing 131 and exchanges heat with structural components constituting the main system unit 100. The inner surface 180 of the wall 131Xe is provided with an increased surface structure 400 extending along the direction of liquid flow (indicated by arrow L1) in the first pump chamber P1. The increased surface structure 400 is composed of depressions and projections that are uniformly formed along the axial direction. The first pump chamber P1 is of a substantially axisymmetric shape with respect to the center axis of the shaft member 120 and provided with a pump inlet 401 on its one axial side (lower side) and a pump outlet 402 on its other axial side (upper side). Liquid flows into the first pump chamber P1 through the pump inlet 401 and out of the first pump chamber P1 through the pump outlet 402. Since the first bellows 141 is caused to expand and contract in the axial direction (i.e. vertical direction) by the shaft member 120, the depressions and projections of the increased surface structure 400 are configured as linear grooves provided on the inner surface 180 of the wall 131Xe that extend in the direction of expansion and contraction of the first bellows 141.

[0041] The second pump chamber P2 is also provided with an increased surface structure similar to the above. Specifically, the inner surface 181 of a wall 131Xf opposed to the second bellows 142 in the second pump chamber P2 is provided with an increased surface structure configured as axial linear grooves that extend along the direction of liquid flow in the second pump chamber P2 (indicated by arrow L2).

<Advantages of the Liquid Supply System According to the Embodiment

[0042] The increased surface structure 400 in the liquid supply system 10 provides an increased contact area with liquid on the inner surface 180 of the wall 131Xe. The inner surface 180 exchanges heat with structural components constituting the first pump chamber and structural components constituting the main system unit 100. Hence, when low temperature liquid flows in the first pump chamber P1, heat exchange between the low temperature liquid and structural components of the system progresses more efficiently as compared to that in conventional structures that do not have the increased surface structure 400. In consequence, the system can be cooled efficiently by supplying low temperature liquid into it. This can lead to a reduction in time taken to cool the liquid supply system in a 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. As above, the increased surface structure 400 is a structure including linear grooves provided on the inner surface that extend uniformly along the direction of liquid flow in the first pump chamber P1. Therefore, the increased surface structure 400 hardly interferes with the flow of liquid in the first pump chamber P1. The second pump chamber P2 is also provided with an increased surface structure similar to that of the first pump chamber P1. This structure also enables efficient heat exchange between low temperature liquid and structural components of the system without interfering with the flow of liquid in the second pump chamber P2.

Others

[0043] While in the above described embodiment the increased surface structure 400 and a like structure are provided respectively on the inner surface 180 of the wall 131Xe that defines the first pump chamber P1 and on the inner surface 181 of the wall 131Xf that defines the second pump chamber P2, the increased surface structure may be provided on any other portion that exchanges heat with structural components of the main system unit 100 and is in contact with low temperature liquid. For example, the increased surface structure may be provided on an inner surface of a supply passage joined with the pump inlet 401 of the first pump chamber P1, an inner surface of a discharge passage joined with the pump outlet 402 of the first pump chamber P1, an inner surface of a supply passage joined with a pump inlet 403 of the second pump chamber P2, or/and an inner surface of a discharge passage joined with a pump outlet 404 of the second pump chamber P2. In the above-described illustrative case, the increased surface structure includes axial linear grooves provided on an inner surface. However, the form of the increased surface structure is not limited linear grooves, but the increased surface structure may be of any form so long as it has a larger contact area with liquid than the structure without the increased surface structure. For example, the increased surface structure may include a spiral groove or an annular groove coaxial with the shaft member 120.

[0044] While we have described an embodiment 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 another embodiment may be applied are not limited to this type. Another embodiment may be applied to pumps in general that take in and discharge liquid, and advantageous effects same as the above-described embodiment can be achieved by providing an increased surface structure that increases contact area with liquid on a portion of an inner surface of a pump chamber in contact with liquid that exchanges heat with structural components of the pump chamber or the main unit of a liquid supply system.

[0045] 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]

[0046]

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
131Xe: inner wall
131Xf: inner wall
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

180: inner wall
181: inner wall
190: inner wall
200: vacuum container
310: inlet pipe
320: outlet pipe
400: increased surface structure
401: inlet of first pump chamber
402: outlet of first pump chamber
403: inlet of second pump chamber
404: outlet of second pump chamber
L1: flow of liquid in first pump chamber
L2: flow of liquid in second pump chamber
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;
a supply passage through which the liquid flowing in through the inlet is supplied to the pump chamber; and
a discharge passage through which the liquid discharged from the pump chamber is brought to the outlet,
wherein a portion of an inner surface of the liquid supply system that is in contact with the liquid is provided with an increased surface structure having an increased liquid contact area and extending along the direction of flow of the liquid.

2. A liquid supply system according to claim 1, wherein the increased surface structure includes depressions and projections.

3. A liquid supply system according to claim 1 or 2, wherein the increased surface structure is provided in the pump chamber.

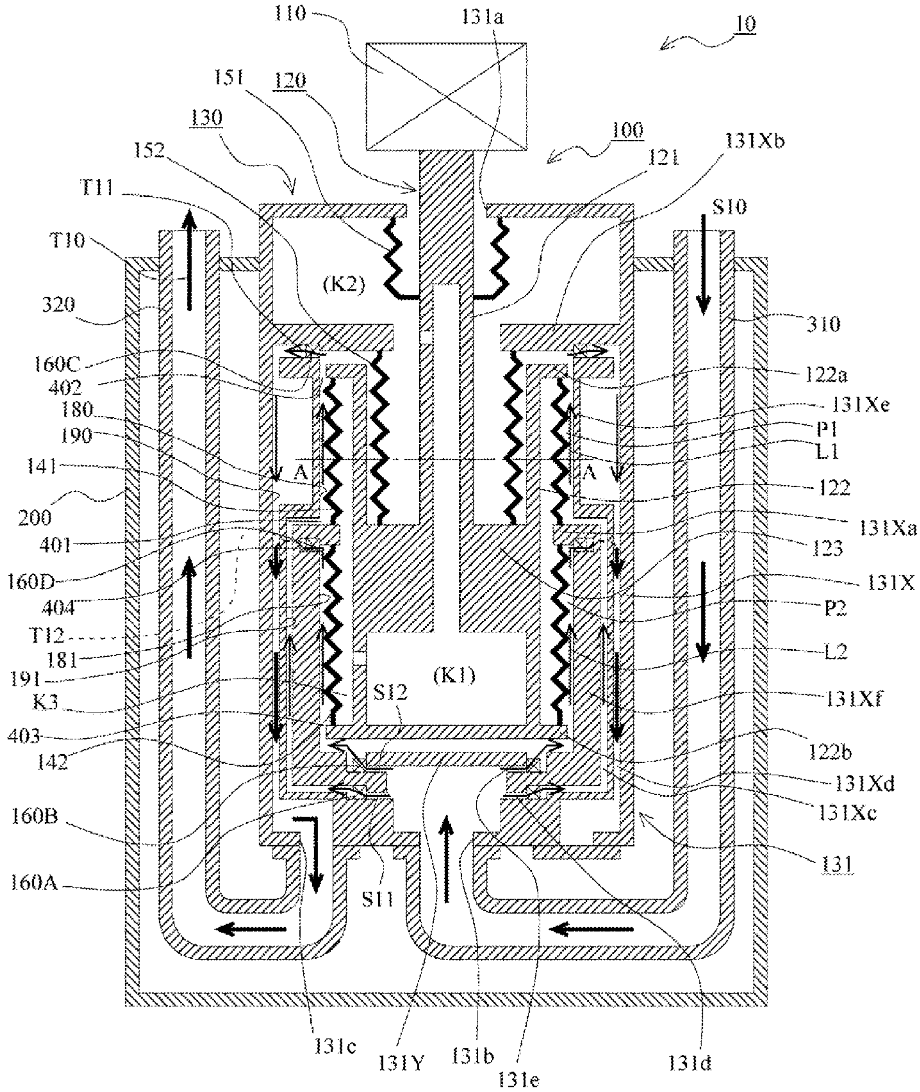
4. A liquid supply system according to claim 3, wherein the pump chamber has a substantially axisymmetric shape, a pump inlet with which the supply passage is joined is provided on one axial side of the pump chamber, a pump outlet with which the discharge passage is joined is provided on the other axial side of the pump chamber, and the increased surface structure is provided uniformly along the axial direction of the pump chamber.

5. A liquid supply system according to any one of claims 1 to 4, wherein the increased surface structure is provided in the supply passage and the discharge passage.

6. A liquid supply system according to any one of claims 1 to 5, 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 surrounding the outer circumference of the second bellows, and the increased surface structure includes depressions and projections that are provided on an inner surface of a wall that defines the space surrounding the outer circumference of the first bellows in the first pump chamber and extend parallel to the direction of expansion and contraction of the first bellows and depressions and projections that are provided on an inner surface of a wall that defines the space surrounding the outer circumference of the second bellows in the second pump chamber and extend parallel to the direction of expansion and contraction of the second bellows.

[Fig. 1]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131a
10
151
120
130
100
152
121
131Xb
T11
S10
T10
(K2)
320
310
160C
122a
402
131Xe
180
P1
190
L1
A
A
141
122
200
131Xa
401
123
160D
131X
404
P2
T12
181
L2
191
(K1)
S12
131Xf
K3
403
142
122b
131Xd
131Xc
160B
131
160A
S11
131c
131Y
131b
131e
131d

Fig.1

[Fig. 2]

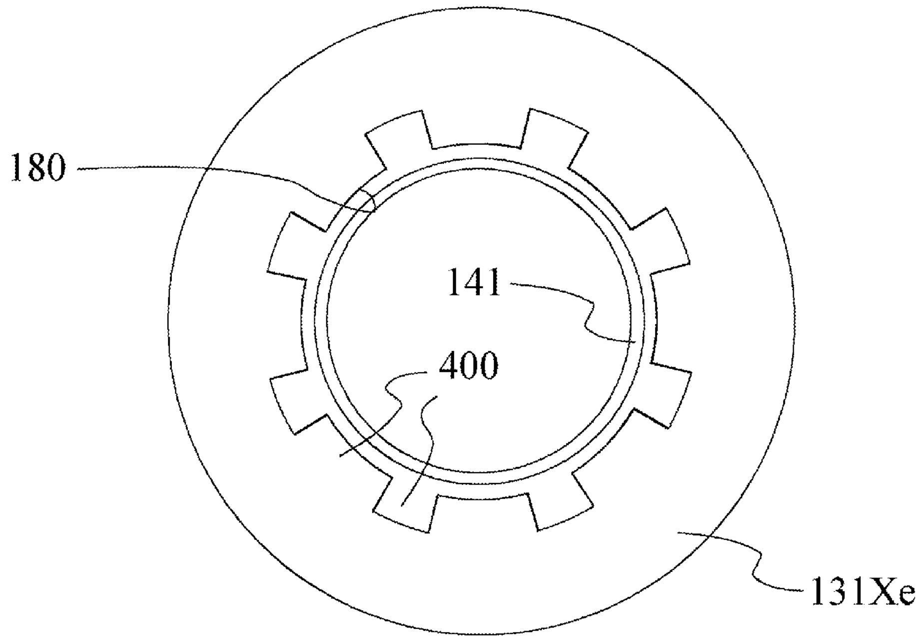

Fig.2

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2018/003624

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

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. F04B15/08, F04B43/08, 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.
X Y	JP 56-151293 A (TEISAN KK) 24 November 1981, publication gazette, page 2, upper right column, line 13, lower left column, line 16 to lower right column, line 16, drawings (Family: none)	1-3, 5 4, 6
Y	JP 2014-1663 A (KOGANEI CORPORATION) 09 January 2014, fig. 7 (Family: none)	4, 6
Y	WO 2016/006648 A1 (EAGLE INDUSTRY CO., LTD.) 14 January 2016, fig. 1 & US 2017/0167475 A1, fig. 1 & EP 3168550 A1 & CN 106662372 A	6
A	JP 2005-504927 A (WESTPORT RESEARCH INC.) 17 February 2005, paragraphs [0020]-[0021] & JP 2001-522968 A & US 2002/0085921 A1, paragraphs [0025]-[0029] & US 5884488 A & US 2004/0105759 A1 & GB 2396891 A & WO 2003/031817 A1 & WO 1999/024714 A1 & CA 2460869 A1 & CN 1564910 A	1-6
A	JP 2012-163105 A (MITSUBISHI HEAVY INDUSTRIES, LTD.) 30 August 2012, fig. 4, 9 & JP 2006-214433 A & JP 2010-180890 A & JP 2010-209919 A	1-6

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

* Special categories of cited documents:
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"O" document referring to an oral disclosure, use, exhibition or other means
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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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"&" document member of the same patent family

Date of the actual completion of the international search 10 April 2018 (10.04.2018)	Date of mailing of the international search report 24 April 2018 (24.04.2018)
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

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Patent documents cited in the description

- WO 2016006648 A **[0006]**