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(54) **LIQUID SUPPLY SYSTEM**

(57) A liquid supply system in which the generation of twisting of a bellows is prevented. The liquid supply system has a first bellows 130 which is fixed to a shaft 150 and expands or contracts in accordance with the reciprocating motion of the shaft 150 and a second bellows 200 which expands or contracts in accordance with the reciprocating motion of the shaft 150., The second bellows 200 and the first bellows 130 forms a pump chamber therebetween and the second bellows 200 has an outer diameter smaller than an outer diameter of the first bellows 130. One end of the second bellows 200 is fixed to one of the shaft 150 and a cylindrical member 161, and the other end of the second bellows 200 is positioned to the other of the shaft 150 and the cylindrical member 161 in a state being allowed to move in a circumferential direction.

[Fig. 1]

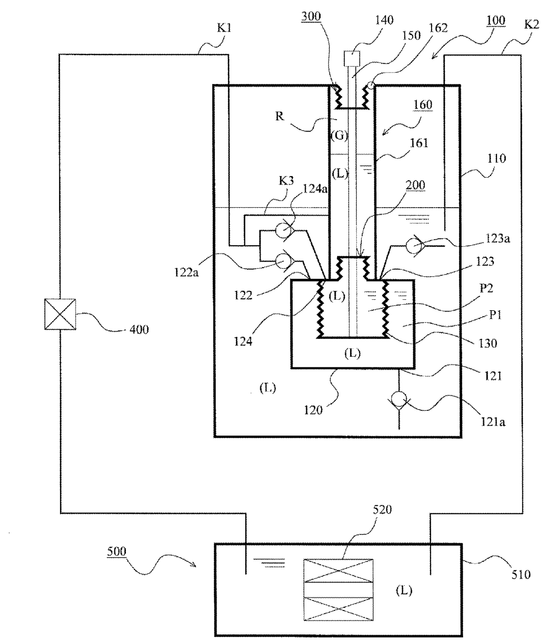

Fig.1

EP 3 505 760 A1

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Description

[Technical Field]

[0001] The present invention relates to a liquid supply system which includes a bellows.

[Background Art]

[0002] A technique is known in which a bellows is used in order to form a sealed space between a shaft which performs reciprocating motion and a cylindrical member through which the shaft is inserted. One end of the bellows is generally fixed to the shaft and the other end is fixed to the cylindrical member. This configuration has an advantage because it includes no sliding portion which can be a cause of sliding abrasion and heat generation by sliding. Therefore a liquid supply system to circulate ultra-low temperature liquid, for example, generally uses a bellows to form a sealed structure (see PTL 1).

[0003] There is no particular issue as long as the shaft and the cylindrical member do not rotate relative to each other. However, the shaft and the cylindrical member may slightly rotate relative to each other due to the mechanism of the system. This may cause the bellows to be twisted, and then torsion buckling may be generated. Such torsion buckling is more likely to be generated in a bellows having a smaller diameter. If the bellows expands and contracts in a state where torsion buckling is generated, stress may be locally concentrated, and the product lifetime of the bellows may be shortened due to fatigue.

[Citation List]

[Patent Literature]

[0004] [PTL 1]
WO 2012/124363

[Summary of Invention]

[Technical Problem]

[0005] It is an object of the present invention to provide a liquid supply system in which generation of twisting of a bellows is suppressed.

[Solution to Problem]

[0006] To achieve the above object, the present invention uses the following means.

[0007] A liquid supply system of one aspect of the present invention is a liquid supply system having
a container,
a shaft which extending from the outside to the inside of the container and configured to perform reciprocating motion by a driving source,
a cylindrical member which is disposed in the container, through which the shaft is inserted,
a first bellows which is fixed to the shaft and configured to expand and contract in accordance with the reciprocating motion of the shaft, and
a second bellows which is configured to expand and contract in accordance with the reciprocating motion of the shaft, the second bellows and the first bellows forming a pump chamber therebetween and the second bellows having an outer diameter smaller than an outer diameter of the first bellows.

[0008] One end of the second bellows is fixed to one of the shaft and the cylindrical member, and the other end of the second bellows is positioned to the other of the shaft and the cylindrical member being allowed to move in a circumferential direction.

[0009] According to the one aspect, one end of the second bellows is fixed to one of the shaft and the cylindrical member, but the other end is positioned to the other of the shaft and the cylindrical member being allowed to move in a circumferential direction. This suppresses the generation of twisting in the second bellows which would be followed by breakage of the second bellows even when the shaft and the cylindrical member rotate relative to each other. Thus, leakage of fluid in the pump chamber can be suppressed.

[0010] A seal portion may be disposed on the other end of the second bellows the seal portion being configured to have a contact with the other of the shaft and the cylindrical member to seal fluid and having a larger area than an effective area of the second bellows.

[0011] In a state where fluid pressure on the opposite side of the pump chamber across the seal portion is higher than fluid pressure inside the pump chamber, a valve body in the seal portion is kept in close contact with a valve sheet in the seal portion, hence stable sealing performance can be achieved. By contrast, in a state where the fluid pressure on the opposite side of the pump chamber across the seal portion is lower than the fluid pressure inside the pump chamber, the contacting state in the seal portion becomes out of contact state by the pressure acting thereon, and the liquid inside the pump chamber flows to a region on the opposite side of the pump chamber across the seal portion, hence pressure can be released, and excessive pressure can be suppressed from acting on the second bellows.

[0012] The liquid supply system may further include a third bellows which is configured to expand and contract in accordance with the reciprocating motion of the shaft, the third bellows forming a sealed space between the cylindrical member and the second bellows and the third bellows, and a part of liquid transferred from the pump chamber is supplied to the sealed space.

[0013] This makes the region on the opposite side of the pump chamber across the seal portion a sealed space, and fluid discharged from the pump is supplied to the sealed space. This enables the pressure in the sealed space to be not less than the pressure in the pump chamber, thus twisting of the second bellows can be suppressed and the sealed state can be kept.

[0014] One end of the third bellows may be fixed to one of the shaft and the cylindrical member, and the other end of the third bellows is positioned to the other of the shaft and the cylindrical member being allowed to move in the circumferential direction.

[0015] This suppresses twisting of both the second bellows and the third bellows and breakage of the bellows. Thus the sealed space formed by the cylindrical member, the second bellows and the third bellows can be kept in a sealed state with certainty.

[0016] Each of the above configurations may be combined and used where possible.

[Advantageous Effects of Invention]

[0017] As described above, according to the present invention, the generation of the twisting in the bellows can be suppressed.

[Brief Description of Drawings]

[0018]

Fig. 1 is a schematic configuration diagram depicting the operating state of the liquid supply system according to an embodiment.
Fig. 2 is a schematic cross-sectional view depicting the sealing structure according to Example 1.
Fig. 3 is a schematic cross-sectional view depicting the sealing structure according to Example 2.
Fig. 4 is a schematic cross-sectional view depicting the sealing structure according to Example 3.
Fig. 5 is a schematic cross-sectional view depicting the sealing structure according to Example 4.
Fig. 6 is a schematic configuration diagram depicting the operating state of the liquid supply system according to a modification of the embodiments.

[Description of Embodiment]

[0019] An embodiment of the present invention will be described based on examples with reference to the drawings. Dimensions, materials, shapes and relative positions of the components described in the examples are not intended to restrict the scope of the invention unless otherwise specified.

(Liquid supply system)

[0020] A general configuration and operation method of a liquid supply system 100 (circulator) according to this embodiment will be described with reference to Fig. 1. The liquid supply system 100 according to this embodiment described bellow supplies ultra-low temperature liquid L to a cooling target apparatus 500 having a resin container 510 and a superconducting coil 520 inside the resin container 510. Examples of the ultra-low temperature liquid L include liquid nitrogen, liquid helium and liquid argon.

[0021] The liquid supply system 100 has a container which contains the ultra-low temperature liquid L (first container 110), a second container 120 which is disposed in the liquid L contained in the first container 110, and a first bellows 130 which is disposed to enter into the second container 120. Within the second container 120, an external space of the first bellows 130 forms a first pump chamber P1. An internal space of the first bellows 130, which is a sealed space, forms a second pump chamber P2. The first bellows 130 is made of metal. Instead of containing liquid, the internal space of the first container 110 may be a vacuum. In such a configuration, a passage for returning liquid back to the first container 110 (later mentioned as a return passage K2) and an inlet for drawing the liquid into the second container 120 (later mentioned as a first inlet 121 and second inlet 123) may be connected.

[0022] The second container 120 has a first inlet 121 which draws the liquid L in the first container 110 into the first pump chamber P1 and a first outlet 122 which delivers the drawn liquid L from the first pump chamber P1 to a supply passage (supply pipe) K1 which is connected to the outside of the system. The second container 120 further has a second inlet 123 which draws the liquid L in the first container 110 into the second pump chamber P2 and a second outlet 124 which delivers the drawn liquid L from the second pump chamber P2 to the supply passage K1. The first inlet 121 and the second inlet 123 has one way valves 121a and 123a, respectively, and the first outlet 122 and the second outlet 124 has one way valves 122a and 124a, respectively.

[0023] A metal shaft 150, which is configured to perform reciprocating motion by a linear actuator 140 (driving source), is disposed from the outside to the inside of the first container 110. The end of the shaft 150 is fixed to the end of the first bellows 130. Thereby the first bellows 130 is capable of expanding and contracting as the shaft 150 performs the reciprocating motion.

[0024] A cushioning structure 160 is provided around the shaft 150 to cushion pressure fluctuation (pulsation) of the liquid L supplied via the supply passage K1. The cushioning structure 160 is disposed in the first container 110, and includes a cylindrical member 161 which is a cylinder (may be a circular cylinder) through which the shaft 150 is inserted, and a second bellows 200 and a third bellows 300 which are disposed at the lower end and upper end of the cylindrical member 161, respectively. The second bellows 200 and the third bellows 300 are both made of metal. The first bellows 130 is fixed to the shaft 150 at a position that is most distant from the driving source (linear actuator 140) among the first bellows 130, the second bellows 200 and the third bellows 300.

[0025] The second bellows 200 is configured to expand and contract in accordance with the reciprocating motion of the shaft 150, and the first bellows 130 and the second bellows 200 are configured to form a sealed space between them. The sealed space corresponds to the above mentioned second pump chamber P2. The outer diameter of the second bellows 200 is smaller than the outer diameter of the first bellows 130.

[0026] The third bellows 300 is configured to expand and contract in accordance with the reciprocating motion of the shaft 150 and the outer diameter of the third bellows 300 is smaller than the outer diameter of the first bellows 130. The sealed space R is formed by the cylindrical member 161, the second bellows 200 and the third bellows 300. A layer of the liquid L and a layer of the gas G generated by vaporization of the liquid L are formed in the sealed space R.

[0027] A branch passage K3, which branches from the supply passage K1, is disposed so as to be connected to the sealed space R. Thereby the pressure of the liquid L, which is supplied via the supply passage K1, is also applied in the sealed space R, and as a result, the gas inside the sealed space R functions as a damper, and absorbs the shock caused by the fluctuation (pulsation) of the pressure of the liquid L supplied via the supply passage K1. The sealed space R is therefore a damper chamber.

[0028] The cushioning structure 160 has, near the third bellows 300, a safety valve 162, which releases the internal pressure of the sealed space R to the outside when the pressure becomes a predetermined value or more. This enables the pressure inside the sealed space R to be released when the pressure becomes abnormally high due to, for example, increase in an amount of vaporized gas G in the sealed space R. This prevents an extreme increase in internal pressure which would cause breakage of the cylindrical member 161, the second bellows 200 and the third bellows 300, thus such breakage can be suppressed.

[0029] In this embodiment, the second bellows 200 is disposed on the upper end side of the first bellows 130, as described above, so that the space inside the first bellows 130 is a sealed space. The sealed space forms the second pump chamber P2, as mentioned above.

[0030] The above configuration allows the liquid L to be delivered from the second pump chamber P2 to the supply passage K1 via the second outlet 124 and the liquid L to be drawn into the first pump chamber P1 via the first inlet 121 when the first bellows 130 contracts. The liquid L is drawn into the second pump chamber P2 via the second inlet 123 and delivered from the first pump chamber P1 to the supply passage K1 via the first outlet 122 when the first bellows 130 expands. Thus, the liquid L is delivered to the supply passage K1 whether the bellows 130 expands or contracts.

[0031] As described above, the liquid supply system 100 according to the embodiment supplies the liquid L to the cooling target apparatus 500 via the supply passage K1 through the repetitive expansion and contraction operations of the first bellows 130. The return passage (return pipe) K2, which is provided to connect the liquid supply system 100 and the cooling target apparatus 500, is configured to return as much liquid L as supplied to the cooling target apparatus 500 to the liquid supply system 100. A cooling apparatus 400 for cooling the liquid L to an ultra-low temperature state is disposed in the supply passage K1. The configuration enables the liquid L, which was cooled to the ultra-low temperature by the cooling apparatus 400, to circulate between the liquid supply system 100 and the cooling target apparatus 500.

[0032] The shaft 150 and the cylindrical member 161 of the liquid supply system 100 according to the embodiment may be slightly rotated relative to each other due to a mechanism of the system. This may generate torsion buckling, particularly in the second bellows 200 and the third bellows 300, of which diameters are small. The liquid supply system 100 according to the embodiment has a structure to suppress the generation of torsion buckling in the second bellows 200 and the third bellows 300.

[0033] Specifically, one end of the second bellows 200 according to the embodiment is fixed to one of the shaft 150 and the cylindrical member 161. The other end of the second bellows 200, on the other hand, is positioned at the other of the shaft 150 and the cylindrical member 161 being allowed to move in the circumferential direction. This suppresses the generation of twisting in the second bellows 200 even when the shaft 150 and the cylindrical member 161 rotate relative to each other.

[0034] Further, one end of the third bellows 300 according to this embodiment is fixed to one of the shaft 150 and the cylindrical member 161. The other end of the third bellows 300, on the other hand, is positioned to the other of the shaft 150 and the cylindrical member 161 being allowed to move in the circumferential direction. This suppresses twisting of third bellows 300 even when the shaft 150 and the cylindrical member 161 rotate relative to each other.

<Advantages of liquid supply system of this embodiment

[0035] As described above, the liquid supply system 100 of this embodiment, the generation of twisting in the second bellows 200 and the third bellows 300 is prevented. This suppresses the generation of torsion buckling in the second bellows 200 and the third bellows 300 and a decrease in the life of the bellows due to fatigue. Further, breakage of the bellows which can be cause of a leak of the liquid can be prevented, thus, the pump chamber can be protected from being exposed to high temperature.

[0036] Specific examples of the sealing structure using each bellows will be described below.

(Example 1)

[0037] A sealing structure according to Example 1 will be described with reference to Fig. 2. A specific example of a sealing structure which includes the second bellows 200 will be shown in Example 1. Fig. 2 is a schematic cross-sectional view depicting the sealing structure according to Example 1.

[0038] The shaft 150 of the sealing structure of Example 1 has an outward flange portion 151 and one end of the second bellows 200 is fixed to it. To the other end of the second bellows 200 is fixed a metal valve body 210. The cylindrical member 161 has an inward flange portion 161a. The end face of the inward flange portion 161a on the sealed space R side is a valve seat 161a1. On the valve seat 161a1 side of the valve body 210, an annular protrusion 211 is disposed as a seal portion. The valve is closed when the annular protrusion 211 is set on the valve seat 161a1.

[0039] As described above, one end of the second bellows 200 of Example 1 is fixed to the shaft 150 and the other end of the second bellows 200 has the valve body 210 disposed on it, which is configured to slide on the valve seat 161a1 in the rotating direction. In other words, the other end of the second bellows 200 is positioned in the state being allowed to move in the circumferential direction with respect to the cylindrical member 161. This suppresses the twisting of the second bellows 200 even when the shaft 150 and the cylindrical member 161 rotate relative to each other. The surface of the valve body 210 or the valve seat 161a1 may be subjected to lubricating treatment such as PTFE coating so that the valve body 210 and the valve seat 161a1 slide with each other more easily.

[0040] In the portion where the other end of the second bellows 200 and the valve body 210 are fixed, the shape of the portion which separate the inside and outside of the second bellows 200 is a circle, and the shape of the tip of the annular protrusion 211, which is a seal portion contacting the valve seat 161a1 in the valve body 210, is a circle. It is designed such that the diameter D2 of the circle of the seal portion is larger than the effective diameter D1 of the second bellows 200. In other words, the area of the seal portion is larger than the effective area of the second bellows 200, hence stable sealing performance can be achieved by the valve body 210. This aspect will be described in more detail below.

[0041] The inside of the second bellows 200 constitutes the second pump chamber P2 and the outside of the second bellows 200 constitutes a damper chamber (sealed space R). The fluid pressure PX in the second pump chamber P2 fluctuates because of pumping, and the maximum pressure thereof is the delivery pressure of the liquid supply system. The fluid pressure PY in the damper chamber, on the other hand, is kept approximately at the delivery pressure because the pressure of the fluid supplied from the first pump chamber P1 and that from the second pump chamber P2 acts thereon, that is, $PY \geq PX$ always holds. The pressing force of the valve body 210 to the valve seat 161a1 depends on the elastic repulsive force by the second bellows 200 and the differential pressure between the fluid pressure in the damper chamber and the fluid pressure in the second pump chamber P2. Therefore if $D2 > D1$, then the valve body 210 can make close contact with the valve seat 161a1 with higher certainty, even under a $PY > PX$ condition. Specifically, the differential pressure of PY and PX acts on the region between S1 and S2, then the force of $(PY - PX) \times (S2 - S1)$ and the elastic repulsive force of the second bellows 200 act on the valve body, where S1 is the effective area of the second bellows 200 corresponding to D1 ($= \pi D1^2/4$), S2 is the seal area corresponding to D2 ($= \pi D2^2/4$), and the downward direction in Fig. 2 is the positive direction. If the force by pressure exceeds the elastic repulsive force of the second bellows 200 for any reason in a state where $PY<PX$ holds, the valve body 210 moves away from the valve seat 161a1 and the valve opens, then the liquid L enters from the second pump chamber P2 to the dumper chamber. Thereby breakage of the first bellows 130 and the second bellows 200 can be prevented. Although the pumping performance may decrease temporarily when the liquid L enters the dumper chamber, the performance of the liquid supply system 100 is not affected.

(Example 2)

[0042] A sealing structure according to Example 2 of the present invention will be described with reference to Fig. 3. Example 2 shows a specific example of the sealing structure which includes the second bellows 200. Fig. 3 is a schematic cross-sectional view depicting the sealing structure according to Example 2.

[0043] The cylindrical member 161 of the sealing structure of Example 2 has an inward flange portion 161b and one end of the second bellows 200 is fixed to it. Specifically, an annular member 230, which is a metal plate, is fixed to one end of the second bellows 200, and the annular member 230 is fixed to the inward flange portion 161b. To the other end of the second bellows 200 is fixed a metal valve body 220. The shaft 150 has an outward flange portion 152. The end face of the outward flange portion 152, on the second pump chamber P2 side, is a valve seat 152a. On the valve seat 152a side of the valve body 220, an annular protrusion 221 is disposed as a seal portion. The valve is closed when the annular protrusion 221 is set on the valve seat 152a.

[0044] As described above, one end of the second bellows 200 of Example 2 is fixed to the cylindrical member 161 and the other end of the second bellows 200 has the valve body 220 disposed on it, which is configured to slide on the valve seat 152a in the rotating direction. In other words, the other end of the second bellows 200 is positioned to the shaft 150 in a state being allowed to move in the circumferential direction. This suppresses the twisting of the second bellows 200 even when the shaft 150 and the cylindrical member 161 rotate relative to each other. The surface of the valve body 220 or the valve seat 161a1 may be subjected to lubricating treatment such as PTFE coating so that the valve body 220 and the valve seat 152a slide with each other more easily.

[0045] In the portion where the other end of the second bellows 200 and the valve body 220 are fixed, the shape of the portion which separates the inside and the outside of the second bellows 200 is a circle, and the shape of the tip of the annular protrusion 221, which is a seal portion contacting the valve seat 152a in the valve body 220 is a circle. It is designed such that the diameter D4 of the circle of the seal portion is larger than the effective diameter D3 of the second bellows 200. Thereby a stable sealing performance can be achieved by the valve body 220, as described in Example 1.

(Example 3)

[0046] A sealing structure according to Example 3 of the present invention will be described with reference to Fig. 4. Example 3 shows a specific example of the sealing structure which includes the second bellows 200. Fig. 4 is a schematic cross-sectional view depicting the sealing structure according to Example 3.

[0047] The shaft 150 of the sealing structure of Example 3 has an outward flange portion 153 and one end of the second bellows 200 is fixed to it. To the other end of the second bellows 200 is fixed a metal seal holding member 240. The seal holding member 240 has a shape which can be obtained by forming an annular groove 241 on an outer peripheral surface of an annular member having a rectangular cross-section. A seal ring 250, which performs the self-sealing function, is installed in the annular groove 241. The portion of the annular groove 241 which makes a close contact with the seal ring 250 functions as the seal portion in this embodiment. This portion makes a contact with the seal ring 250 on the cylindrical member 161 side, thus the fluid is sealed. The seal ring 250 shown in Fig. 4 as an example is a V ring having a V-shaped cross-section. However, the seal ring 250 is not limited to the V ring, but can be various seal rings which perform a self-sealing function, such as a U ring having a U-shaped cross-section and a D ring having a D-shaped cross-section. The seal ring 250 may be made of thin metal or the like, instead of resins such as PTFE and PI.

[0048] An inward flange portion 161c is disposed in the cylindrical member 161. The inward flange portion 161c and the seal holding member 240 are not fixed to each other. In other words, the seal holding member 240 is configured to be slidable on the inward flange portion 161c. The seal ring 250 and the inner peripheral surface of the cylindrical member 161 are slidable with each other.

[0049] As described above, one end of the second bellows 200 of Example 3 is fixed to the shaft 150 and the other end of the second bellows 200 has the seal holding member 240 disposed on it, which is configured to slide on the inward flange portion 161c of the cylindrical member 161 in the rotating direction. Further, the seal ring 250 and the inner peripheral surface of the cylindrical member 161 are slidable with each other. In other words, the other end of the second bellows 200 is positioned to the cylindrical member 161 in a state being allowed to move in the circumferential direction. This suppresses the twisting of the second bellows 200 even when the shaft 150 and the cylindrical member 161 rotate relative to each other. The surface of the seal ring 250 or the inner peripheral surface of the cylindrical member 161 may be subjected to lubricating treatment such as PTFE coating and silver plating so that the seal ring 250 and the inner peripheral surface of the cylindrical member 161 slide with each other more easily.

[0050] In the portion where the other end of the second bellows 200 and the seal holding member 240 are fixed, the shape of the portion which separates the inside and outside of the second bellows 200 is a circle. It is designed such that the inner diameter D6 of the annular groove 241 formed in the seal holding member 240 is larger than the effective diameter D5 of the second bellows 200. Thereby separation of the seal holding member 240 from the inward flange portion 161c can be suppressed due to the same mechanism as described in Example 1 as to the configuration D2 > D1.

[0051] One end of the second bellows 200 of Example 3 is fixed to the shaft 150 and the other end of the second bellows 200 is positioned to the cylindrical member 161 in the state being allowed to move in the circumferential direction. However, one end of the second bellows 200 may be fixed to the cylindrical member 161. In this case, a seal holding member configured to hold a seal ring having a self-sealing function may be disposed on the other end of the second bellows 200, and the seal holding member may be configured to slide on the shaft 150.

(Example 4)

[0052] A sealing structure according to Example 4 of the present invention will be described with reference to Fig. 5. Example 4 shows a specific example of the sealing structure which includes a third bellows 300. Fig. 5 is a schematic cross-sectional view depicting the sealing structure according to Example 4.

[0053] One end of the third bellows 300 of the sealing structure of Example 4 is fixed to the cylindrical member 161. Specifically, the cylindrical member 161 and one end of the third bellows 300 are directly fixed to the first container 110, respectively, whereby one end of the third bellows 300 is fixed to the cylindrical member 161. Further, a metal seal holding member 310 is fixed to the other end of the third bellows 300. The seal holding member 310 has a cylindrical member, and one end of the cylindrical member has an outward flange portion 311 and the other end of the cylindrical member has an annular groove 312 disposed in an inner peripheral surface thereof. The other end of the third bellows 300 is fixed to the outward flange portion 311 in the seal holding member 310. A seal ring 320 made of a rubber-like elastic material is installed in the annular groove 312 of the seal holding member 310. In the example in Fig. 5, the seal ring 320 is an O ring having a circle-shaped cross-section. However, the seal ring 320 is not limited to an O ring, but may be various seal rings such as a square ring having a rectangular cross-section. A rubber material may be used for the seal ring 320 because it is in an environment exposed to air.

[0054] The shaft 150 of the sealing structure Example 4 has a large diameter portion 154 located nearer to the inside of the first container 110 and a small diameter portion 155 located nearer to the outside of the first container 110 (nearer to the air). The small diameter portion 155 is inserted through the cylindrical seal holding member 310. The seal holding member 310 is disposed so that a step surface between the large diameter portion 154 and the small diameter portion 155 faces the end face of the outward flange portion 311. There is a gap between the step surface and the end face of the outward flange portion 311. The step surface and the outward flange portion 311 are configured to slide with each other when they make a contact with each other.

[0055] The seal holding member 310 is positioned with respect to the shaft 150 by constraining force of the seal ring 320 to the shaft 150 (smaller diameter portion 155). This constraining force allows the seal holding member 310 to perform reciprocating motion together with the shaft 150 when the shaft 150 performs reciprocating motion, whereby the third bellows 300 expands and contracts. Further, when the shaft 150 rotates relative to the cylindrical member 161, the shaft 150 and the seal ring 320 are slidable with each other.

[0056] As described above, one end of the third bellows 300 of Example 4 is fixed to the cylindrical member 161. The seal ring 320 and the shaft 150 are slidable in the rotating direction as described above, hence the seal holding member 310 disposed on the other end of the third bellows 300 is rotatable around the shaft 150. In other words, the other end of the third bellows 300 is positioned in a state being allowed to move in the circumferential direction around the shaft 150. This suppresses the twisting of the third bellows 300 even when the shaft 150 and the cylindrical member 161 rotate relative to each other. The surface of the seal ring 320 or on the shaft 150 may be subjected to lubricating treatment such as PTFE coating so that the seal ring 320 and the shaft 150 slide with each other more easily.

(Other)

[0057] The above examples show configurations where the second container 120 is provided in the liquid L contained in the first container 110, thus both the region inside the first bellows 130 and the region outside the first bellows 130 are pump chambers. However, the present invention can be applied to a liquid supply system without the second container, and only the region inside the first bellows is a pump chamber. The present invention can be applied to the liquid supply system 100, illustrated in Fig. 6. Fig. 6 is a schematic configuration diagram depicting the operating state of the liquid supply system according to a modification of the embodiments. The basic configuration of the modification is the same as that of the liquid supply system illustrated in Fig. 1, hence the same elements as Fig. 1 are denoted with the same reference signs, and descriptions thereof will be omitted. The liquid supply system 100 illustrated in Fig. 6 has a fourth bellows 135 in the second container 120, which is fixed to the shaft 150 and expands and contracts in accordance with the reciprocating motion of the shaft 150, similarly to the first bellows 130. A first pump chamber P1 is formed between the outside of the fourth bellows 135 and the second container 120 and a second pump chamber P2 is formed between the outside of the first bellows 130, the second container 120 and the second bellows 200. To this liquid supply system 100 can be applied the above mentioned sealing structures of Examples 1 to 4. The inside of the first container 110 of the liquid supply system 100 may be a vacuum without containing liquid. In this case, a return passage K2 for returning the fluid back to the first container 110 and an inlet (first inlet 121 and second inlet 123) for drawing the liquid into the second container 120 are connected.

[Reference Signs List]

[0058]

100	Liquid supply system
110	First container
120	Second container
121	First inlet
121a, 123a	One way valve
122	First outlet
122a, 124a	One way valve
123	Second inlet
124	Second outlet
130	First bellows
135	Fourth bellows
140	Linear actuator
150	Shaft
151, 152, 153	Outward flange portion
152a	Valve seat
154	Large diameter portion
155	Small diameter portion
160	Cushioning structure
161	Cylindrical member
161a, 161b, 161c	Inward flange portion
161a1	Valve seat
162	Safety valve
200	Second bellows
210	Valve body
211	Annular protrusion
220	Valve body
221	Annular protrusion
230	Annular member
240	Seal holding member
241	Annular groove
250	Seal ring

300	Third bellows
310	Seal holding member
311	Outward flange portion
312	Annular groove
320	Seal ring
400	Cooling apparatus
500	Cooling target apparatus
510	Container
520	Superconducting coil
K1	Supply passage
K2	Return passage
K3	Branch passage
L	Liquid
P1	First pump chamber
P2	Second pump chamber
R	Sealed space

Claims

1. A liquid supply system, comprising:

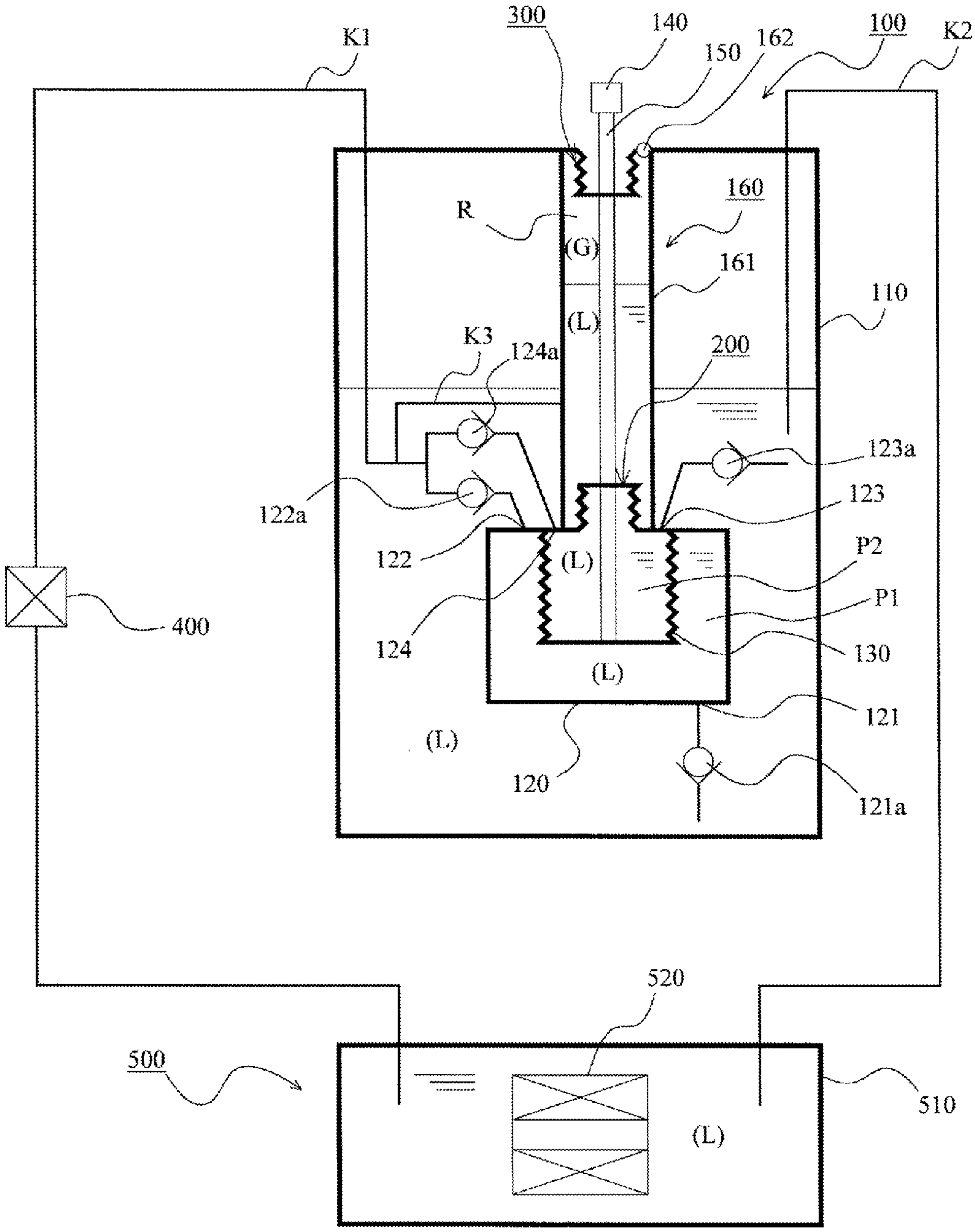
a container;
a shaft which extending from the outside to the inside of the container and configured to perform reciprocating motion by a driving source;
a cylindrical member which is disposed in the container, through which the shaft is inserted;
a first bellows which is fixed to the shaft and configured to expand and contract in accordance with the reciprocating motion of the shaft; and
a second bellows which is configured to expand and contract in accordance with the reciprocating motion of the shaft, the second bellows and the first bellows forming a pump chamber therebetween and the second bellows having an outer diameter smaller than an outer diameter of the first bellows, wherein
one end of the second bellows is fixed to one of the shaft and the cylindrical member, and
the other end of the second bellows is positioned to the other of the shaft and the cylindrical member in a state being allowed to move in a circumferential direction.

2. The liquid supply system according to claim 1, wherein
a seal portion is disposed on the other end of the second bellows, the seal portion being configured to have a contact with the other of the shaft and the cylindrical member to seal fluid and having a larger area than an effective area of the second bellows.

3. The liquid supply system according to claim 1 or 2, further comprising
a third bellows which is configured to expand and contract in accordance with the reciprocating motion of the shaft, the third bellows forming a sealed space between the cylindrical member and the second bellows and the third bellows, wherein
a part of liquid transferred from the pump chamber is supplied to the sealed space.

4. The liquid supply system according to claim 3, wherein
one end of the third bellows is fixed to one of the shaft and the cylindrical member, and
the other end of the third bellows is positioned to the other of the shaft and the cylindrical member in a state being allowed to move in the circumferential direction.

[Fig. 1]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162
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K1
K2
R
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160
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(L)
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K3
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122
(L)
P2
P1
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120
121a
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510
(L)

Fig.1

[Fig. 2]

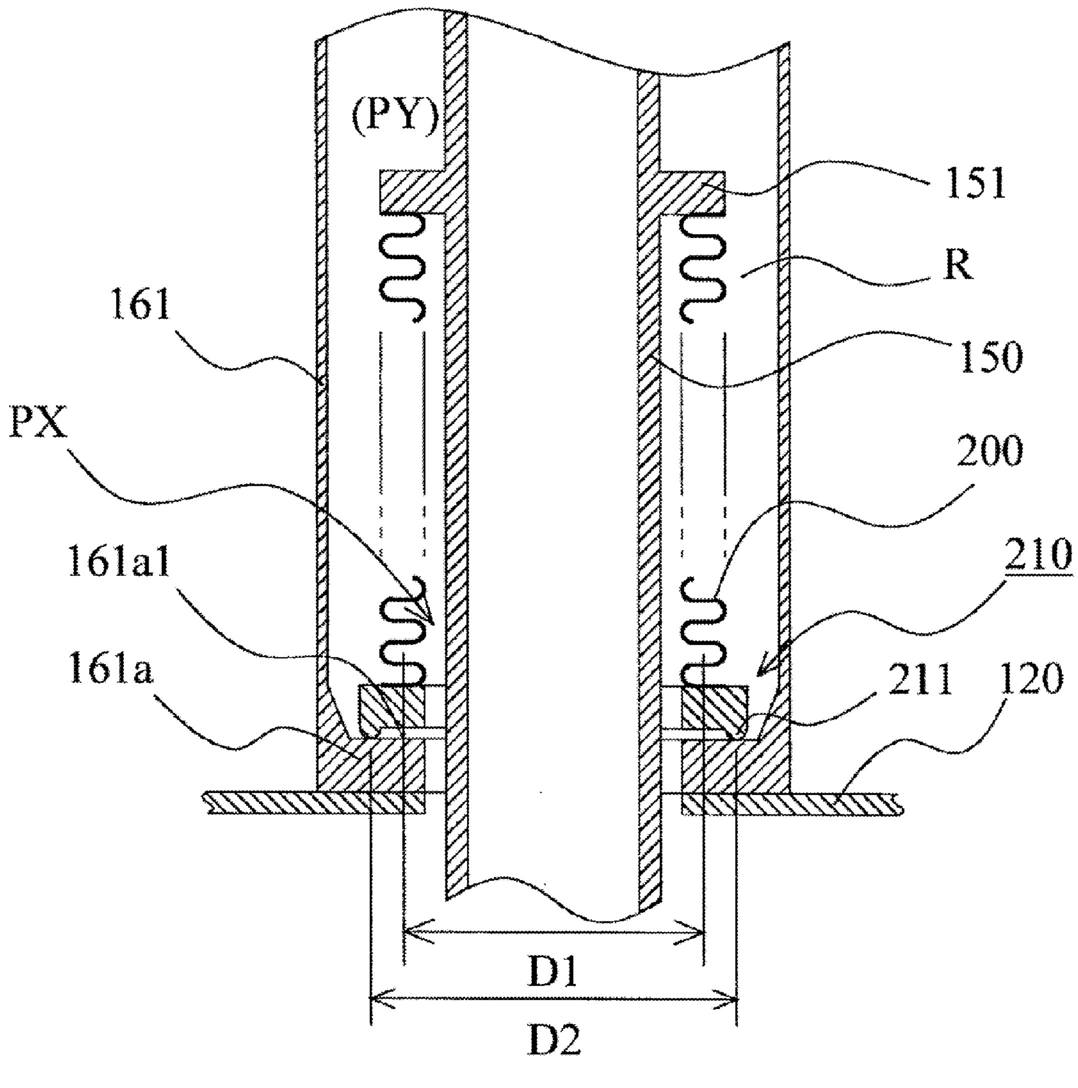


Fig.2

[Fig. 3]

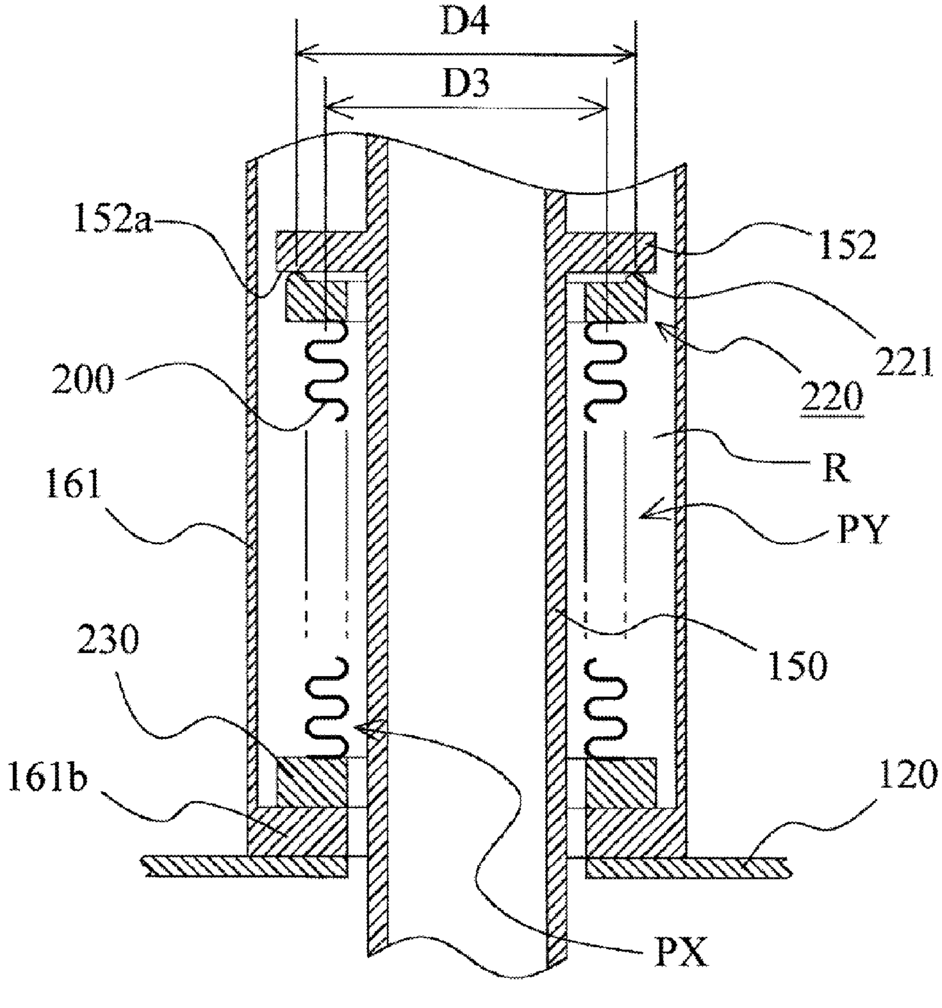


Fig.3

[Fig. 4]

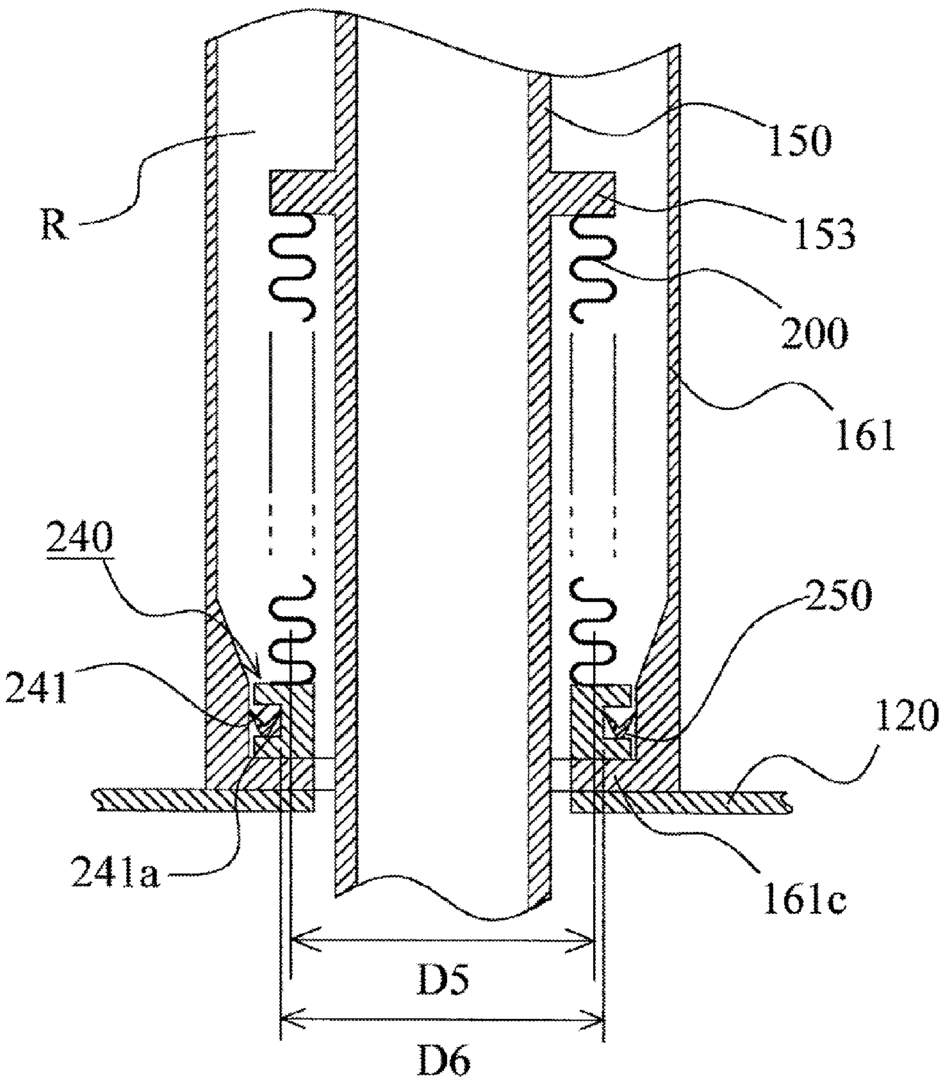


Fig.4

[Fig. 5]

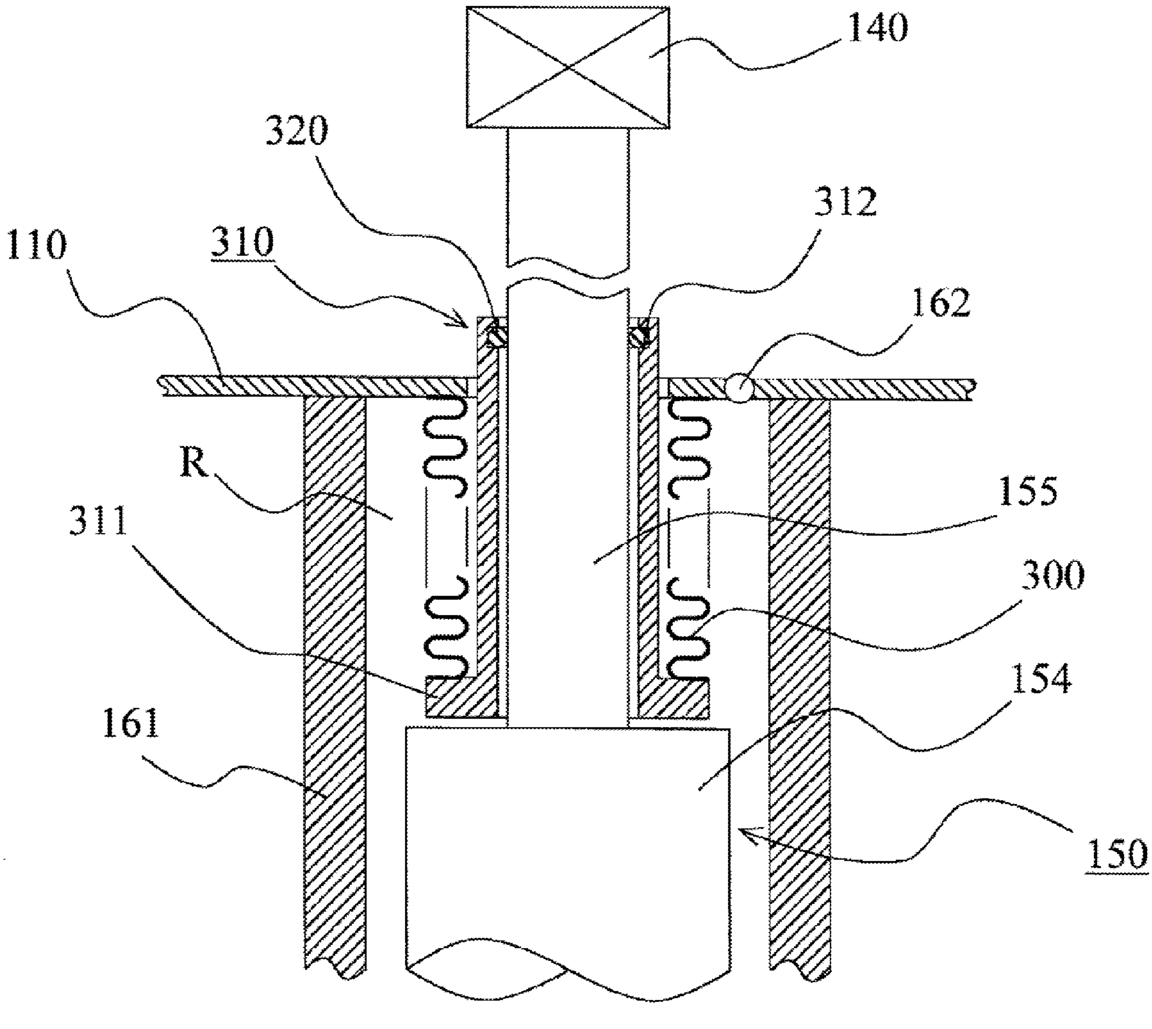
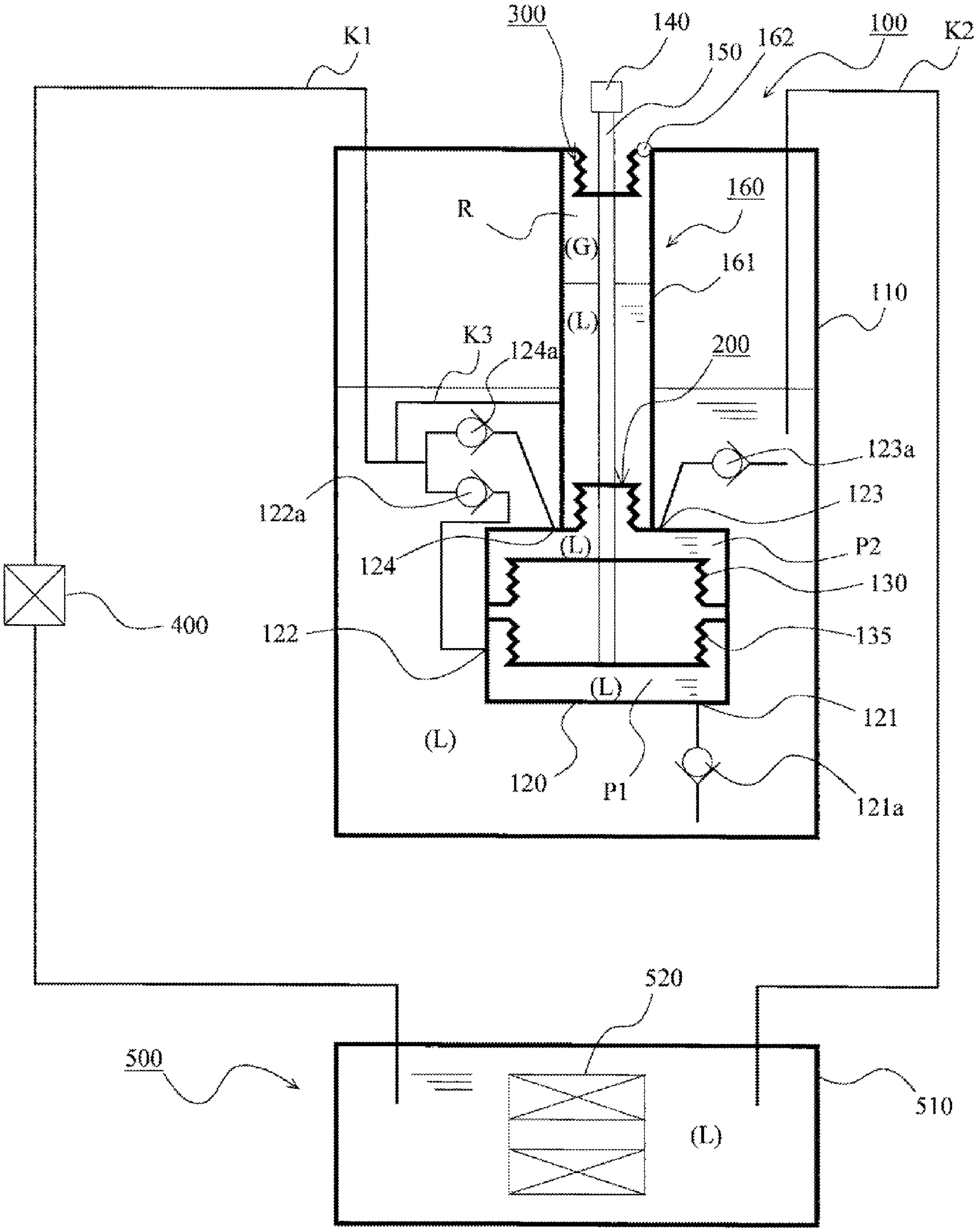


Fig.5

[Fig. 6]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124
(L)
P2
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121
(L)
120
P1
121a
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(L)

Fig.6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2017/029592

A. CLASSIFICATION OF SUBJECT MATTER
F04B43/08(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)
F04B43/08

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

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2017
Kokai Jitsuyo Shinan Koho	1971-2017	Toroku Jitsuyo Shinan Koho	1994-2017

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.
Y A	WO 2012/124363 A1 (Eagle Kogyo Co., Ltd.), 20 September 2012 (20.09.2012), paragraphs [0059] to [0066]; fig. 4 to 5 & US 2014/0054318 A1 paragraphs [0067] to [0074]; fig. 4 to 5 & EP 2687793 A1 & CN 103261817 A	1,3-4 2
Y A	Microfilm of the specification and drawings annexed to the request of Japanese Utility Model Application No. 107317/1988(Laid-open No. 29386/1990) (Eagle Kogyo Co., Ltd.), 26 February 1990 (26.02.1990), specification, page 4, line 17 to page 7, line 13; fig. 1 (Family: none)	1,3-4 2

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

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"O" document referring to an oral disclosure, use, exhibition or other means
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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search
18 October 2017 (18.10.17)

Date of mailing of the international search report
31 October 2017 (31.10.17)

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 2012124363 A **[0004]**