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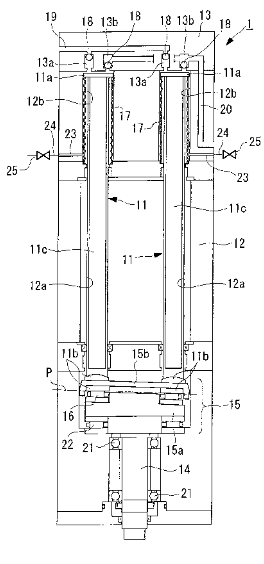
(54) BOOSTER PUMP AND STORAGE TANK FOR LOW-TEMPERATURE FLUID COMPRISING SAME

(57) A low-temperature-fluid storage tank capable of efficiently increasing the pressure of fluid without heating the fluid is provided. There is provided a booster pump which includes a piston having a piston head and a piston rod and a cylinder having a compression chamber that accommodates the piston head so that a fluid is compressed by one end surface of the piston head. The piston head is provided with a bellows for separating a space adjacent to the piston rod from a space adjacent to the cylinder in the compression chamber.

FIG. 1



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Description

Technical Field

[0001] The present invention relates to a booster pump for compressing low-temperature fluids to increase the pressure and to a low-temperature-fluid storage tank having the same.

Background Art

[0002] Some known (low-temperature-fluid) booster pumps for compressing low-temperature (e.g., -273°C to 0°C) fluids (e.g., hydrogen, nitrogen, LNG) to increase the pressure have piston rings on piston heads thereof (refer to, for example, non-Patent Document 1).
Non-patent Document 1:
Takuya Endo et al., "Shin Enerugii Jidousha (New Energy Automobile)," Sankaido, January 1995, p. 221-222

Disclosure of Invention

[0003] However, such a known (low-temperature-fluid) booster pump has a problem in that a sliding motion occurs while the outer circumferential surfaces of the piston rings are being pressed onto the inner circumferential surface of a cylinder in order to maintain hermeticity, and consequently, friction between these piston rings and the cylinder generates heat, which warms up the fluid. Another problem is that, particularly when high pressure is to be achieved, a high-pressure fluid flowing towards the inner circumferential surfaces of the piston rings even more forcibly presses the outer circumferential surfaces of the piston rings onto the inner circumferential surface of the cylinder, which produces still more considerable friction between these piston rings and the cylinder and consequently generates a larger amount of heat.
In addition, it is not possible to completely eliminate gaps between the outer circumferential surfaces of the piston rings and the inner circumferential surface of the cylinder, and therefore, fluid leaks through these gaps, thus causing the compression efficiency to decrease.
Furthermore, such a known (low-temperature-fluid) booster pump requires a piston rod disposed between a piston head and a drive mechanism to have a large diameter in order to prevent this piston rod from buckling due to compressive force when a low-temperature fluid is to be compressed. For this reason, heat originating from the drive mechanism is transmitted to low-temperature fluid via the piston rod and the piston head, thereby warming up the low-temperature fluid so considerably as to cause boil-off.

[0004] The present invention has been conceived in light of the above-described circumstances, and an object of the present invention is to provide a booster pump for increasing the pressure of a fluid efficiently without heating the fluid and to provide a low-temperature-fluid storage tank having such a booster pump.

[0005] To overcome the above-described problems, the present invention employs the following solutions.
The present invention provides a booster pump which includes a piston having a piston head and a piston rod and a cylinder having a compression chamber that accommodates the piston head so that a fluid is compressed by one end surface of the piston head, wherein the piston head is provided with a bellows for separating a space adjacent to the piston rod from a space adjacent to the cylinder in the compression chamber.
According to the present invention, the bellows separates a space adjacent to the piston rod from a space adjacent to the cylinder in the compression chamber, and there is no component (e.g., piston ring in the known art) that moves in contact with the inner circumferential surface of the compression chamber. This prevents heat from being generated in the compression chamber and therefore prevents the fluid from being heated.
In addition, since the bellows completely separates a space adjacent to the piston rod from a space adjacent to the cylinder in the compression chamber, the fluid is prevented from leaking from the cylinder side of the compression chamber to the piston rod side of the compression chamber. This improves the pump efficiency.

[0006] In the above-described invention, it is preferable that a filler filling a space between an outer surface of the bellows and an inner circumferential surface of the cylinder be provided.
By doing so, the gap between the outer surface of the bellows and the inner circumferential surface of the compression chamber is filled, and the dead volume of the compression chamber decreases. This improves the pump efficiency.

[0007] In the above-described invention, it is preferable that a ring-shaped sealing member be provided at one end portion, adjacent to the piston head, of the bellows.
By doing so, the sealing member can reduce leakage of the fluid from one end surface towards the other end surface of the piston head, which would reduce the pressure applied to the outer circumferential surface of the bellows. This allows a low-pressure bellows which does not need to meet strict robust design requirements to be employed and therefore allows the piston to have a large stroke. Consequently, the compression efficiency (pump efficiency) can be improved.
This sealing member neither has tension, as has been problematic, for example, with a piston ring in the known art, nor generates heat, as with a piston ring, because the bellows considerably restricts the stroke of the piston (the stroke is small).

[0008] In the above-described invention, it is preferable that the piston rod have a heat-insulating vacuum structure that is hollow and vacuumed.
As a result of the piston rod having a hollow structure, the weight of the piston rod can be reduced so that the piston can be pushed up under a small load. In addition, by vacuuming the interior of the piston rod, the piston rod

can block heat to reduce the amount of heat propagating from the piston rod into the fluid.

[0009] The present invention provides a booster pump which includes at least two of the above-described booster pumps, wherein multistage compression is performed with these booster pumps.

According to the present invention, if, for example, two booster pumps are provided, one booster pump can be used as a low-pressure pump and the other can be used as a high-pressure pump. By doing so, since the low-pressure pump can employ a low-pressure bellows, the piston can have a large stroke to easily increase the pressure of the fluid from a low pressure to an intermediate pressure. Furthermore, since the high-pressure pump can employ a high-pressure bellows, the intermediate pressure of the fluid can easily be increased to a high pressure, even though the piston cannot have a large stroke.

In other words, if the pressure of the fluid is to be increased from low pressure to high pressure in one stroke using only one booster pump, the high-pressure bellows needs to be employed, which does not allow a large stroke. This makes it difficult to increase the fluid to the desired pressure (high pressure).

In contrast, as described above, the fluid can easily be increased to the desired pressure by carrying out dual-stage compression of the fluid using, for example, two pumps.

[0010] The present invention provides a low-temperature-fluid storage tank for storing a low-temperature fluid in a low-temperature state. The low-temperature-fluid storage tank includes the above-described booster pump or the above-described booster; a low-temperature-fluid reservoir reserving the low-temperature fluid; and a low-temperature container for accommodating the booster pump or the booster and the low-temperature-fluid reservoir.

According to the present invention, since the booster pump or the booster is disposed in the low-temperature container, the booster pump or the booster is forcibly cooled and is not easily heated up.

[0011] In the above-described invention, it is preferable that the booster pump or the booster be disposed downstream of the low-temperature-fluid reservoir and outside the low-temperature-fluid reservoir.

Since the booster pump or the booster is disposed outside the low-temperature-fluid reservoir (i.e., separately from the low-temperature-fluid reservoir in the heat-insulated vacuum chamber of the low-temperature container), heat generated in a driving source of the booster pump or the booster is prevented from being transmitted to the low-temperature fluid reserved in the low-temperature-fluid reservoir, and therefore, temperature increase and vaporization of the low-temperature fluid can be prevented.

[0012] In the above-described invention, it is preferable that a low-temperature slush fluid in a solid/liquid two-phase state be reserved in the low-temperature-fluid reservoir.

The low-temperature-fluid storage layer contains the slushy low-temperature fluid (mixture of solid low-temperature fluid and liquid low-temperature fluid in a liquid/ice state) and experiences vaporization less easily than tanks containing only liquid low-temperature fluids. This improves the suction performance of the booster pump or the booster and therefore increases the amount of low-temperature fluid supplied.

[0013] In the above-described invention, it is preferable that a mesh be provided at an outlet of the low-temperature-fluid reservoir.

Solid low-temperature fluid of the slush fluid is captured by the mesh, and therefore, only liquid low-temperature fluid is supplied to the booster pump or the booster downstream of the low-temperature-fluid reservoir. This prevents the booster pump or the booster from clogging.

[0014] In the above-described invention, it is preferable that a heater be provided in the low-temperature-fluid reservoir.

By doing so, the solid low-temperature fluid in the low-temperature-fluid reservoir is heated by the heater into a liquid low-temperature fluid, which then passes though the mesh up to the booster pump or the booster.

[0015] In the above-described invention, it is preferable that a heat exchanger be disposed downstream of the booster pump or the booster.

By doing so, the low-temperature fluid that has passed through the booster pump or the booster by the heat exchanger is vaporized by the heat exchanger and is then supplied to, for example, an engine disposed downstream for smooth consumption in the engine.

[0016] In the above-described invention, it is preferable that a radiation shield plate be provided on an inner surface of the low-temperature container.

By doing so, the radiation shield plate prevents heat from being transmitted from the outside to the inside of the low-temperature container. This prevents an increase in the temperature of the heat-insulating vacuum layer in the low-temperature container.

[0017] The present invention provides a low-temperature-fluid boosting pump which includes a cylinder block having therein a compression chamber; and a piston head that is accommodated in the compression chamber and reciprocates in the compression chamber so that a low-temperature fluid is compressed by one end surface of the piston head, wherein a flexible partition for separating a space adjacent to an inner circumferential side from a space adjacent to an outer circumferential side of the piston head is provided between the one end surface of the piston head and an inner surface of the compression chamber which faces the one end surface.

According to the present invention, as a result of the piston head moving in one direction, a low-temperature fluid is drawn into (supplied to) the inner space (i.e., the space formed by the one end surface of the piston head, the inner circumferential surface of the partition, and the inner surface of the compression chamber) of the partition.

Then, as a result of the piston head moving in the other direction, the low-temperature fluid is compressed (pressure-boosted) to a predetermined pressure.
More specifically, there are no components (e.g., piston rings in the known art) that move in contact with each other between the piston head and the inner circumferential surface of the compression chamber and between the partition and the inner circumferential surface of the compression chamber.
This prevents heat from being generated in the compression chamber and therefore prevents the low-temperature fluid from being heated.
In addition, the partition completely partitions the inner circumferential side (inward position in the radial direction) from the outer circumferential side (outward position in the radial direction) of the compression chamber. Therefore, low-temperature fluid can be prevented from leaking from the inner circumferential side of the compression chamber to the outer circumferential side of the compression chamber (or from the outer circumferential side of the compression chamber to the inner circumferential side of the compression chamber). This improves the compression efficiency of the low-temperature-fluid boosting pump.

[0018] In the above-described invention, it is preferable that a pressure-boosted fluid reside on an outer side of the partition.
For example, a vaporized low-temperature fluid having a predetermined pressure is provided (supplied) to an outer side of the partition, and the pressure difference between the inner side and the outer side of the partition becomes small (becomes closer).
More specifically, for example, a low-temperature fluid that has been vaporized as a result of being heated by the heat exchanger and subjected to pressure adjustment by the pressure regulator to a predetermined pressure (e.g., a pressure half the pressure-boosting force of the present booster pump) exists on the outer side (towards the outside in the radial direction) of the partition. Because of this, deformation of the partition can be prevented when the low-temperature fluid drawn into the inner space of the partition is to be compressed, and therefore, the service life of the partition can be extended. This improves the reliability of the low-temperature-fluid boosting pump.

[0019] In the above-described invention, it is preferable that an outer side of the partition be vacuumed.
In other words, the space between the partition and the cylinder block is vacuumed so that the heat on an inner side of the partition (i.e., heat of the low-temperature fluid compressed on the inner side of the partition) is prevented from being transmitted to the cylinder block.
By doing so, not only is an increase in the temperature of the cylinder block suppressed, but also an increase in the temperature of the low-temperature fluid flowing into the compression chamber is suppressed.

[0020] The present invention provides a low-temperature-fluid boosting pump which includes a piston rod driven by a drive unit connected to a driving source; a piston head that is connected to the piston rod and reciprocates with the piston rod; and a cylinder having a compression chamber that accommodates the piston head so that a low-temperature fluid is compressed by one end surface of the piston head, wherein the drive unit is disposed adjacent to the one end surface of the piston head, and a shank of the piston rod is subjected to a tensile force in a direction substantially equal to a direction in which the shank extends when the low-temperature fluid is to be compressed.
According to the present invention, as a result of the piston rod being pulled towards the drive unit, the low-temperature fluid is compressed by one end surface of the piston head. In other words, when the low-temperature fluid is to be compressed, no compressive force is applied to the piston rod.
As a result, the diameter of the piston rod can be reduced compared with a piston rod in the known art, which is subjected to a compressive force. Therefore, not only can the amount of heat entering from a driving source be reduced, but also the weight of the piston rod can be reduced. Consequently, the weight of the entire pump can also be reduced.
In addition, since the piston rod is not subjected to a compressive force when the low-temperature fluid is to be compressed, the diameter of the piston head can be increased. In other words, for the known pump where a compressive force is applied to the piston rod, the diameter of the piston head is limited to, for example, 40 mm to prevent the piston rod from buckling. For this reason, the known pump required, for example, five cylinders to achieve a sufficient flow volume of low-temperature fluid. For the pump according to the present invention, however, the diameter of the piston head can be, for example, 100 mm, and therefore, a sufficient flow volume can be achieved with a single cylinder.
As a result, for the pump according to the present invention, not only can the structure of the pump be simplified, but also the entire pump can be made lightweight and compact.

[0021] In the above-described invention, it is preferable that the piston head be divided into at least two concentric subsections to achieve a multistage compression structure where the low-temperature fluid is gradually increased to a desired pressure by sequentially passing through the one end surface of the divided piston head. The piston head is divided into, for example, two subsections, one subsection disposed towards the outside in the radial direction and the other disposed towards the inside in the radial direction, so that the first compression (first-stage compression) is carried out with the subsection disposed towards the outside in the radial direction and the second compression (second-stage compression) is carried out with the subsection disposed towards the inside in the radial direction. In other words, instead of increasing the pressure from a low pressure to a high pressure in one stroke, the low-temperature fluid is temporarily increased to an intermediate pressure, which is then increased to a desired pressure (high pressure).

By doing so, the stroke of the piston head can be made small, and therefore, the size of the entire pump in the longitudinal direction can be reduced. This contributes to compact design of the pump.

[0022] In the above-described invention, it is preferable that a flexible partition for separating a space adjacent to the piston rod from a space adjacent to the cylinder in the compression chamber be provided adjacent to the one end surface and adjacent to the other end surface of the piston head.

The partition separates the space adjacent to the piston rod from the space adjacent to the cylinder in the compression chamber, and there is no component (e.g., piston ring in the known art) that moves in contact with the inner circumferential surface of the compression chamber. This prevents heat from being generated in the compression chamber and therefore prevents the flow-temperature fluid from being heated.

In addition, since the partition completely separates a space adjacent to the piston rod from a space adjacent to the cylinder in the compression chamber, the low-temperature fluid is prevented from leaking from the cylinder side of the compression chamber to the piston rod side of the compression chamber. This improves the compression efficiency.

[0023] In the above-described invention, it is preferable that a flexible partition for separating a space adjacent to the piston rod from a space adjacent to the cylinder in the compression chamber be provided adjacent to the other end surface of the piston head.

By doing so, since all the flexible partitions are provided on the side opposite to the one end surface (compressive surface) of the piston head, the length of the pump in the height direction (longitudinal direction) can be reduced, and therefore, the pump can be made compact.

In addition, since the one end surface (compressive surface) of the piston head can be utilized to the full extent for compression of the low-temperature fluid, a larger amount of low-temperature fluid can be compressed at a time. In short, the efficiency (performance) of the pump can be improved.

[0024] In the above-described invention, it is preferable that a precooling layer be formed in the cylinder.

By doing so, the entire pump can be cooled sufficiently before the pump is started. This decreases vaporization (boil-off) of the low-temperature fluid supplied to the pump.

Furthermore, since this precooling layer also serves as a heat-insulating layer while the pump is being operated, vaporization (boil-off) of the low-temperature fluid can be reduced also while the pump is being operated.

[0025] In the above-described invention, it is preferable that the drive unit be linked to the piston rod via a heat-insulating connection section.

Since the drive unit is linked to the piston rod via, for example, rolling elements (e.g., balls and rollers) in point or line contact, heat can be significantly prevented from being transmitted (entering) from the drive unit (i.e., driving source) to the piston rod (i.e., piston head).

[0026] In the above-described invention, it is preferable that the piston head be linked to the piston rod via a heat insulator.

Since the piston head is linked to the piston rod via the heat insulator, even if heat is transmitted (enters) from the drive unit to the piston rod, heat being transmitted (entering) from the piston rod to the piston head is blocked by the heat insulator.

[0027] In the above-described invention, it is preferable that a guiding member for guiding the shank of the piston rod be provided between the cylinder and the piston rod.

The guiding member is provided to prevent the piston rod, the piston head, etc., which are housed in the cylinder and reciprocate in the cylinder, from interfering with the inner wall surface (cylinder wall) of the cylinder.

By doing so, reciprocating members such as the piston rod and the piston head perform reciprocal movement in the cylinder without wobbling or vibrating. This can prevent such reciprocating members from interfering with the inner wall surface of the cylinder, and furthermore, allows the reciprocating members to be driven smoothly with minimum driving force.

[0028] In the above-described invention, it is preferable that a space between the cylinder and the shank of the piston rod be a vacuum.

In other words, since the space between the cylinder and the piston rod is vacuumed, heat from the piston rod (i.e., heat from the driving source to the piston rod) is prevented from being transmitted to the cylinder.

As a result, not only is an increase in the temperature of the cylinder suppressed, but also an increase in the temperature of the low-temperature fluid flowing into the compression chamber is suppressed.

[0029] In the above-described invention, it is preferable that the cylinder be immersed in low-temperature fluid stored in a low-temperature-fluid storage tank and be attachable to and detachable from the low-temperature-fluid storage tank.

By doing so, the exterior of a portion that accommodates portions for compressing the low-temperature fluid therein, such as the cylinder and the piston head, is immersed in the low-temperature fluid and is always maintained in a low-temperature state. Furthermore, the cylinder is mounted on a lower portion (bottom portion) of the low-temperature-fluid storage tank such that it is easily replaceable.

[0030] It is preferable that the drive unit and the cylinder be immersed in low-temperature fluid stored in a low-temperature-fluid storage tank and be attachable to and detachable from the low-temperature-fluid storage tank.

By doing so, the exterior of the entire pump, including a portion that accommodates portions for compressing the low-temperature fluid therein, such as the cylinder and the piston head, is immersed in the low-temperature fluid and is always maintained in a low-temperature state. Furthermore, the low-temperature-fluid boosting pump is mounted on a lower portion (bottom portion) of the low-temperature-fluid storage tank such that it is easily replaceable.

[0031] The present invention provides a low-temperature-fluid feeder which includes the above-described low-temperature-fluid boosting pump; a chamber for reserving a low-temperature fluid whose pressure has been increased by the above-described low-temperature-fluid boosting pump; and a fuel injector supplied with the low-temperature fluid from the chamber.

According to the present invention, the low-temperature fluid whose pressure has been increased to a desired pressure by the low-temperature-fluid boosting pump is temporarily reserved in the chamber disposed downstream of the low-temperature-fluid boosting pump and then passes through a fuel injector into, for example, a combustion chamber, such as an engine.

[0032] In the above-described invention, it is preferable that a booster-fluid feeding unit for liquefying or vaporizing the low-temperature fluid in the chamber and supplying the low-temperature fluid into the cylinder disposed adjacent to the other end surface of the piston head of the low-temperature-fluid boosting pump be provided.

By doing so, the low-temperature fluid in the chamber (or the fluid generated by liquefying or vaporizing the low-temperature fluid in the chamber and decreasing the pressure of the liquefied or vaporized fluid using, for example, a pressure regulator) is supplied into the cylinder disposed adjacent to the other end surface of the piston head. This decreases the difference between the pressure on the one end surface (compressive surface) side and the pressure on the other end surface side of the piston head, thus allowing a bellows with low pressure resistance to be employed.

[0033] In the above-described invention, it is preferable that a booster-fluid feeding unit for vaporizing the low-temperature fluid in the above-described chamber in a path to the fuel injector and for supplying the low-temperature fluid to the cylinder disposed adjacent to the other end surface of the piston head of the low-temperature-fluid boosting pump be provided.

By doing so, the low-temperature fluid in the chamber (or the fluid generated by or vaporizing the low-temperature fluid in the chamber and decreasing the pressure of the vaporized fluid using, for example, a pressure regulator) is supplied into the cylinder disposed adjacent to the other end surface of the piston head. This decreases the difference between the pressure on the one end surface (compressive surface) side and the pressure on the other end surface side of the piston head, thus allowing a bellows with low pressure resistance to be employed.

[0034] In the above-described invention, it is preferable that the chamber be provided with a relief valve.

By doing so, if the pressure of the chamber storing the low-temperature fluid exceeds a predetermined pressure, the relief valve operates to prevent the chamber from being damaged. The low-temperature fluid discharged from the relief valve returns through, for example, a return pipe to the suction side of the pump (or a separate fuel battery, if any fuel battery is provided).

[0035] The present invention provides a low-temperature-fluid boosting pump which includes a cylinder block having therein a compression chamber; and a piston head that is accommodated in the compression chamber and reciprocates in the compression chamber so that a low-temperature fluid is compressed by one end surface of the piston head, wherein a flexible partition for separating a space adjacent to an inner circumferential side from a space adjacent to an outer circumferential side in the compression chamber is provided adjacent to the other end surface of the piston head.

According to the present invention, as a result of the piston head moving in one direction, a low-temperature fluid is drawn into (supplied to) the compression chamber. Then, as a result of the piston head moving in the other direction, the low-temperature fluid is compressed (pressure-boosted) to a predetermined pressure.

More specifically, there are no components (e.g., piston rings in the known art) that move in contact with each other between the piston head and the inner circumferential surface of the compression chamber and between the partition and the inner circumferential surface of the compression chamber.

This prevents heat from being generated in the compression chamber and therefore prevents the low-temperature fluid from being heated.

In addition, the partition completely partitions the inner circumferential side (inward position in the radial direction) from the outer circumferential side (outward position in the radial direction) of the compression chamber. Therefore, low-temperature fluid can be prevented from leaking from the inner circumferential side of the compression chamber to the outer circumferential side of the compression chamber (or from the outer circumferential side of the compression chamber to the inner circumferential side of the compression chamber). This improves the compression efficiency of the low-temperature-fluid boosting pump.

[0036] In the above-described invention, it is preferable that a pressure-boosted fluid reside on an inner side of the partition.

For example, a vaporized low-temperature fluid having a predetermined pressure is provided at (supplied to) an inner side of the partition, and the pressure difference between the inner side and the outer side of the partition becomes small (becomes closer).

More specifically, for example, a low-temperature fluid that has been vaporized as a result of being heated by the heat exchanger and subjected to pressure adjustment by the pressure regulator to a predetermined pressure (e.g., a pressure half the pressure-boosting force of the present booster pump) exists on the inner side (towards the inside in the radial direction) of the partition.

Because of this, deformation of the partition can be prevented when the low-temperature fluid drawn into the compression chamber is to be compressed, and therefore, the service life of the partition can be extended. This improves the reliability of the low-temperature-fluid boosting pump.

[0037] In the above-described invention, it is preferable that an inner side of the partition be vacuumed.

By doing so, even if, for example, a piston rod linked to the piston head is provided on the inner side of the partition, heat from this piston rod (e.g., heat being transmitted from the driving source to the piston rod) is prevented from being transmitted to the outer side of the partition. As a result, not only is an increase in the temperature of the cylinder block disposed on the outer side of the partition suppressed, but also an increase in the temperature of the low-temperature fluid flowing into the compression chamber is suppressed.

[0038] In the above-described invention, it is preferable that a guiding member for guiding the piston head be provided between the cylinder block and the piston head. The guiding member is provided to prevent the piston rod, the piston head, etc., which are housed in the cylinder and reciprocate in the cylinder, from interfering with the inner wall surface (cylinder wall) of the cylinder.

By doing so, reciprocating members such as the piston rod and the piston head perform reciprocal movement in the cylinder without wobbling or vibrating. This can prevent such reciprocating members from interfering with the inner wall surface of the cylinder, and furthermore, allows the reciprocating members to be driven smoothly with minimum driving force.

[0039] In the above-described invention, it is preferable that the cylinder block be immersed in low-temperature fluid stored in a low-temperature-fluid storage tank and be attachable to and detachable from the low-temperature-fluid storage tank.

By doing so, the exterior of a portion that accommodates portions for compressing the low-temperature fluid therein, such as the cylinder block and the piston head, is immersed in the low-temperature fluid and is always maintained in a low-temperature state. Furthermore, the cylinder block is mounted on a lower portion (bottom portion) of the low-temperature-fluid storage tank such that it is easily replaceable.

[0040] The present invention affords an advantage in that the pressure of fluid can be increased efficiently without heating the fluid.

Brief Description of Drawings

[0041]

[FIG. 1] Fig. 1 is a schematic longitudinal sectional view of a first embodiment of a booster pump according to the present invention.

[FIG. 2] Fig. 2 is a magnified and simplified cross-sectional view of a main part shown in Fig. 1.

[FIG. 3] Fig. 3 is a magnified cross-sectional view of a main part of a second embodiment of a booster pump according to the present invention.

[FIG. 4] Fig. 4 is a magnified cross-sectional view of a main part of a third embodiment of a booster pump according to the present invention.

[FIG. 5] Fig. 5 is a magnified cross-sectional view of a main part of a fourth embodiment of a booster pump according to the present invention.

[FIG. 6] Fig. 6 is a magnified cross-sectional view of a main part of a fifth embodiment of a booster pump according to the present invention.

[FIG. 7] Fig. 7 is a schematic diagram of a main part of one embodiment of a booster according to the present invention.

[FIG. 8] Fig. 8 is a graph illustrating dual-stage compression achieved using the booster shown in Fig. 7.

[FIG. 9] Fig. 9 is a schematic diagram depicting one embodiment of a low-temperature-fluid storage tank according to the present invention.

[FIG. 10] Fig. 10 is a schematic diagram depicting another embodiment of a low-temperature-fluid storage tank according to the present invention.

[FIG. 11] Fig. 11 is a schematic longitudinal sectional view of a sixth embodiment of a low-temperature-fluid boosting pump according to the present invention.

[FIG. 12] Fig. 12 is a cross-sectional view taken along line XII-XII of Fig. 11.

[FIG. 13] Fig. 13 is a schematic longitudinal sectional view of a seventh embodiment of a low-temperature-fluid boosting pump according to the present invention.

[FIG. 14] Fig. 14 is a schematic longitudinal sectional view of an eighth embodiment of a low-temperature-fluid boosting pump according to the present invention.

[FIG. 15] Fig. 15 is a cross-sectional view taken along line XV-XV of Fig. 14.

[FIG. 16] Fig. 16 is a magnified longitudinal sectional view of a main part of a ninth embodiment of a low-temperature-fluid boosting pump according to the present invention.

[FIG. 17] Fig. 17 is a schematic longitudinal sectional view of a tenth embodiment of a low-temperature-fluid boosting pump according to the present invention.

[FIG. 18] Fig. 18 is a schematic longitudinal sectional view of an eleventh embodiment of a low-temperature-fluid boosting pump according to the present invention.

[FIG. 19] Fig. 19 is a schematic longitudinal sectional view of a twelfth embodiment of a low-temperature-fluid boosting pump according to the present invention.

[FIG. 20] Fig. 20 is a schematic longitudinal sectional view of a thirteenth embodiment of a low-temperature-fluid boosting pump according to the present invention.

[FIG. 21] Fig. 21 is a schematic longitudinal sectional view of a fourteenth embodiment of a low-temperature-fluid boosting pump according to the present invention.

[FIG. 22] Fig. 22 is a magnified longitudinal sectional view of another embodiment of a bellows applied to a low-temperature-fluid boosting pump according to the present invention.

[FIG. 23] Fig. 23 is a magnified longitudinal sectional view of another embodiment of a heat-insulating connection section applied to a low-temperature-fluid boosting pump according to the present invention.

[FIG. 24] Fig. 24 is a schematic longitudinal sectional view illustrating a fifteenth embodiment of a low-temperature-fluid boosting pump according to the present invention.

[FIG. 25] Fig. 25 is across-sectional view taken along line XXV-XXV of Fig. 24.

[FIG. 26] Fig. 26 is a schematic longitudinal sectional view of a sixteenth embodiment of a low-temperature-fluid boosting pump according to the present invention.

Best Mode for Carrying Out the Invention

[0042] A first embodiment of a (low-temperature-fluid) booster pump according to the present invention will now be described with reference to the drawings.

As shown in Fig. 1, a booster pump 1 according to this embodiment is a so-called swash-plate (or swash) booster pump. The booster pump 1 includes major components such as a plurality of (e.g., seven) pistons 11; a cylinder block 12; a cylinder head 13; a drive shaft 14; and a swash plate (also called a "yoke") 15.

[0043] Each piston 11 is a substantially rod-like member which has a circular cross-section. Each piston 11 has a piston head 11a on one end portion thereof and a piston shoe 11b on the other end portion thereof. Each of the pistons 11 is reciprocably housed in a cylinder 12a, which will be described later.

The piston head 11a is a so-called large-diameter portion that has an outer diameter larger than the outer diameter of a piston rod 11c that links this piston head 11a and the piston shoe 11b. A low-temperature fluid (e.g., liquid hydrogen, liquid nitrogen, liquefied carbon dioxide, liquefied natural gas, or liquefied propane gas) is compressed by one flat end surface (upper end surface in Fig. 1) of this piston head 11a.

Like the piston head 11a, the piston shoe 11b is also a so-called large-diameter portion that has an outer diameter larger than the outer diameter of the piston rod 11c. The piston shoe 11b is partially interposed, on an end-surface side thereof, between a shoe plate 15a and a retainer ring 15b of the swash plate 15, which will be described later. Furthermore, the end surface of the piston shoe 11b slides along a tilt angle of the swash plate 15 (a sliding surface P of a thrust roller bearing 16 disposed between the shoe plate 15a and the retainer ring 15b).

The cylinder block 12 has therein the same number of cylinders 12a as that of the pistons 11 and the cylinders 12a are formed in a ring, extending along a longitudinal direction (vertical direction in Fig. 1). Each cylinder 12a accommodates one piston 11.

A compression chamber 12b having an inner diameter larger than the outer diameter of the piston head 11a is provided on one end of each cylinder 12a (upper side in Fig. 1) so that this compression chamber 12b accommodates the piston head 11a.

[0044] As shown in Fig. 1 and Fig. 2, which is a magnified view of the main part shown in Fig. 1, a bellows 17 is provided in the compression chamber 12b.

This bellows 17 partitions (separates) an inner circumferential side (piston 11 side) from an outer circumferential side (cylinder block 12 side) of the compression chamber 12b, which is disposed closer to the piston shoe 11b (lower side in Fig. 1) than the piston head 11a. One end surface of the bellows 17 is affixed to a surface opposite (other end surface) one end surface of the piston head 11a, and the other end of the bellows 17 is affixed to an inner wall surface of the cylinder block 12.

Furthermore, this bellows 17 is made of, for example, stainless steel or Inconel, which exhibits elasticity at (super) low temperatures.

[0045] The cylinder head 13 covers one end surface (upper end surface in Fig. 1) of the cylinder block 12 to close the open ends of the cylinders 12a formed in the cylinder block 12 (i.e., open ends of the compression chambers 12b).

On one end surface (lower end surface in Fig. 1) of this cylinder head 13, that is, on the surface which faces one end surface of the cylinder block 12, a suction port 13a and a discharge port 13b are provided for each compression chamber 12b. Each of the suction port 13a and the discharge port 13b is provided with a ball check valve 18 (a spring is not shown in the figure for the sake of simplicity) to control suction and discharge of low-temperature fluid. Furthermore, each suction port 13a communicates with a fluid-suction channel 19 formed in the cylinder head 13, whereas each discharge port 13b communicates with a fluid-discharge channel 20 formed in the cylinder head 13 and the cylinder block 12. Therefore, low-temperature fluid flowing from the fluid-suction channel 19 through each suction port 13a to the compression chamber 12b is subjected to a pressure increase as a result of being compressed by one end surface of the piston head 11a and then goes out from the discharge port 13b through the fluid-discharge channel 20.

[0046] The drive shaft 14 transmits a driving force from a driving source (e.g., an electric motor or an engine), not shown in the figure, to the swash plate 15. The drive shaft 14 is rotatably supported at the other end portion of the cylinder block 12 by bearings 21.

The swash plate 15 includes the shoe plate 15a and the retainer ring 15b. The sliding surface P of the thrust roller bearing 16 disposed between the shoe plate 15a and the retainer ring 15b is defined at an angle of, for example, 1.43 degree relative to an axis perpendicular to the longitudinal axis of the cylinder block 12. Furthermore, the above-described piston shoe 11b is partially interposed between the retainer ring 15b and the thrust roller bearing 16.

On the other hand, a thrust roller bearing 22 is disposed also between the shoe plate 15 and the cylinder block 12. This thrust roller bearing 22 provides a thrust (load) in the axial direction (longitudinal direction of the cylinder block 12) .

The shoe plate 15a, retainer ring 15b, and thrust roller bearings 16 and 22 rotate integrally with the drive shaft 14.

Therefore, when the drive shaft 14 is rotated (in one direction) by the driving source, the piston shoes 11b slide along the sliding surface P, and thereby the pistons 11 reciprocate in the cylinder 12, thus causing low-temperature fluid flowing in the compression chambers 12b to be compressed successively. In this embodiment, the stroke of each piston 11 is set to 2 mm.

[0047] Reference numeral 23 in Fig. 1 denotes continuous holes that allow the respective compression chambers 12b to communicate with the outside of the booster pump 1. A pipe 24 is connected to each of these continuous holes 23, and an on-off valve 25 is disposed at an intermediate point in this pipe 24.

When low-temperature fluid is drawn into each compression chamber 12b, the continuous hole 23, the pipe 24, and the on-off valve 25 are used to cause low-temperature fluid residing adjacent to the other end surface of the piston head 11a to flow out of the compression chamber 12b to reduce the drive resistance of the piston 11 or to cause low-temperature fluid built up in the compression chamber 12b disposed adjacent to the other end surface of the piston head 11a to flow out of the compression chamber 12b.

Therefore, the on-off valves 25 are closed (off) during a compression stroke or if it is not necessary to expel low-temperature fluids out of the compression chambers 12b.

[0048] The booster pump 1 according to this embodiment does not include a component (e.g., piston ring in the known art) that moves in contact with the inner circumferential surfaces of the compression chambers 12b. This prevents heat from being generated in the compression chambers 12b and therefore prevents the low-temperature fluid from being heated.

Furthermore, the bellows 17 completely separates the inner circumferential side from the outer circumferential side of each compression chamber 12b disposed closer to the piston shoe 11b than the piston head 11a. This can prevent the low-temperature fluid from leaking from the outer circumferential side of the compression chamber 12b into the inner circumferential side of the compression chamber 12b. In other words, the low-temperature fluid can be prevented from flowing out from the compression chamber 12b side towards the piston shoe 11b side along the piston rods 11c. As a result, the compression efficiency of the booster pump 1 can be improved.

[0049] A second embodiment of a (low-temperature-fluid) booster pump according to the present invention will now be described with reference to Fig. 3.

A booster pump 2 in this embodiment differs from the booster pump according to the above-described first embodiment in that (thin) wires (fillers) 31 made of a material that can be used at (super) low temperatures, such as Teflon®, is wound around the outer circumferential surface of the bellows 17. The other components are the same as those described in the above-described embodiment, and hence a description thereof will be omitted.

The same components as those in the above-described first embodiment are denoted with the same reference numerals or symbols.

[0050] As shown in Fig. 3, the wires 31 are wound around the outer surface of the bellows 17 so as to minimize the gap between the outer surface of the bellows 17 and the inner circumferential surface of the compression chamber 12b.

Here, care should be exercised to prevent the outer surface of the wires 31 wound around the outer surface of the bellows 17 from coming into contact with the inner circumferential surface of the compression chamber 12b, particularly when the piston 11 retracts (goes down in Fig. 1) and the bellows 17 contracts.

[0051] According to the booster pump 2 of this embodiment, the gap between the outer surface of the bellows 17 and the inner circumferential surface of the compression chamber 12b is minimized to reduce a dead volume of the compression chamber 12b. This increases the compression efficiency.

The other effects and advantages are the same as those of the above-described first embodiment, and hence a description thereof will be omitted.

[0052] A third embodiment of a (low-temperature-fluid) booster pump according to the present invention will now be described with reference to Fig. 4.

A booster pump 3 in this embodiment differs from the booster pump according to the above-described second embodiment in that spacers (fillers) 41 made of a material that can be used at (super) low temperatures, such as Teflon®, are provided on the outer circumferential surface of the bellows 17. The other components are the same as those described in the above-described embodiment, and hence a description thereof will be omitted.

The same components as those in the above-described embodiment are denoted with the same reference numerals or symbols.

[0053] As shown in Fig. 4, one spacer 41, which is substantially ring-shaped in plan view, is disposed in each valley (portion recessed towards the piston rod 11c, that is, portion further away from the inner circumferential surface of the compression chamber 12b) of the bellows 17 so as to minimize the gap between the outer surface of the bellows 17 and the inner circumferential surface of the compression chamber 12b. This spacer 41 in each valley has a cross section whose shape is substantially equal to the shape of the cross section of each valley of the bellows 17 so as not to prevent the bellows 17 from extending and contracting.

Here, care should be exercised, as described in the second embodiment, to prevent the outer surface of the spacer 41 disposed in each valley of the bellows 17 from coming into contact with the inner circumferential surface of the compression chamber 12b, particularly when the piston 11 retracts (goes down in Fig. 1) and the bellows 17 contracts.

[0054] Also, according to the booster pump 3 of this embodiment, the gap between the outer surface of the bellows 17 and the inner circumferential surface of the compression chamber 12b is minimized to reduce a dead volume of the compression chamber 12b. This increases the compression efficiency.

The other effects and advantages are the same as those of the above-described first embodiment, and hence a description thereof will be omitted.

[0055] A fourth embodiment of a (low-temperature-fluid) booster pump according to the present invention will now be described with reference to Fig. 5.

A booster pump 4 in this embodiment differs from the booster pumps according to the above-described second and third embodiments in that particulate filler 51 made of a material that can be used at (super) low temperatures, such as Teflon®, is disposed on or near the outer circumferential surface of the bellows 17. The other components are the same as those described in the above-described embodiments, and hence a description thereof will be omitted.

The same components as those in the above-described embodiments are denoted with the same reference numerals or symbols.

[0056] As shown in Fig. 5, the particulate filler 51 is disposed between the outer surface of the bellows 17 and the inner circumferential surface of the compression chamber 12b so as to minimize the gap between the outer surface of the bellows 17 and the inner circumferential surface of the compression chamber 12b.

Furthermore, an anti-flow ring 52 is provided at one end portion of the bellows 17 to prevent the filler 51 from flowing towards one end surface of the piston head 11a. This ring 52 is formed so as to have an outer diameter that is smaller than the inner diameter of the compression chamber 12b. This prevents the outer circumferential surface of the ring 52 from sliding along the inner circumferential surface of the compression chamber 12b.

Particles constituting the filler 51 are each formed so as to have an outer diameter larger than the size of the gap between the outer circumferential surface of the ring 52 and the inner circumferential surface of the compression chamber 12b. Furthermore, as much filler 51 as necessary is supplied so long as it does not prevent the bellows 17 from extending and contracting.

[0057] Also, according to the booster pump 4 of this embodiment, the gap between the outer surface of the bellows 17 and the inner circumferential surface of the compression chamber 12b is minimized to reduce a dead volume of the compression chamber 12b. This increases the compression efficiency.

The other effects and advantages are the same as those of the above-described first embodiment, and hence a description thereof will be omitted.

[0058] A fifth embodiment of a (low-temperature-fluid) booster pump according to the present invention will now be described with reference to Fig. 6.

A booster pump 5 in this embodiment differs from the booster pump according to the above-described embodiment in that a sealing member 61 made of a material that can be used at (super) low temperatures, such as Teflon®, is affixed at one end portion on the outer circumferential surface of the bellows 17. The other components are the same as those described in the above-described embodiment, and hence a description thereof will be omitted.

The same components as those in the above-described embodiment are denoted with the same reference numerals or symbols.

[0059] As shown in Fig. 6, the sealing member 61 for reducing the pressure applied by the low-temperature fluid to the outer circumferential surface of the bellows 17 is disposed at one end portion of the bellows 17. This sealing member 61 is formed so as to have an outer diameter that is substantially equal to the inner diameter of the compression chamber 12b so that the outer circumferential surface of the ring 52 moves along in slight contact with the inner circumferential surface of the compression chamber 12b. This sealing member 61 neither has tension, as has been problematic, for example, with a piston ring in the known art, nor generates heat, as with a known piston ring, because the bellows 17 considerably restricts the stroke of the piston 11 (the stroke is small). In addition, low-temperature fluid built up in the compression chamber 12b disposed adjacent to the other end surface of the piston head 11a are stored temporarily in a buffer (chamber), not shown in the figure, through the above-described continuous hole 23, pipe 24, and on-off valve 25 and are then vaporized for use. Alternatively, this low-temperature fluid returns through a pipe, not shown in the figure, to the fluid-suction channel 19 of the booster pump 5 for the purpose of recompression.

[0060] According to the booster pump 5 of this embodiment, the sealing member 61 can reduce leakage of the low-temperature fluid from one end surface towards the other end surface of the piston head 11a, which would reduce the pressure applied to the outer circumferential surface of the bellows 17. This allows a low-pressure bellows which does not need to meet strict robust design requirements to be employed and therefore allows the piston 11 to have a large stroke. Consequently, the compression efficiency (pump efficiency) can be improved.

Furthermore, since the outer circumferential surface of the sealing member 61 is designed to move along in slight

contact with the inner circumferential surface of the compression chamber 12b, heat generation in the compression chamber 12b can be reduced significantly. Consequently, heating of the low-temperature fluid can also be moderated.
The other effects and advantages are the same as those of the above-described first embodiment, and hence a description thereof will be omitted.

[0061] A (low-temperature-fluid) booster 6 including one of the above-described (low-temperature-fluid) booster pumps as a low-pressure pump 6L and one of the above-described (low-temperature-fluid) booster pumps as a high-pressure pump 6H will be described below with reference to Figs. 7 and 8.
The low-pressure pump 6L compresses low-pressure (low bulk modulus) low-temperature fluid to an intermediate pressure. The low-pressure pump 6L includes a low-pressure bellows 17a which does not need to meet strict robust design requirements so long as it can withstand intermediate pressure.
On the other hand, the high-pressure pump 6H compresses to high pressure the intermediate-pressure (high bulk modulus) low-temperature fluid compressed by the low-pressure pump 6L. The high-pressure pump 6H includes a high-pressure bellows 17b which meets strict robust design requirements so as to withstand high pressure.

[0062] According to this booster 6, since the low-pressure pump 6L employs the low-pressure bellows 17a, the piston 11 can have a large stroke to easily increase the pressure of the low-temperature fluid to an intermediate pressure. Furthermore, since the high-pressure pump 6H employs the high-pressure bellows 17b, the intermediate pressure of the low-temperature fluid can easily be increased to a high pressure, even though the piston 11 cannot have a large stroke in the high-pressure pump 6H.
In other words, if the pressure of low-temperature fluid is to be increased from low pressure to high pressure in one stroke using only one booster pump, the high-pressure bellows 17b needs to be employed, which does not allow a large stroke. This makes it difficult to increase the low-temperature fluid to the desired pressure (high pressure).
In contrast, as described above, the low-temperature fluid can be increased to the desired pressure more easily by carrying out dual-stage compression of the low-temperature fluid using two pumps.

[0063] One embodiment of a low-temperature-fluid storage tank including a (low-temperature-fluid) booster pump or a (low-temperature-fluid) booster will now be described with reference to Fig. 9.
A low-temperature-fluid storage tank 7 in this embodiment includes major components such as a (low-temperature-fluid) booster pump 71 or a (low-temperature-fluid) booster 72; a low-temperature container 73 having therein a heat-insulated vacuum chamber 73a; a low-temperature-fluid reservoir 74; and a heat exchanger 75.
The booster pump 71 or the booster 72 increases low-temperature fluid to a desired pressure. The booster pump 71 can be realized by, for example, one of the above-described (low-temperature-fluid) booster pumps 1, 2, 3, 4, and 5. The booster 72 can be realized by, for example, the above-described (low-temperature-fluid) booster 6.

[0064] The low-temperature container 73 has a vacuum inside and has a radiation shield plate 76, such as a copper plate, affixed to the inner surface thereof. The above-described booster pump 71 or the booster 72, the low-temperature-fluid reservoir 74, to be described later, and the heat exchanger 75 are housed in the heat-insulated vacuum chamber 73a of the low-temperature container 73.
The low-temperature-fluid storage layer 74 stores therein a low-temperature (e.g., -253°C) fluid (e.g., liquid hydrogen). This stored low-temperature fluid is guided to the low-temperature-fluid boosting pump 71 or the low-temperature-fluid booster 72 through a pipe 77.
One end of the heat exchanger 75 is in contact with the inner surface of the low-temperature container 73 (i.e., inner surface of the radiation shield plate 76). The heat exchanger 75 exchanges heat with the low-temperature container 73 to vaporize a low-temperature fluid that has been subjected to a pressure increase by the booster pump 71 or the booster 72 and guided through a pipe 78. The low-temperature fluid (gas) vaporized by the heat exchanger 75 is supplied to, for example, an engine through a pipe 79. Furthermore, cool air collected by the heat exchanger 75 is used to cool the above-described radiation shield plate 76 or is stored in a regenerating agent, not shown in the figure, provided in the heat-insulated vacuum chamber 73.

[0065] According to this low-temperature-fluid storage tank 7, as shown in Fig. 9, the booster pump 71 or the booster 72 is disposed in the heat-insulated vacuum chamber 73a and outside the low-temperature-fluid reservoir 74 (i.e., disposed separated from the low-temperature-fluid reservoir 74 in the heat-insulated vacuum chamber 73a). Therefore, the booster pump 71 or the booster 72 is forcibly cooled and is not easily heated up, and furthermore, heat generated from the driving source can be prevented from being transmitted to the low-temperature fluid reserved in the low-temperature-fluid reservoir 74. Consequently, an increase in temperature of the low-temperature fluid can also be prevented.
It is preferable that the booster pump 71 or the booster 72 be cooled sufficiently before being operated.

[0066] Another embodiment of a low-temperature-fluid storage tank provided with a (low-temperature-fluid) booster pump or a (low-temperature-fluid) booster will be described below with reference to Fig. 10.
A low-temperature-fluid storage tank 8 in this embodiment includes major components such as a (low-temperature-fluid) booster pump 81 or a (low-temperature-fluid) booster 82; a low-temperature container 83 having therein a heat-insulated vacuum chamber 83a; a low-temper-

ature-fluid reservoir 84; and a heater 85.

The booster pump 81 or the booster 82 increases low-temperature fluid to a desired pressure. The booster pump 81 can be realized by, for example, one of the above-described (low-temperature-fluid) booster pumps 1, 2, 3, 4, and 5. The (low-temperature-fluid) booster 82 can be realized by, for example, the above-described (low-temperature-fluid) booster 6.

[0067] The low-temperature container 83 has a vacuum inside and has a radiation shield plate 86, such as a copper plate, affixed to the inner surface thereof. The above-described booster pump 81 or the booster 82 and the low-temperature-fluid reservoir 84, to be described later, are housed in the heat-insulated vacuum chamber 83a of the low-temperature container 83.

The low-temperature-fluid storage layer 84 stores therein a low-temperature (e.g., -260°C) slushy fluid (e.g., slush hydrogen: mixture of solid hydrogen and liquid hydrogen in a liquid/ice state, with higher density and a higher coldness capacity than liquid hydrogen). This stored low-temperature fluid is guided to the low-temperature-fluid boosting pump 81 or the low-temperature-fluid booster 82 through a pipe 87.

If slush hydrogen is stored in the low-temperature-fluid storage layer 84, the slush hydrogen is produced by a slush hydrogen producing apparatus, not shown in the figure, provided in this low-temperature-fluid storage layer 84 or by a slush hydrogen producing facility 88 separately provided outside the low-temperature container 83.

[0068] A mesh (screen) 89 is provided in the pipe 86. This mesh 89 is formed so as to pass only liquid low-temperature fluid (e.g., liquid hydrogen) (i.e., so as to block solid hydrogen). By doing so, the booster pump 81 or the booster 82 downstream is supplied with only liquid low-temperature fluid to prevent clogging from occurring in the booster pump 81 or the booster 82.

The heater 85 changes (melts) solid low-temperature fluid (e.g., solid hydrogen) into liquid low-temperature fluid (e.g., liquid hydrogen).

Furthermore, it is more preferable that the above-described heat exchanger 75 be disposed downstream of the booster pump 81 or the booster 82 inside (or outside) the low-temperature container 83.

[0069] According to this low-temperature-fluid storage tank 8, the low-temperature-fluid storage layer 84 contains a slushy low-temperature fluid and experiences vaporization less easily than tanks containing only liquid low-temperature fluids. This improves the suction performance of the booster pump 81 or the booster 82 and therefore increases the amount of low-temperature fluid supplied.

[0070] Although a dual-stage compression technique using two pumps is employed in the embodiment described with reference to Figs. 7 and 8, the present invention is not limited to this technique. Three-stage compression using three pumps or multi-stage compression using three or more pumps can also be employed.

Furthermore, such multi-stage compression does not always require a plurality of pumps. Instead, multi-stage compression may be achieved with a single pump.

[0071] In addition, the booster pump according to the present invention can be used to increase the pressure of not only low-temperature fluids but also fluids having various temperatures ranging from normal to high temperatures.

Furthermore, the piston rods of the booster pump preferably have a heat-insulating vacuum structure that is hollow and vacuumed. As a result of the piston rods having a hollow structure in this manner, the weight of the piston rods can be reduced so that the pistons can be pushed up under a small load. In addition, by vacuuming the interiors of the piston rods, the piston rods can block heat to reduce the amount of heat propagating from the piston rods into the fluids.

[0072] A sixth embodiment of a low-temperature-fluid boosting pump according to the present invention will be described below with reference to drawings.

As shown in Fig. 11, a low-temperature-fluid boosting pump 101 according to this embodiment includes major components such as a drive unit 111 and a pump unit 112 driven by this drive unit 111.

The drive unit 111 includes a rod 115 and a power transmission unit 116 for transmitting a driving force from a driving source (e.g., an electric motor or an engine), not shown in the figure, to the rod 115.

The rod 115 is a substantially rod-like member having a circular cross section, extending downwards from the lower end surface of the power transmission unit 116. The rod 115 has a heat-insulating connection section 128 at a lower end portion thereof.

The power transmission unit 116 causes the rod 115 to reciprocate linearly in the vertical direction (in the direction indicated by the arrow in Fig. 11) with a stroke of, for example, 2 mm by using a driving force from the driving source, not shown in the figure.

[0073] The pump unit 112 includes a piston 121, a piston rod 122, and a cylinder block 123.

The piston 121 includes one piston main body 124 and one or more (four in this embodiment) piston heads 125, and is reciprocably housed in a cylinder 126 formed in the cylinder block 123.

The piston main body 124 is a substantially disc-shaped member. One end portion of the piston rod 122 is linked to a center portion of the piston main body 124. In addition, four rods 127 for linking the lower end surfaces of the respective piston heads 125 to the upper end surface of the piston main body 124 are provided on the outer circumference of the piston main body 124.

The four piston heads 125 are arranged at regular intervals (90°) as shown in Fig. 12. Each of the piston heads 125 is a substantially disc-shaped member and is constructed so as to compress low-temperature fluids (e.g., liquid hydrogen, liquid nitrogen, liquefied carbon dioxide, liquefied natural gas), liquefied propane gases, etc. by means of one end surface thereof (upper end surface in

Fig. 11).

[0074] The piston rod 122 is a circular-cross-section, substantially rod-like member and has one end portion thereof linked to the upper end surface of the piston main body 124, as described above, and the other end portion thereof connected to an end portion (lower end portion in Fig. 11) of the rod 115 via the heat-insulating connection section 128.

The heat-insulating connection section 128 includes an end portion 128a of the rod 115 having a structure similar to the inner race of a roller bearing; the other end portion 128b of the piston rod 122 having a structure similar to the outer race of a roller bearing; and a plurality of (four in this embodiment) rolling elements (e.g., balls and rollers) 128c disposed between the end portion 128a of the rod 115 and the other end portion 128b of the piston rod 122.

By doing so, the end portion 128a of the rod 115 and the other end portion 128b of the piston rod 122 are linked to each other in point or line contact via the rolling elements 128c. This significantly reduces the amount of heat transmitted (entering) from the rod 115 to the piston rod 122.

In addition, since the piston rod 122 is designed to have the maximum possible length, even if heat is transmitted (enters) from the rod 115 to the piston rod 122, the amount of heat transmitted (entering) from the piston rod 122 to the piston main body 124 is minimized.

[0075] A through-hole 123a through which the rod 115 passes is formed in the top center of the cylinder block 123. An inner space 129 communicating with the through-hole 123a is formed inside the top portion of the cylinder block 123. The heat-insulating connection section 128 is accommodated in this inner space 129.

Furthermore, in the cylinder block 123 below this inner space 129, the cylinder 126 communicating with the inner space 129 via a through-hole 123b through which the piston rod 122 passes is formed in the longitudinal direction (vertical direction in Fig. 11). One end (upper side in Fig. 11) of the cylinder 126 constitutes compression chambers 126a each having an inner diameter larger than the outer diameter of the piston head 125. The piston heads 125 are accommodated in these compression chambers 126a, respectively.

As indicated by reference symbol 123c, the interiors of the side wall, the bottom surface, and the top surface of the cylinder block 123 are hollow and vacuumed to achieve a heat-insulating vacuum structure.

[0076] On the other hand, a suction port 123d and a discharge port 123e communicating with a compression chamber 126a are provided at a position which faces the center of one end surface of the corresponding piston head 125 in the cylinder block 123, disposed between the compression chamber 126a and the inner space 129. The suction port 123d and the discharge port 123e are each provided with a ball check valve 130 to control suction and discharge of low-temperature fluids.

Each suction port 123d is provided so as to communicate with a fluid-suction channel 131 formed in the cylinder block 123, whereas each discharge port 123e is provided so as to communicate with a fluid-discharge channel 132 formed in the cylinder block 123. Therefore, a low-temperature fluid guided from the fluid-suction channel 131 via each suction port 123d into the compression chamber 126a is compressed by one end surface of the piston head 125 so that the pressure is increased to, for example, 30 MPa. Thereafter, the low-temperature fluid is guided out of the cylinder block 123 from the discharge port 123e via the fluid-discharge channel 132.

The low-temperature fluid that has been guided out of the cylinder block 123 via the fluid-discharge channel 132 is temporarily stored (reserved) in a chamber 134 via a pipe 133. The low-temperature fluid reserved in the chamber 134 is guided into a heat exchanger 136 through a pipe 135 and then vaporized. Most of the low-temperature fluid is supplied to a fuel injector, not shown in the figure, through a pipe 137, whereas part of the low-temperature fluid is guided through a pipe 138 and a pressure regulator (decompressor) 139 into the cylinder 126 (a space between the lower surface at the other end portion of the piston main body 124, disposed adjacent to the other end side, i.e., the side opposite to the compression chambers 126a, of the cylinder 126, and the bottom surface of the cylinder 126).

Low-temperature fluid whose pressure has been increased to, for example, 30 MPa is reserved in the chamber 134.

In addition, vaporized low-temperature fluid whose pressure has been decreased to, for example, 15 MPa by the pressure regulator 139 is supplied into the cylinder 126.

[0077] Each compression chamber 126a has a bellows (partition) 140 therein. This bellows 140 partitions (separates) an inner circumferential side (inward position in the radial direction) from an outer circumferential side (outward position in the radial direction) of the corresponding compression chamber 126a, which is disposed above the piston head 125 (on the opposite side to the piston main body 124). One end of the bellows 140 is affixed to an outer circumferential end portion on one end surface of the piston head 125, and the other end of the bellows 140 is affixed to the inner wall surface of the cylinder block 123 located at an outward position in the radial direction of the suction port 123d and the discharge port 123e.

Furthermore, a bellows (partition) 141 is also provided at an outward position in the radial direction at one end portion of the piston rod 122. This bellows 141 partitions (separates) an inner circumferential side (adjacent to the piston rod 122) from an outer circumferential side (adjacent to the cylinder block 123) of the piston rod 122 at one end portion thereof. One end of the bellows 141 is affixed to the upper end surface of the piston main body 124, and the other end of the bellows 141 is affixed to the inner wall surface of the cylinder block 123.

Furthermore, these bellows 140 and 141 are made of, for example, stainless steel or Inconel, which exhibits elasticity at (super) low temperatures.

Reference numerals 142, 143, and 144 in Fig. 11 each denote a (heat-insulating) sealing member which is ring-shaped in plan view.

Fig. 12 is a cross-sectional view taken along line XII-XII of Fig. 11.

[0078] With the above-described structure, when the rod 115 of the drive unit 111 reciprocates linearly in the vertical direction, the piston rod 122 linked to the rod 115 through the heat-insulating connection section 128 reciprocates linearly in the vertical direction together with the piston 121, low-temperature fluid supplied from the suction ports 123d is compressed by one end surface of each piston head 125 so that the pressure is increased, and then the low-temperature fluid is expelled from the discharge port 123e via the fluid-discharge channel 132 to the outside of the cylinder block 123.

[0079] The low-temperature-fluid boosting pump 101 according to this embodiment does not include a component (e.g., piston ring in the known art) that moves in contact with the inner circumferential surfaces of the compression chambers 126a. This prevents heat from being generated in the compression chambers 126a and therefore prevents the low-temperature fluid from being heated.

In addition, each bellows 140 completely partitions an inner circumferential side (inward position in the radial direction) from an outer circumferential side (outward position in the radial direction) of the corresponding compression chamber 126a. Therefore, low-temperature fluid can be prevented from leaking from the inner circumferential side of the compression chamber 126a to the outer circumferential side of the compression chamber 126a (or from the outer circumferential side of the compression chamber 126a to the inner circumferential side of the compression chamber 126a). This improves the compression efficiency of the low-temperature-fluid boosting pump 101.

Furthermore, since low-temperature fluid that is vaporized by the heat exchanger 136 and subjected to pressure adjustment to a predetermined pressure (e.g., 15 MPa) by the pressure regulator 139 exists outside each bellows 140 (outward position in the radial direction), deformation of the bellows 140 can be reduced when low-temperature fluid drawn into the bellows 140 is to be compressed. This extends the service life of the bellows 140 and increases the reliability of the low-temperature-fluid boosting pump 101.

[0080] In addition, according to the low-temperature-fluid boosting pump 101 of this embodiment, since low-temperature fluid is compressed in the inner space of each bellows 140 (the space defined by the inner circumferential surface of the bellows 140, one end surface of the piston head 125, and the top surface of the compression chamber 126a), the length of each rod 127 linking the piston head 125 to the piston main body 124 can be reduced. Consequently, not only can the length of the pump unit 112 in the longitudinal direction (axial direction) be reduced, but also the length of the entire pump in the longitudinal direction (axial direction) can be reduced. This contributes to compact and lightweight design of the pump.

[0081] Furthermore, as a result of the piston rod 122 being pulled towards the drive unit 111 (upward in Fig. 11), low-temperature fluid is compressed by one end surface of each piston head 125. In other words, when low-temperature fluid is to be compressed, no compressive force is applied to the piston rod 122.

As a result, the diameter of the piston rod 122 can be reduced compared with a piston rod in the known art, which is subjected to a compressive force. Therefore, not only can the amount of heat entering from a driving source be reduced, but also the weight of the piston rod 122 can be reduced. Consequently, the weight of the entire pump can also be reduced.

[0082] In addition, the heat-insulating connection section 128 reduces the amount of heat entering from the rod 115 to the piston rod 122, thereby further reducing the amount of heat entering from the driving source.

Furthermore, because the piston main body 124 is provided between the piston rod 122 and the piston heads 125, heat from the piston rod 122 reaches the piston heads 125 through the piston main body 124. This can further reduce the input amount of heat.

In addition, since the rod 115 connecting to the power transmission unit 116 extends to the side where the suction ports 123d and the discharge ports 123e are disposed (upper side in Fig. 11), not only can the length of the pump unit 112 in the longitudinal direction (axial direction) be reduced, but also the length of the entire pump in the longitudinal direction (axial direction) can be reduced. This contributes to compact and lightweight design of the pump.

[0083] A seventh embodiment of a low-temperature-fluid boosting pump according to the present invention will now be described with reference to Fig. 13.

A low-temperature-fluid boosting pump 202 according to this embodiment is a so-called swash plate (or swash) pump. The low-temperature-fluid boosting pump 202 includes major components such as a drive unit 261 and a pump unit 262 that is driven by this drive unit 261.

The same components as those in the above-described sixth embodiment are denoted with the same reference numerals or symbols.

[0084] The drive unit 261 includes a rod 265 and a power transmission unit 266 that transmits a driving force from a driving source (e.g., an electric motor or an engine), not shown in the figure, to the rod 265.

The rod 265 is a substantially rod-like member having a circular cross section, extending downwards from the lower end surface of the power transmission unit 266.

The power transmission unit 266 rotates the rod 265 in one direction (direction indicated by the arrow in Fig. 13) using a driving force from a driving source, not shown in the figure.

[0085] The pump unit 262 includes one or more (four in this embodiment) pistons 271, a swash plate (also called a "yoke") 272, and a cylinder block 273.

Each piston 271 is a circular-cross-section, substantially rod-like member having a piston head 271a at one end portion thereof and a piston shoe 271b at the other end portion thereof. Each piston 271 is reciprocably housed in a cylinder 276.

The piston head 271a is a so-called large-diameter portion that has an outer diameter larger than the outer diameter of a piston rod 271c that links this piston head 271a and the piston shoe 271b. Low-temperature fluid (e.g., liquid hydrogen, liquid nitrogen, liquefied carbon dioxide, liquefied natural gas), liquefied propane gas, etc. are compressed by one flat end surface (upper end surface in Fig. 13) of this piston head 271a.

Like the piston head 271a, the piston shoe 271b is also a so-called large-diameter portion that has an outer diameter larger than the outer diameter of the piston rod 271c. One end surface (lower surface in Fig. 13) of the piston shoe 271b slides along a sliding surface P of the swash plate 272 having a tilt angle.

[0086] The cylinder block 273 has therein the same number of compression chambers 126a as that of the pistons 271 and the compression chambers 126a are formed along a longitudinal direction (vertical direction in Fig. 13). Each compression chamber 126a accommodates one piston head 271a.

As shown in Fig. 13, the piston shoes 271b and the swash plate 272 are housed adjacent to the other end side (lower side in Fig. 13) of the cylinder 276.

Furthermore, a through-hole 123a through which the rod 265 passes is formed in the center of the cylinder block 273. Furthermore, the interiors of the side wall, the bottom surface, and the top surface of the cylinder block 123 constitute a heat-insulating vacuum structure that is hollow and vacuumed, as shown by reference symbol 123c.

[0087] On the other hand, a suction port 123d and a discharge port 123e communicating with a compression chamber 126a are provided at a position which faces the center of one end surface of the corresponding piston head 271a, i.e., at a top portion in the cylinder block 273. The suction port 123d and the discharge port 123e are each provided with a ball check valve 130 to control suction and discharge of low-temperature fluid.

Each suction port 123d is provided so as to communicate with a fluid-suction channel 131 formed in the cylinder block 123, whereas each discharge port 123e is provided so as to communicate with a fluid-discharge channel 132 formed in the cylinder block 123. Therefore, low-temperature fluid guided from the fluid-suction channel 131 via each suction port 123d into the compression chamber 126a is compressed by one end surface of the piston head 271a so that the pressure is increased to, for example, 30 MPa. Thereafter, the low-temperature fluid is guided out of the cylinder block 273 from the discharge port 123e via the fluid-discharge channel 132.

The low-temperature fluid that has been guided out of the cylinder block 273 via the fluid-discharge channel 132 is temporarily stored (reserved) in a chamber 134 via a pipe 133. The low-temperature fluid reserved in the chamber 134 is guided into a heat exchanger 136 through a pipe 135 and then vaporized. Most of the low-temperature fluid is supplied to a fuel injector, not shown in the figure, through a pipe 137, whereas part of the low-temperature fluid is guided through a pipe 138 and a pressure regulator (decompressor) 139 into the compression chamber 126a (i.e., a space adjacent to the other end surface of each piston head 271a, located opposite to a bellows 140).

Low-temperature fluid whose pressure has been increased to, for example, 30 MPa is reserved in the chamber 134.

In addition, vaporized low-temperature fluid whose pressure has been decreased to, for example, 15 MPa by the pressure regulator 139 is supplied into the compression chamber 126a.

[0088] Each compression chamber 126a has the bellows (partition) 140 therein. This bellows 140 partitions (separates) an inner circumferential side (inward position in the radial direction) from an outer circumferential side (outward position in the radial direction) of the corresponding compression chamber 126a, which is disposed above the piston head 271a (on the opposite side to the piston rod 271c). One end of the bellows 140 is affixed to an outer circumferential end portion on one end surface of the piston head 271a, and the other end of the bellows 140 is affixed to the inner wall surface of the cylinder block 273 located at an outward position in the radial direction of the suction port 123d and the discharge port 123e.

Furthermore, a bellows (partition) 280 is also provided at an outward position in the radial direction at one end portion of the piston rod 271c. This bellows 280 partitions (separates) an inner circumferential side (adjacent to the piston rod 271c) from an outer circumferential side (adjacent to the cylinder block 273) of the piston rod 271c at one end portion thereof. One end of the bellows 280 is affixed to an outer circumferential end portion on the other end surface (upper surface in Fig. 13) of the piston shoe 271b, and the other end of the bellows 280 is affixed to the inner wall surface of the cylinder block 273.

These bellows 140 and 280 are made of, for example, stainless steel or Inconel, which exhibits elasticity at (super) low temperatures.

Reference numerals 142, 143, and 144 in Fig. 13 each denote a (heat-insulating) sealing member which is ring-shaped in plan view. Reference numerals 281 and 282 each denote a thrust roller bearing.

[0089] With the above-described structure, when the rod 265 is rotated by the driving source (in one direction), the piston shoes 271b slide along the sliding surface P by means of the thrust bearings 281, and furthermore, the pistons 271 are caused to reciprocate in the cylinder 276, thereby successively compressing low-temperature fluid flowing into the compression chambers 126a. In this embodiment, the strokes of the pistons 271 are set to, for example, 2 mm.

[0090] The low-temperature-fluid boosting pump 202 according to this embodiment does not include a component (e.g., piston ring in the known art) that moves in contact with the inner circumferential surfaces of the compression chambers 126a. This prevents heat from being generated in the compression chambers 126a and therefore prevents the low-temperature fluid from being heated.

In addition, each bellows 140 completely partitions (separates) an inner circumferential side (inward position in the radial direction) from an outer circumferential side (outward position in the radial direction) of the corresponding compression chamber 126a. Therefore, low-temperature fluid can be prevented from leaking from the inner circumferential side of the compression chamber 126a to the outer circumferential side of the compression chamber 126a (or from the outer circumferential side of the compression chamber 126a to the inner circumferential side of the compression chamber 126a). This improves the compression efficiency of the low-temperature-fluid boosting pump 202.

Furthermore, since low-temperature fluid that is vaporized by the heat exchanger 136 and subjected to pressure adjustment to a predetermined pressure (e.g., 15 MPa) by the pressure regulator 139 exists outside each bellows 140 (outward position in the radial direction), deformation of the bellows 140 can be reduced when low-temperature fluid drawn into the bellows 140 is to be compressed. This extends the service life of the bellows 140 and increases the reliability of the low-temperature-fluid boosting pump 202.

[0091] In addition, according to the low-temperature-fluid boosting pump 202 of this embodiment, since low-temperature fluid is compressed in the inner space of each bellows 140 (the space defined by the inner circumferential surface of the bellows 140, one end surface of the piston head 271a, and the top surface of the compression chamber 126a), the length of each piston rod 271c linking the piston head 271a to the piston shoe 271b can be reduced. Consequently, not only can the length of the pump unit 262 in the longitudinal direction (axial direction) be reduced, but also the length of the entire pump in the longitudinal direction (axial direction) can be reduced. This contributes to compact and lightweight design of the pump.

[0092] Furthermore, as a result of the rod 265 being rotated in one direction (as indicated by the arrow in Fig. 13), the low-temperature fluid is compressed by one end surface of each piston head 271a. In other words, when the low-temperature fluid is to be compressed, no compressive force is applied to the rod 265.

As a result, the diameter of the rod 265 can be reduced compared with the type of piston rod used in the known art, which is subjected to a compressive force. Therefore, not only can the amount of heat entering from a driving source be reduced, but also the weight of the rod 265 can be reduced. Consequently, the weight of the entire pump can also be reduced.

In addition, since the rod 265 connecting to the power transmission unit 266 extends to the side where the suction ports 123d and the discharge ports 123e are disposed (upper side in Fig. 13), not only can the length of the pump unit 262 in the longitudinal direction (axial direction) be reduced, but also the length of the entire pump in the longitudinal direction (axial direction) can be reduced. This contributes to compact and lightweight design of the pump.

[0093] Although a four-cylinder structure provided with four pistons and four cylinders has been described in the above-described embodiment, the present invention is not limited to this structure. For example, a single-cylinder, two-cylinder, three-cylinder, or five-or-more-cylinder structure is also acceptable.

[0094] Furthermore, the thrust roller bearing 282 described in the seventh embodiment is not limited to the type of bearing that supports the swash plate 272 at a single point in the center on the bottom surface of the swash plate 272, as shown in Fig. 13. Instead, the entire bottom surface of the swash plate 272 can be supported with two or more thrust roller bearings disposed in the circumferential direction.

In addition, it is preferable that the angle of this swash plate 272 be variable using, for example, an actuator. In other words, a variable-capacity structure is preferable. By doing so, the amount of discharge by the pump can be changed simply by changing the angle of the swash plate 272, i.e., without changing the number of revolutions for driving the pump.

[0095] Furthermore, although each of the suction port 123d and the discharge port 123e is provided with the ball check valve 130 in the above-described embodiment, the present invention is not limited to this structure. Instead, a forcible drive system as seen with, for example, a DOHC of an internal-combustion engine is also acceptable. Furthermore, a structure with a reed valve, a poppet valve, etc. can also be used.

[0096] In addition, although low-temperature fluid vaporized by the heat exchanger 136 is supplied to the outside of the bellows 140 and 280 in the above-described sixth embodiment or the seventh embodiment, the present invention is not limited to this structure. Instead, the space receiving vaporized low-temperature fluid can be vacuumed.

More specifically, the spaces between the bellows 140 and 280 and the cylinder blocks 123 and 273 are vacuumed to prevent heat in the bellows 140 and 280 (i.e., heat of low-temperature fluid compressed at the inner sides of the bellows 140 and 280) from being transmitted to the cylinder blocks 123 and 273.

By doing so, not only is an increase in the temperature of the cylinder blocks 123 and 273 suppressed, but also an increase in the temperature of the low-temperature fluid flowing into the compression chambers is suppressed.

In this case, the pipe 138 and the pressure regulator 139 shown in Figs. 11 and 13 are omitted.

[0097] Furthermore, in the above-described sixth embodiment, it is more preferable that a guiding member be provided, for example, between the piston rod 122 and the cylinder block 123 or between the linkage member 124 and the cylinder 126 so that the piston main body, the piston heads, etc. that are housed in the cylinder to reciprocate in the cylinder do not interfere with the inner wall surface of the cylinder (cylinder wall).

Examples of such a guiding member include a linear bearing disposed between the piston rod 122 and the cylinder block 123 or between the outer circumferential surface of the linkage member 124 and the inner wall surface of the cylinder 126, a member that guides a cylindrical protrusion protruding downwards from the lower end surface of the linkage member 124 into a cylindrical indentation (dent) formed in the center of the bottom surface of cylinder 126, and so forth.

By doing so, reciprocating members such as the piston main body and the piston heads perform reciprocal movement in the cylinder without wobbling or vibrating. This can prevent such reciprocating members from interfering with the inner wall surface of the cylinder, and furthermore, allows the reciprocating members to be driven smoothly with minimum driving force.

[0098] In addition, in each of the above-described sixth and the seventh embodiments, spaces receiving the low-temperature fluid vaporized in these embodiments can be vacuumed.

By doing so, not only is an increase in the temperature of the cylinder blocks suppressed, but also an increase in the temperature of low-temperature fluid flowing into the compression chambers is suppressed.

In this case, the pipe 138 and the pressure regulator 139 shown in Figs. 11 and 13 are omitted.

[0099] Furthermore, in the above-described sixth embodiment, it is more preferable that an vacuumed space be formed between the piston rod 122 and the cylinder block 123.

For example, a bellows (same as the bellows 141) for separating a space adjacent to the inner circumferential side from a space adjacent to the outer circumferential side of the piston rod 122 is provided between the lower surface of the other end portion 128b of the piston rod 122 and the upper surface of the bottom of the inner space 129 shown in Fig. 11.

More specifically, the space between the cylinder block 123 and the piston rod 122 is vacuumed to prevent heat from the piston rod 122 (i.e., heat moving from the drive unit 111 side to the piston rod 122 side) from being transmitted to the cylinder block 123.

By doing so, not only is an increase in the temperature of the cylinder blocks 123 suppressed, but also an increase in the temperature of low-temperature fluid flowing into the compression chambers 126a is suppressed.

[0100] An eighth embodiment of a low-temperature-fluid boosting pump according to the present invention will be described with reference to the drawings.

As shown in Fig. 14, a low-temperature-fluid boosting pump 301 according to this embodiment includes major components such as a drive unit 311 and a pump unit 312 driven by this drive unit 311.

The drive unit 311 includes a cam 313; a reciprocating section 314; a linear bearing 315; an urging member 316; and a casing 317 for accommodating these elements.

The cam 313 is a circular arc cam (convex cam) having a maximum lift of, for example, 2 mm and is fixed on a drive shaft 318 of a driving source (e.g., an electric motor or an engine), not shown in the figure. The cam 313 rotates in one direction along with the drive shaft 318, which rotates as a result of the driving source being driven.

[0101] The reciprocating section 314 is a substantially cylindrical member having an inner space formed therein. The reciprocating section 314 has a roller bearing 319 in the inner space thereof, and furthermore, a substantially bar-like rod 320 having a circular cross section extends downwards from the lower end surface of the reciprocating section 314.

The roller bearing 319 includes an inner race (inner ring) 319a; an outer race (outer ring) 319b; and a plurality of rolling elements (e.g., balls and rollers) 319c disposed between the inner race 319a and the outer race 319b. The inner race 319a is affixed to a shaft 314a protruding in the inner space of the reciprocating section 314, whereas the outer race 319b rotates together with the cam 313 as a result of the outer surface thereof being in line contact with the outer surface of the rotating cam 313.

[0102] The linear bearing 315 guides the outer circumferential surface, at a radially outward position, of the reciprocating section 314 such that the reciprocating section 314 reciprocates linearly in the vertical direction. The linear bearing 315 is affixed to an inner surface of a side wall of the casing 317 at a radially outward position of the reciprocating section 314. A plurality of rolling elements (e.g., balls and rollers) 315a is disposed in the linear bearing 315. By doing so, the reciprocating section 314 can perform smooth linear reciprocation in the vertical direction.

The linear bearing 315 can be made of, for example, resin, titanium, or ceramic.

The urging member 316 is affixed to an inner wall surface at the upper portion of the casing 317. The urging member 316 is, for example, a compression spring that is disposed above the reciprocating section 314 to urge the reciprocating section 314 downwards, that is, to urge the outer surface of the outer race 319b of the roller bearing 319 onto the outer surface of the cam 313.

The casing 317 is a substantially cylindrical member having an inner space therein for accommodating the cam 313, the reciprocating section 314, the linear bearing 315, and the urging member 316. The casing 317 is disposed above the pump unit 312.

[0103] With the above-described structure, as the driving source is driven to cause the cam 313 to rotate along with the drive shaft 318, the roller bearing 319, whose outer surface is pressed against the outer surface of the cam 313, reciprocates linearly in the vertical direction together with the reciprocating section 314. Accordingly, the rod 320 also reciprocates in the vertical direction.

[0104] The pump unit 312 includes a piston 321, a piston rod 322, and a cylinder block 323.

The piston 321 includes a piston main body 324 and a piston head 325 and is reciprocably housed in a cylinder 326 formed in the cylinder block 323.

The piston main body 324 is a substantially cup-shaped hollow member with a bottom. The piston main body 324 has the piston head 325 formed at one end portion (upper end portion in Fig. 14) thereof and has, in the center of the other end portion (bottom) thereof, a through-hole 324a through which one end portion of the piston rod 322 passes and one end portion of the piston rod 322 which is mounted via a heat insulator 327. In addition, as indicated by reference symbol 324b, the interior of the side wall of the piston main body 324 has a heat-insulating vacuum structure that is hollow and vacuumed.

The piston head 325 is a member which is ring-shaped in plan view (doughnut) and has in the center thereof a through-hole 325a through which the piston rod 322 and a bulkhead 334, to be described later, pass. A low-temperature fluid (e.g., liquid hydrogen, liquid nitrogen, liquefied carbon dioxide, liquefied natural gas, or liquefied propane gas) is compressed by one flat end surface (upper end surface in Fig. 14) of the piston head 325.

[0105] The piston rod 322 is a circular-cross-section, substantially rod-like member and has one end portion thereof affixed to the center at the other end portion of the piston main body 324 via the heat insulator 327, as described above, and the other end portion thereof connected to an end portion (lower end portion in Fig. 14) of the rod 320 via a heat-insulating connection section 328.

The heat-insulating connection section 328 includes an end portion 328a of the rod 320 having a structure similar to the inner race of a roller bearing; the other end portion 328b of the piston rod 322 having a structure similar to the outer race of a roller bearing; and a plurality of (four in this embodiment) rolling elements (e.g., balls and rollers) 328c disposed between the end portion 328a of the rod 320 and the other end portion 328b of the piston rod 322.

By doing so, the end portion 328a of the rod 320 and the other end portion 328b of the piston rod 322 are linked to each other in point or line contact via the rolling elements 328c. This significantly reduces the amount of heat transmitted (entering) from the rod 320 to the piston rod 322.

In addition, since one end portion of the piston rod 322 is linked to the center of the other end portion of the piston main body 324 via the heat insulator 327, even if heat is transmitted (enters) from the rod 320 to the piston rod 322, heat transmitted (entering) from the piston rod 322 to the piston main body 324 is blocked by the heat insulator 327.

[0106] A through-hole 323a through which the rod 320 passes is formed in the top center of the cylinder block 323. An inner space 329 communicating with the through-hole 323a is formed inside the top portion of the cylinder block 323. The heat-insulating connection section 328 is accommodated in this inner space 329.

Furthermore, in the cylinder block 323 disposed below this inner space 329, the cylinder 326 communicating with the inner space 329 via a through-hole 323b through which the piston rod 322 passes is formed in the longitudinal direction (vertical direction in Fig. 14). One end (upper side in Fig. 14) of the cylinder 326 constitutes a compression chamber 126a having an inner diameter larger than the outer diameter of the piston head 325. The piston head 325 is accommodated in this compression chamber 326a.

As indicated by reference symbol 323c, the interiors of the side wall, the bottom surface, and the top surface of the cylinder block 323 are hollow and vacuumed to achieve a heat-insulating vacuum structure.

[0107] On the other hand, a suction port 323d and a discharge port 323e communicating with the compression chamber 326a are provided at a position which faces a circumferential portion on one end surface of the piston head 325 between the compression chamber 326a and the inner space 329 in the cylinder block 323. The suction port 323d and the discharge port 323e are each provided with a poppet check valve (or a ball check valve, a reed valve, a forcibly driven valve) 330 having a valve body 330a and a spring 330b to control suction and discharge of low-temperature fluid.

The suction port 323d is provided so as to communicate with a fluid-suction channel 331 formed in the cylinder block 323, whereas the discharge port 323e is provided so as to communicate with a fluid-discharge channel 332 formed in the cylinder block 323. Therefore, low-temperature fluid guided from the fluid-suction channel 331 via the suction port 323d into the compression chamber 326a is compressed by one end surface of the piston head 325 so that the pressure is increased to, for example, 30 MPa. Thereafter, the low-temperature fluid is guided out of the cylinder block 323 from the discharge port 323e via the fluid-discharge channel 332.

The low-temperature fluid that has been guided out of the cylinder block 323 via the fluid-discharge channel 332 is temporarily stored (reserved) in a chamber C via a pipe 333. Thereafter, the low-temperature fluid is supplied to a fuel injector, not shown in the figure, via a pipe 335.

Low-temperature fluid whose pressure has been increased to, for example, 30 MPa is reserved in the chamber C.

[0108] The bulkhead 334 enclosing the shank outer surface of the piston rod 322 is disposed between the piston rod 322 and the piston 321. As indicated by reference symbol 334a, this bulkhead 334 has a heat-insulating vacuum structure that is hollow and vacuumed. Because of this, radiant heat from the piston rod 322 is prevented from being transmitted to the piston 321.

[0109] The compression chamber 326a has a bellows (partition) 336 therein. This bellows 336 separates (partitions) an inner circumferential side (piston 321 side) from an outer circumferential side (cylinder block 323 side) of the compression chamber 326a, which is disposed closer to the piston main body 324 (lower side in Fig. 14) than the piston head 325. One end of the bellows 336 is affixed to a surface opposite (the other end surface) one end surface of the piston head 325, and the other end of the bellows 336 is affixed to the inner wall surface of the cylinder block 323.

A bellows (partition) 337 is also provided at a radially outward position of the bulkhead 334 and above one end surface of the piston head 325. This bellows 337 separates (partitions) an inner circumferential side (piston rod 322 side) from an outer circumferential side (cylinder block 323 side) in the upper section of the cylinder 326. One end of the bellows 337 is affixed to one end surface of the piston head 325, whereas the other end of the bellows 337 is affixed to the inner wall surface of the cylinder block 323.

Furthermore, these bellows 336 and 337 are each made of, for example, stainless steel or Inconel, which exhibits elasticity at (super) low temperatures.

Fig. 15 is a cross-sectional view taken along line XV-XV of Fig. 14. The imaginary line in Fig. 15 (two-dot chain line) denotes the bellows 337.

Furthermore, reference numerals 338, 339, 340, and 341 in Fig. 14 each denote a (heat-insulating) sealing member which is ring-shaped in plan view.

[0110] With the above-described structure, when the rod 320 of the drive unit 311 reciprocates linearly in the vertical direction, the piston rod 322 linked to the rod 320 through the heat-insulating connection section 328 reciprocates linearly in the vertical direction together with the piston 321, low-temperature fluid supplied from the suction port 323d is compressed by one end surface of the piston head 325 so that the pressure is increased, and then the low-temperature fluid is expelled from the discharge port 323e via the fluid-discharge channel 332 to the outside of the cylinder block 323.

[0111] According to the low-temperature-fluid boosting pump 301 of this embodiment, as a result of the piston rod 322 being pulled towards the drive unit 311 (upwards in Fig. 14), low-temperature fluid is compressed by one end surface of the piston head 325. In short, when low-temperature fluid is to be compressed, the piston rod 322 is not subjected to a compressive force.

As a result, the diameter of the piston rod 322 can be reduced compared with a piston rod in the known art, which is subjected to a compressive force (if the piston rod 322 is made of, for example, Inconel, the diameter of the piston rod 322 can be, for example, 8 mm). Therefore, not only can the amount of heat entering from the driving source be reduced, but also the weight of the piston rod 322 can be reduced. Consequently, the weight of the entire pump can also be reduced.

[0112] In addition, when low-temperature fluid is to be compressed, the piston rod 322 is not subjected to a compressive force. For this reason, the diameter of the piston head 325 can be increased (e.g., diameter of 100 mm). In other words, for the known pump where a compressive force is applied to the piston rod, the diameter of the piston head is limited to, for example, 40 mm to prevent the piston rod from buckling. For this reason, the known pump required, for example, five cylinders to achieve a sufficient flow volume of low-temperature fluid. For the pump according to the present invention, however, the diameter of the piston head 325 can be, for example, 100 mm, and therefore, a sufficient flow volume can be achieved with a single cylinder.

As a result, for the pump according to the present invention, not only can the structure of the pump be simplified, but also the entire pump can be made lightweight and compact.

[0113] Furthermore, since the cam 313 is in line contact with the roller bearing 319, the amount of heat entering from the driving source can be further reduced.

In addition, since the heat-insulating connection section 328 reduces the amount of heat entering from the rod 320 into the piston rod 322, the amount of heat entering from the driving source can be further reduced.

Moreover, even if heat is transmitted (enters) from the rod 320 to the piston rod 322, heat can be prevented from being transmitted (entering) from the piston rod 322 to the piston main body 324 by the heat insulator 327.

Furthermore, since the piston main body 324 is provided between the piston rod 322 and the piston head 325 so that heat from the piston rod 322 reaches the piston head 325 via the piston main body 324, the amount of heat input can be further reduced.

Also, since the piston main body 324 has a heat-insulating vacuum structure that is hollow and vacuumed, the amount of heat input can be further reduced.

Because of this, the amount of heat input to the piston head 325 can be reduced, and therefore, low-temperature fluid compressed by one end surface of the piston head 325 can be prevented from being vaporized (boiled off).

[0114] Furthermore, the low-temperature-fluid boosting pump 301 according to this embodiment does not include a component (e.g., piston ring in the known art) that moves in contact with the inner circumferential surface of the compression chamber 326a. This prevents heat from being generated in the compression chamber 326a and therefore prevents the low-temperature fluid from being heated.

[0115] A ninth embodiment of a low-temperature-fluid boosting pump according to the present invention will now be described with reference to Fig. 16.

A low-temperature-fluid boosting pump 402 according to this embodiment differs from the pump in the above-described eighth embodiment in that the piston head 325 is provided directly at one end portion of the piston rod 322. The other components are the same as those described in the above-described embodiment, and hence a description thereof will be omitted.

The same components as those in the above-described eighth embodiment are denoted with the same reference numerals or symbols.

[0116] As shown in Fig. 16, in the low-temperature-fluid boosting pump 402 according to this embodiment, the length of the piston rod 322 is about one-fourth of that in the eighth embodiment, and one end portion of the piston rod 322 is affixed directly to a through-hole 325b formed in the center of the piston head 325 via the heat insulator 327. For this reason, in this embodiment, the piston main body 324, the bulkhead 334, and the cylinder 326 that is provided below the bellows 336 in the eighth embodiment are omitted. Therefore, in this embodiment, the length of the entire pump in the longitudinal direction (vertical direction in the figure) is reduced by the length of the omitted components.

Omitting the piston main body 324 and the bulkhead 334 may seem to cause a problem in that heat enters from the driving source. In fact, however, as described above, the cam 313 is in line contact with the roller bearing 319, and furthermore, the end portion 328a of the rod 320 is linked to the other end portion 328b of the piston rod 322 in point or line contact through the rolling elements 328c of the heat-insulating connection section 328. Therefore, there is substantially no problem of heat entering from the driving source.

This embodiment affords an advantage in that the longitudinal length of a pump unit 412 can be reduced considerably, which allows the longitudinal length of the entire pump to be reduced and therefore the pump to be made compact.

[0117] A tenth embodiment of a low-temperature-fluid boosting pump according to the present invention will be described with reference to Fig. 17.

A low-temperature-fluid boosting pump 503 according to this embodiment differs from the pump in the above-described eighth embodiment in that a first compression (first-stage compression) is performed with the outer circumferential side of a piston head 525 and a second compression (second-stage compression) is performed with the inner circumferential side of the piston head 525. The other components are the same as those described in the above-described embodiment, and hence a description thereof will be omitted.

The same components as those in the above-described eighth embodiment are denoted with the same reference numerals or symbols.

[0118] As shown in Fig. 17, according to the low-temperature-fluid boosting pump 503 of this embodiment, a first compression is performed with the outer circumferential side of the piston head 525, a second compression is performed with the inner circumferential side of the piston head 525, and a drive unit 311 and a low-pressure chamber 534 are provided in a cylinder block 523.

A piston 521 in this embodiment includes a piston main body 524 and the piston head 525, and is reciprocably housed in a cylinder 326 formed in the cylinder block 523. The piston head 525 is a member which is ring-shaped in plan view (doughnut), and has a first compressive surface 525a on one end surface (upper end surface in Fig. 17) adjacent to the outer circumferential side thereof and a second compressive surface 525b on one end surface adjacent to the inner circumferential side thereof. A low-temperature fluid (e.g., liquid hydrogen, liquid nitrogen, liquefied carbon dioxide, liquefied natural gas, or liquefied propane gas) is compressed by these flat compressive surfaces 525a and 525b.

[0119] Therefore, low-temperature fluid guided from a fluid-suction channel 331 through a suction port P1 on the low-pressure side into a compression chamber 326a is compressed by the first compressive surface 525a of the piston head 525 for pressure increase to, for example, 5 MPa. Thereafter, the low-temperature fluid flows from a discharge port P2 on the low-pressure side through a first communication channel (a flow channel for connecting between the discharge port P2 on the low-pressure side and the low-pressure chamber 534) R1 and is then temporarily reserved in the low-pressure chamber 534.

The low-temperature fluid reserved in the low-pressure chamber 534 is guided from the low-pressure chamber 534 through a second communication channel (flow channel that connects between the low-pressure chamber 534 and a suction port P3 on the high-pressure side) into the suction port P3 on the high-pressure side, and is then drawn into the compression chamber 326a. The low-temperature fluid drawn into the compression chamber 326a is compressed by the second compressive surface 525b of the piston head 525 to increase the pressure to, for example, 30 MPa. Thereafter, the low-temperature fluid is expelled out of the cylinder block 523 from a discharge port P4 on the high-pressure side via a fluid-discharge channel 332. The low-temperature fluid that has been expelled out of the cylinder block 523 passes through a pipe 333, is temporarily reserved in a chamber C, and is supplied to a fuel injector, not shown in the figure, through a pipe 335.

[0120] According to the low-temperature-fluid boosting pump 503 of this embodiment, low-temperature fluid is subjected to a pressure increase to, for example, 5 MPa with the first compressive surface 525a of the piston head 525 and is then subjected to another pressure increase with the second compressive surface 525b of the piston head 525, up to a desired pressure (e.g., 30 MPa). In short, this embodiment employs a dual-stage compression technique where low-temperature fluid is temporarily increased to an intermediate pressure and is then further increased to a desired pressure (high pressure), instead of increasing the low-temperature fluid from a low pressure to a high pressure in one stroke.

By doing so, since the stroke of the piston 521 (i.e., the maximum lift of the cam 313) can be reduced, the longitudinal length of a pump unit 512 can be further reduced, which can reduce the longitudinal length of the entire pump. This contributes to more compact design of the pump.

In addition, as a result of the stroke of the piston 521 being reduced, the expansion ratio of the bellows 336 and 337 can be decreased (i.e., the bellows 336 and 337 can be expanded or contracted within a smaller range). Therefore, the service life of these bellows 336 and 337 can be extended, and accordingly, the reliability of the pump can be improved.

The other effects and advantages are the same as those of the above-described eighth embodiment, and hence a description thereof will be omitted.

[0121] An eleventh embodiment of a low-temperature-fluid boosting pump according to the present invention will now be described with reference to Fig. 18.

A low-temperature-fluid boosting pump 604 according to this embodiment differs from the pump in the above-described eighth embodiment in that a precooling layer 630 is provided on an inner side of a heat-insulating vacuum structure 323c of a cylinder block 623 which constitutes a pump unit 612. The other components are the same as those described in the above-described embodiment, and hence a description thereof will be omitted.

The same components as those in the above-described eighth embodiment are denoted with the same reference numerals or symbols.

[0122] As shown Fig. 18, the low-temperature-fluid boosting pump 604 according to this embodiment is provided with the precooling layer 630 in the side wall, the bottom surface, and the top surface of the cylinder block 623. A coolant inlet pipe 631 and a coolant outlet pipe 632 are connected to this precooling layer 630 so that a coolant (low-temperature fluid such as liquid hydrogen, liquid nitrogen, liquefied carbon dioxide, liquefied natural gas, or liquefied propane gas) supplied into the precooling layer 630 from the coolant inlet pipe 631 is guided to the outside of the cylinder block 623 via the coolant outlet pipe 632.

[0123] By providing this precooling layer 630, the entire pump can be cooled sufficiently before the pump is started. This decreases vaporization (boil-off) of low-temperature fluid supplied to the low-temperature-fluid boosting pump 604.

Furthermore, since this precooling layer 630 also serves as a heat-insulating layer while the pump is being operated, vaporization (boil-off) of the low-temperature fluid can be reduced also while the pump is being operated.

The other effects and advantages are the same as those of the above-described eighth embodiment, and hence a description thereof will be omitted.

[0124] A twelfth embodiment of a low-temperature-fluid boosting pump according to the present invention will now be described with reference to Fig. 19.

A low-temperature-fluid boosting pump 705 according to this embodiment differs from the pump in the above-described eleventh embodiment in that a bellows 737 is provided in place of the bellows 337. The other components are the same as those described in the above-described embodiment, and hence a description thereof will be omitted.

The same components as those in the above-described eleventh embodiment are denoted with the same reference numerals or symbols.

[0125] As shown in Fig. 19, the bellows (partition) 737 of the low-temperature-fluid boosting pump 705 according to this embodiment is provided at a radially inward position of a bellows 336 and in a compression chamber 326a, which is disposed closer to a piston main body 324 (lower side in Fig. 19) than a piston head 325. One end of the bellows 737 is affixed to a surface opposite (the other end surface) the one end surface of the piston head 325, and the other end of the bellows 737 is affixed to the top surface of a tongue portion of a bulkhead 334.

Like the above-described bellows 336 and 337, the bellows 737 is made of, for example, stainless steel or Inconel, which exhibits elasticity at (super) low temperatures.

[0126] In this manner, by providing the bellows 737 on the same side as the bellows 336, that is, the side opposite to the one end surface (compressive surface) of the piston head 325, the length of the pump in the height direction (vertical direction in the figure) can be reduced, and therefore, the entire pump can be made compact.

In addition, since the compressive surface of the piston head 325 can have a larger area than that in the eleventh embodiment, a larger amount of low-temperature fluid can be compressed at a time. In short, the efficiency (performance) of the pump can be improved.

The other effects and advantages are the same as those of the above-described eleventh embodiment, and hence a description thereof will be omitted.

Reference numeral 712 in the figure denotes a pump unit.

[0127] A thirteenth embodiment of a low-temperature-fluid boosting pump according to the present invention will be described with reference to Fig. 20.

A low-temperature-fluid boosting pump 806 according to this embodiment differs from the pump in the above-described twelfth embodiment in that a bellows 837 is additionally provided. The other components are the same as those described in the above-described embodiment, and hence a description thereof will be omitted.

The same components as those in the above-described twelfth embodiment are denoted with the same reference numerals or symbols.

[0128] As shown in Fig. 20, the low-temperature-fluid boosting pump 806 according to this embodiment is provided with another bellows (partition) 837 adjacent to the other end side (lower side in the figure) of the bellows 737. This bellows 837 has one end thereof affixed to a lower surface of a tongue portion of a bulkhead 334 and has the other end thereof affixed to an upper surface of the inner wall at the other end portion of a piston main body 324. This bellows 837 separates (partitions) an inner circumferential side (piston rod 322 side) from an outer circumferential side (cylinder block 323 side) in the space between the lower surface of the tongue portion of the bulkhead 334 and the upper surface of the inner wall at the other end portion of the piston main body 324.

Like the above-described bellows 336, 337, and 737, the bellows 837 is made of, for example, stainless steel or

Inconel, which exhibits elasticity at (super) low temperatures.

[0129] With the bellows 837 provided, the pressure in the space defined by the bellows 837 and the above-described sealing member 341 adjacent to the piston rod 322 is maintained substantially at atmospheric pressure. Therefore, the difference (pressure difference) between the pressure on the inner circumferential side and the pressure on the outer circumferential side of the bellows 336, 737, and 837 can be reduced. This allows the service life of these bellows 336, 737, and 837 to be extended. Consequently, the reliability of the pump can be improved.

The other effects and advantages are the same as those of the above-described eleventh embodiment, and hence a description thereof will be omitted.

Reference numeral 812 in the figure denotes a pump unit.

[0130] A fourteenth embodiment of a low-temperature-fluid boosting pump according to the present invention will be described with reference to Fig. 21.

A low-temperature-fluid boosting pump 907 according to this embodiment differs from the pump in the above-described eighth embodiment in that a booster-fluid feeding unit 930 is provided. The other components are the same as those described in the above-described embodiment, and hence a description thereof will be omitted.

The same components as those in the above-described eighth embodiment are denoted with the same reference numerals or symbols.

[0131] As shown in Fig. 21, the low-temperature-fluid boosting pump 907 according to this embodiment is provided with the booster-fluid feeding unit 930. This booster-fluid feeding unit 930 includes a communicating tube 931 that connects the interior of a chamber C to the interior of a cylinder 326 (a space between the lower surface at the other end portion of a piston main body 324, disposed adjacent to the other end side, i.e., the side opposite to a compression chamber 326a, of the cylinder 326, and the bottom surface of the cylinder 326) and a pressure regulator (decompressor) 932 disposed at an intermediate point in this communicating tube 931.

[0132] By providing this booster-fluid feeding unit 930, low-temperature fluid whose pressure has been decreased by the pressure regulator 932 to, for example, 15 MPa can be supplied to the cylinder 326. Therefore, the difference between the pressure on the one end surface (compressive surface) side and the pressure on the other end surface side of a piston head 325 can be reduced, and consequently, a bellows with low pressure resistance can be employed.

The other effects and advantages are the same as those of the above-described thirteenth embodiment, and hence a description thereof will be omitted.

Reference numeral 912 in the figure denotes a pump unit.

[0133] The present invention is not limited to the above-described embodiments. For example, the bellows 336, 337, 737, and 837 can be realized by bellows having cross sections as indicated by solid lines or two-dot chain lines in Fig. 22.

More specifically, convex bellows having one projection towards the outside in the radial direction, as indicated by the solid lines in Fig. 22, or concave bellows having one indentation towards the inside in the radial direction, as indicated by the two-dot chain lines in Fig. 22, can be employed.

[0134] Furthermore, the heat-insulating connection sections 128 and 328 are not limited to those described above. A heat-insulating connection section as shown in, for example, Fig. 23 can also be employed.

In a heat-insulating connection section 428 shown in Fig. 23, a heat insulator 428c is interposed between an end portion 428a of a cross-sectionally T-shaped rod 320 and the other end portion 428b of a cross-sectionally T-shaped piston rod 322, and furthermore, these elements are linked to each other with fasteners J, such as bolts or nuts.

[0135] In addition, although a dual-stage compression technique for compression using the outer circumferential side and the inner circumferential side of the piston head 525 has been employed in the embodiment described with reference to Fig. 17, the present invention is not limited to this technique. Instead, one end surface of the piston head may be further divided in a concentric manner to achieve a three-or-more-stage compression technique.

[0136] Furthermore, it is more preferable that the above-described chamber C and the low-pressure chamber 534 include a relief valve so that low-temperature fluid discharged from this relief valve returns through a return pipe to the suction side of the pump (or a separate fuel battery, if any fuel battery is provided).

[0137] A fifteenth embodiment of a low-temperature-fluid boosting pump according to the present invention will be described with reference to Fig. 24.

As shown in Fig. 24, a low-temperature-fluid boosting pump 1008 according to this embodiment includes major components such as a drive unit 1111 and a pump unit 1112 driven by this drive unit 1111.

The drive unit 1111 includes a rod 1115 and a power transmission unit 1116 for transmitting a driving force from a driving source (e.g., an electric motor or an engine), not shown in the figure, to the rod 1115.

The rod 1115 is a circular-cross-section, substantially rod-like member extending downwards from a lower end surface of the power transmission unit 1116 and has a heat-insulating connection section 328 at a lower end portion thereof.

The power transmission unit 1116 causes the rod 1115 to reciprocate linearly in the vertical direction (as indicated by the arrow in Fig. 24) with a stroke of, for example, 2 mm by using a driving force from the driving source, not shown in the figure.

[0138] The pump unit 1112 includes a piston 1121, a piston rod 1122, and a cylinder block 1123.

The piston 1121 includes one linkage member 1124 and one or more (four in this embodiment) piston heads 1125, and is reciprocably housed in a cylinder 1126 formed in the cylinder block 1123.

The linkage member 1124 is a substantially disc-shaped member. One end portion of the piston rod 1122 is linked to a center portion of the linkage member 1124. In addition, four rods 1127 for linking the lower end surfaces of the respective piston heads 1125 to the upper end surface of the linkage member 1124 are provided on the outer circumference of the linkage member 1124. These four rods 1127 are arranged at regular intervals (90°) as shown in Fig. 25.

Each of the piston heads 1125 is a substantially disc-shaped member and is constructed so as to compress a low-temperature fluid (e.g., liquid hydrogen, liquid nitrogen, liquefied carbon dioxide, liquefied natural gas), liquefied propane gases, etc. by means of one end surface thereof (upper end surface in Fig. 24).

[0139] The piston rod 1122 is a circular-cross-section, substantially rod-like member and has one end portion thereof linked to the upper end surface of the linkage member 1124, as described above, and the other end portion thereof connected to an end portion (lower end portion in Fig. 24) of the rod 1115 via the heat-insulating connection section 328.

The heat-insulating connection section 328 includes an end portion 328a of the rod 1115 having a structure similar to the inner race of a roller bearing; the other end portion 328b of the piston rod 1122 having a structure similar to the outer race of a roller bearing; and a plurality of (four in this embodiment) rolling elements (e.g., balls and rollers) 328c disposed between the end portion 328a of the rod 1115 and the other end portion 328bof the piston rod 1122.

By doing so, the end portion 328a of the rod 1115 and the other end portion 328b of the piston rod 1122 are linked to each other in point or line contact via the rolling elements 328c. This significantly reduces the amount of heat being transmitted (entering) from the rod 1115 to the piston rod 1122.

In addition, since the piston rod 1122 is designed to have a maximum possible length, even if heat is transmitted (enters) from the rod 1115 to the piston rod 1122, the amount of heat being transmitted (entering) from the piston rod 1122 to the linkage member 1124 is minimized.

[0140] A through-hole 323a through which the rod 1115 passes is formed in the top center of the cylinder block 1123. An inner space 329 communicating with the through-hole 323a is formed inside the top portion of the cylinder block 1123. The heat-insulating connection section 328 is accommodated in this inner space 329.

Furthermore, in the cylinder block 1123 below this inner space 329, the cylinder 1126 communicating with the inner space 329 via a through-hole 1123b through which the piston rod 1122 passes is formed in the longitudinal direction (vertical direction in Fig. 24). One end (upper side in Fig. 24) of the cylinder 1126 constitutes compression chambers 1126a each having an inner diameter larger than the outer diameter of the piston head 1125. The piston heads 1125 are accommodated in these compression chambers 1126a, respectively.

As indicated by reference symbol 1123c, the interiors of the side wall, the bottom surface, and the top surface of the cylinder block 1123 are hollow and vacuumed to achieve a heat-insulating vacuum structure.

[0141] On the other hand, a suction port 1123d and a discharge port 1123e communicating with a compression chamber 1126a are provided at a position that faces the center of one end surface of the corresponding piston head 1125 in the cylinder block 1123, disposed between the compression chamber 1126a and the inner space 329. The suction port 1123d and the discharge port 1123e are each provided with a ball check valve 1130 to control suction and discharge of low-temperature fluid.

Each suction port 1123d is provided so as to communicate with a fluid-suction channel 1131 formed in the cylinder block 1123, whereas each discharge port 1123e is provided so as to communicate with a fluid-discharge channel 1132 formed in the cylinder block 1123. Therefore, low-temperature fluid guided from the fluid-suction channel 1131 via each suction port 1123d into the compression chamber 1126a is compressed by one end surface of the piston head 1125 so that the pressure is increased to, for example, 30 MPa. Thereafter, the low-temperature fluid is guided out of the cylinder block 1123 from the discharge port 1123e via the fluid-discharge channel 1132.

The low-temperature fluid that has been guided out of the cylinder block 1123 via the fluid-discharge channel 1132 is temporarily stored (reserved) in a chamber 1134 via a pipe 1133. The low-temperature fluid reserved in the chamber 1134 is guided into a heat exchanger 1136 through a pipe 1135 and then vaporized. Most of the low-temperature fluid is supplied to a fuel injector, not shown in the figure, through a pipe 1137, whereas part of the low-temperature fluid is guided through a pipe 1138 and a pressure regulator (decompressor) 1139 into the cylinder 1126 (a space between the lower surface at the other end portion of the linkage member 1124, disposed adjacent to the other end side, i.e., the side opposite to the compression chambers 1126a, of the cylinder 1126, and the bottom surface of the cylinder 1126).

Low-temperature fluid whose pressure has been increased to, for example, 30 MPa is reserved in the chamber 1134.

In addition, vaporized low-temperature fluid whose pressure has been decreased to, for example, 15 MPa by the pressure regulator 1139 is supplied into the cylinder 1126.

[0142] Each compression chamber 1126a has a bellows (partition) 1140 therein. This bellows 1140 partitions (separates) an inner circumferential side (rod 1127 side) from an outer circumferential side (cylinder block 1123 side) of the corresponding compression chamber 1126a, which is disposed closer to the linkage member 1124 (lower side in Fig. 24) than the piston head 1125. One end of the bellows 1140 is affixed to a surface opposite (the other end surface) one end surface of the piston head 1125, and the other end of the bellows 1140 is affixed to the inner wall surface of the cylinder block 1123. Furthermore, a bellows (partition) 1141 is also provided at an outward position in the radial direction at one end portion of the piston rod 1122. This bellows 1141 partitions (separates) an inner circumferential side (adjacent to the piston rod 1122) from an outer circumferential side (adjacent to the cylinder block 1123) of the piston rod 1122 at one end portion thereof. One end of the bellows 1141 is affixed to the upper end surface of the linkage member 1124, and the other end of the bellows 1141 is affixed to the inner wall surface of the cylinder block 1123. These bellows 1140 and 1141 are made of, for example, stainless steel or Inconel, which exhibits elasticity at (super) low temperatures.

Reference numerals 1142, 1143, and 1144 in Fig. 24 each denote a (heat-insulating) sealing member which is ring-shaped in plan view.

Fig. 25 is a cross-sectional view taken along line XXV-XXV of Fig. 24.

[0143] With the above-described structure, when the rod 1115 of the drive unit 1111 reciprocates linearly in the vertical direction, the piston rod 1122 linked to the rod 1115 through the heat-insulating connection section 328 reciprocates linearly in the vertical direction together with the piston 1121, the low-temperature fluid supplied from the suction ports 1123d is compressed by one end surface of each piston head 1125 so that the pressure is increased, and then the low-temperature fluid is expelled from the discharge port 1123e via the fluid-discharge channel 1132 to the outside of the cylinder block 1123.

[0144] According to the low-temperature-fluid boosting pump 1008 of this embodiment, as a result of the piston rod 1122 being pulled towards the drive unit 1111 (upward in Fig. 24), low-temperature fluid is compressed by one end surface of each piston head 1125. In other words, when low-temperature fluid is to be compressed, no compressive force is applied to the piston rod 1122. As a result, the diameter of the piston rod 1122 can be reduced compared with a piston rod in the known art, which is subjected to a compressive force. Therefore, not only can the amount of heat entering from a driving source be reduced, but also the weight of the piston rod 1122 can be reduced. Consequently, the weight of the entire pump can also be reduced.

[0145] Furthermore, since there is no component (e.g., piston ring in the known art) that moves in contact with the inner circumferential surfaces of the compression chambers 1126a, heat is prevented from being generated in the compression chambers 1126a, and therefore, low-temperature fluid is prevented from being heated.

In addition, each bellows 1140 completely partitions (separates) an inner circumferential side (inward position in the radial direction) from an outer circumferential side (outward position in the radial direction) of the corresponding compression chamber 1126a. Therefore, low-temperature fluid can be prevented from leaking from the inner circumferential side of the compression chamber 1126a to the outer circumferential side of the compression chamber 1126a (or from the outer circumferential side of the compression chamber 1126a to the inner circumferential side of the compression chamber 1126a). This improves the compression efficiency of the low-temperature-fluid boosting pump 1008. Furthermore, since low-temperature fluid that is vaporized by the heat exchanger 1136 and subjected to pressure adjustment to a predetermined pressure (e.g., 15 MPa) by the pressure regulator 1139 exists outside each bellows 1140 (outward position in the radial direction), deformation of the bellows 1140 can be reduced when low-temperature fluid drawn into the bellows 1140 is to be compressed. This extends the service life of the bellows 1140 and increases the reliability of the low-temperature-fluid boosting pump 1008.

[0146] In addition, the heat-insulating connection section 328 reduces the amount of heat entering from the rod 1115 to the piston rod 1122, thereby further reducing the amount of heat entering from the driving source.

Furthermore, because the linkage member 1124 is provided between the piston rod 1122 and the piston heads 1125, heat from the piston rod 1122 reaches the piston heads 1125 through the linkage member 1124. This can further reduce the amount of input heat.

In addition, since the rod 1115 connecting to the power transmission unit 1116 extends to the side where the suction ports 1123d and the discharge ports 1123e are disposed (upper side in Fig. 24), not only can the length of the pump unit 1112 in the longitudinal direction (axial direction) be reduced, but also the length of the entire pump in the longitudinal direction (axial direction) can be reduced. This contributes to compact and lightweight design of the pump.

[0147] A sixteenth embodiment of a low-temperature-fluid boosting pump according to the present invention will be described with reference to Fig. 26.

A low-temperature-fluid boosting pump 2009 according to this embodiment is a so-called swash plate (or swash) pump. The low-temperature-fluid boosting pump 2009 includes major components such as a drive unit 2161 and a pump unit 2162 that is driven by this drive unit 2161. The same components as those in the above-described fifteenth embodiment are denoted with the same reference numerals or symbols.

[0148] The drive unit 2161 includes a rod 2165 and a power transmission unit 2166 that transmits a driving force from a driving source (e.g., an electric motor or an engine), not shown in the figure, to the rod 2165.

The rod 2165 is a substantially rod-like member having a circular cross section, extending downwards from the lower end surface of the power transmission unit 2166. The power transmission unit 2166 rotates the rod 2165 in one direction (direction indicated by the arrow in Fig. 26) using a driving force from a driving source, not shown in the figure.

[0149] The pump unit 2162 includes one or more (four in this embodiment) pistons 2171, a swash plate (also called a "yoke") 2172, and a cylinder block 2173.

Each piston 2171 is a circular-cross-section, substantially rod-like member having a piston head 2171a at one end portion thereof and a piston shoe 2171b at the other end portion thereof. Each piston 2171 is reciprocably housed in the cylinder 2176.

The piston head 2171a is a so-called large-diameter portion that has an outer diameter larger than the outer diameter of a piston rod 2171c that links this piston head 2171a and the piston shoe 2171b, and (for example, liquid hydrogen, liquid nitrogen, liquefied carbon dioxide, liquefied natural gas), liquefied propane gas, etc. is compressed by one flat end surface (upper end surface in Fig. 26) of this piston head 2171a.

Like the piston head 2171a, the piston shoe 2171b is also a so-called large-diameter portion that has an outer diameter larger than the outer diameter of the piston rod 2171c. One end surface (lower surface in Fig. 26) of the piston shoe 2171b slides along a sliding surface P of the swash plate 2172 having a tilt angle.

[0150] The cylinder block 2173 contains the same number of compression chambers 1126a as that of the pistons 2171, and the compression chambers 1126a are formed along a longitudinal direction (vertical direction in Fig. 26). Each compression chamber 1126a accommodates one piston head 2171a.

As shown in Fig. 26, the piston shoes 2171b and the swash plate 2172 are housed adjacent to the other end side (lower side in Fig. 26) of the cylinder 2176.

Furthermore, a through-hole 1123a through which the rod 2165 passes is formed in the center of the cylinder block 2173. In addition, the interiors of the side wall, the bottom surface, and the top surface of the cylinder block 2173 constitute a heat-insulating vacuum structure that is hollow and vacuumed, as shown by reference symbol 1123c.

[0151] On the other hand, a suction port 1123d and a discharge port 1123e communicating with a compression chamber 1126a are provided at a position that faces the center of one end surface of the corresponding piston head 2171a, i.e., at a top portion in the cylinder block 2173. The suction port 1123d and the discharge port 1123e are each provided with a ball check valve 1130 to control suction and discharge of low-temperature fluid.

Each suction port 1123d is provided so as to communicate with a fluid-suction channel 1131 formed in the cylinder block 2173, whereas each discharge port 1123e is provided so as to communicate with a fluid-discharge channel 1132 formed in the cylinder block 2173. Therefore, a low-temperature fluid guided from the fluid-suction channel 1131 via each suction port 1123d into the compression chamber 1126a is compressed by one end surface of the piston head 2171a so that the pressure is increased to, for example, 30 MPa. Thereafter, the low-temperature fluid is guided out of the cylinder block 2173 from the discharge port 1123e via the fluid-discharge channel 1132.

The low-temperature fluid that has been guided out of the cylinder block 2173 via the fluid-discharge channel 1132 is temporarily stored (reserved) in a chamber 1134 via a pipe 1133. The low-temperature fluid reserved in the chamber 1134 is guided into a heat exchanger 1136 through a pipe 1135 and then vaporized. Most of the low-temperature fluid is supplied to a fuel injector, not shown in the figure, through a pipe 1137, whereas part of the low-temperature fluid is guided through a pipe 1138 and a pressure regulator (decompressor) 1139 into the compression chambers 1126a (i.e., a space adjacent to the other end surface of each piston head 2171a, located opposite to a bellows 1140).

Low-temperature fluid whose pressure has been increased to, for example, 30 MPa is reserved in the chamber 1134.

In addition, vaporized low-temperature fluid whose pressure has been decreased to, for example, 15 MPa by the pressure regulator 1139 is supplied into the compression chambers 1126a.

[0152] Each compression chamber 1126a has the bellows (partition) 1140 therein. This bellows 1140 partitions (separates) an inner circumferential side (piston rod 2171c side) from an outer circumferential side (cylinder block 2173 side) of the corresponding compression chamber 1126a, which is disposed closer to the piston shoe 2171b (lower side in Fig. 26) than the piston head 2171a. One end of the bellows 1140 is affixed to a surface opposite (the other end surface) one end surface of the piston head 2171a, and the other end of the bellows 1140 is affixed to the inner wall surface of the cylinder block 2173.

Furthermore, a bellows (partition) 2180 is also provided at an outward position in the radial direction at one end portion of each piston rod 2171c. This bellows 2180 partitions (separates) an inner circumferential side (adjacent to the piston rod 2171c) from an outer circumferential side (adjacent to the cylinder block 2173) of the corresponding piston rod 2171c at one end portion thereof. One end of the bellows 2180 is affixed to an outer circumferential end portion on the other end surface (upper surface in Fig. 26) of the piston shoe 2171b, and the other end of the bellows 2180 is affixed to the inner wall surface of the cylinder block 2173.

These bellows 1140 and 2180 are made of, for example, stainless steel or Inconel, which exhibits elasticity at (super) low temperatures.

Reference numerals 1142, 1143, and 1144 in Fig. 26 each denote a (heat-insulating) sealing member which is ring-shaped in plan view. Reference numerals 2181 and 2182 each denote a thrust roller bearing.

[0153] With the above-described structure, when the rod 2165 is rotated by the driving source (in one direction), the piston shoes 2171b slide along the sliding surface P by means of the thrust bearings 2181, and furthermore, the pistons 2171 are caused to reciprocate in the cylinder 2176, thereby successively compressing low-temperature fluid flowing into the compression chambers 1126a. In this embodiment, the strokes of the pistons 2171 are set to, for example, 2 mm.

[0154] According to the low-temperature-fluid boosting pump 2009 of this embodiment, as a result of the rod 2165 being rotated in one direction (as indicated by the arrow in Fig. 26), low-temperature fluid is compressed by one end surface of each piston head 2171a. In other words, when low-temperature fluid is to be compressed, no compressive force is applied to the rod 2165.
As a result, the diameter of the rod 2165 can be reduced compared with the type of piston rod used in the known art, which is subjected to a compressive force. Therefore, not only can the amount of heat entering from a driving source be reduced, but also the weight of the rod 2165 can be reduced. Consequently, the weight of the entire pump can also be reduced.

[0155] Furthermore, since there is no component (e.g., piston ring in the known art) that moves in contact with the inner circumferential surfaces of the compression chambers 1126a, heat is prevented from being generated in the compression chambers 1126a, and therefore, low-temperature fluid is prevented from being heated.
In addition, each bellows 1140 completely partitions (separates) an inner circumferential side (inward position in the radial direction) from an outer circumferential side (outward position in the radial direction) of the corresponding compression chamber 1126a. Therefore, low-temperature fluid can be prevented from leaking from the inner circumferential side of the compression chamber 1126a to the outer circumferential side of the compression chamber 1126a (or from the outer circumferential side of the compression chamber 1126a to the inner circumferential side of the compression chamber 1126a). This improves the compression efficiency of the low-temperature-fluid boosting pump 2009. Furthermore, since low-temperature fluid that is vaporized by the heat exchanger 1136 and is subjected to pressure adjustment to a predetermined pressure (e.g., 15 MPa) by the pressure regulator 1139 exists outside each bellows 140 (outward position in the radial direction), deformation of the bellows 1140 can be reduced when the low-temperature fluid drawn into the bellows 1140 is to be compressed. This extends the service life of the bellows 1140 and increases the reliability of the low-temperature-fluid boosting pump 2009.

[0156] In addition, since the rod 2165 connecting to the power transmission unit 2166 extends to the side where the suction ports 1123d and the discharge ports 1123e are disposed (upper side in Fig. 26), not only can the length of the pump unit 2162 in the longitudinal direction (axial direction) be reduced, but also the length of the entire pump in the longitudinal direction (axial direction) can be reduced. This contributes to compact and lightweight design of the pump.

[0157] Although a four-cylinder structure provided with four pistons and four cylinders has been described in the above-described embodiment, the present invention is not limited to this structure. For example, a single-cylinder, two-cylinder, three-cylinder, or five-or-more-cylinder structure is also acceptable.

[0158] Furthermore, the thrust roller bearing 2182 described in the sixteenth embodiment is not limited to the type of bearing that supports the swash plate 2172 at a single point in the center on the bottom surface of the swash plate 2172, as shown in Fig. 26. Instead, the entire bottom surface of the swash plate 2172 can be supported with two or more thrust roller bearings disposed in the circumferential direction.
In addition, it is preferable that the angle of this swash plate 2172 be variable using, for example, an actuator. In other words, a variable-capacity structure is preferable. By doing so, the amount of discharge of the pump can be changed simply by changing the angle of the swash plate 2172, i.e., without changing the number of revolutions for driving the pump.

[0159] Furthermore, although each of the suction port 1123d and the discharge port 1123e is provided with the ball check valve 1130 in the above-described embodiment, the present invention is not limited to this structure. Instead, a forcible drive system as seen with, for example, a DOHC of an internal-combustion engine is also acceptable. Furthermore, a structure with a reed valve, a poppet valve, etc. can also be used.

[0160] In addition, the present invention is not limited to the above-described embodiments. For example, the bellows 1140, 1141, and 2180 can be realized by bellows having cross sections as indicated by solid lines or two-dot chain lines in Fig. 22.
More specifically, convex bellows having one projection towards the outside in the radial direction, as indicated by the solid lines in Fig. 22, or concave bellows having one indentation towards the inside in the radial direction, as indicated by the two-dot chain lines in Fig. 22, can be employed.

[0161] Furthermore, the heat-insulating connection section 328 shown in Fig. 24 is not limited to that described above. A heat-insulating connection section as shown in, for example, Fig. 23 can also be employed.

[0162] Furthermore, it is more preferable that the above-described chamber 1134 include a relief valve so that low-temperature fluid discharged from this relief valve returns through a return pipe to the suction side of the pump (or a separate fuel battery, if any fuel battery is provided).

[0163] Furthermore, the drive unit 311 according to the eighth to fourteenth embodiments is not limited to a cam-driven drive unit as shown in the figures. The drive unit 311 can be realized by, for example, a crank-driven drive unit where the rod 320 is forcibly driven.

[0164] In addition, it is more preferable that, in the fifteenth and sixteenth embodiments, the piston rod 1122 be linked (connected) to the linkage member 1124 and the rod 2165 be linked (connected) to the swash plate 2172 through the heat insulator 327 described in the eighth to fourteenth embodiments.

[0165] Moreover, in each of the above-described

eighth to fifteenth embodiments, it is more preferable that a guiding member be provided, for example, between the piston rods 322 and 1122 and the cylinder blocks 323 and 1123, between the piston main bodies 324 and 524 and the cylinder 326, or between the linkage member 1124 and the cylinder 1126, so that the piston main bodies, the piston heads, etc. that are housed in the cylinders and reciprocate in the cylinders do not interfere with the inner wall surfaces of the cylinders (cylinder walls).
Examples of such a guiding member include a linear bearing disposed between the piston rods 322 and 1122 and cylinder blocks 323 and 1123, between the outer circumferential surfaces of the piston main bodies 324 and 524 and the inner wall surface of the cylinder 326, or between the outer circumferential surface of the linkage member 1124 and the inner wall surface of the cylinder 1126, a member that guides a cylindrical protrusion protruding downwards from the lower end surfaces of the piston main bodies 324 and 524 into a cylindrical indentation (dent) formed in the centers of the bottom surfaces of the cylinders 326 and 1126, and so forth.
By doing so, reciprocating members such as the piston main bodies and the piston heads perform reciprocal movement in the cylinders without wobbling or vibrating. This can prevent such reciprocating members from interfering with the inner wall surfaces of the cylinders, and furthermore, allows the reciprocating members to be driven smoothly with minimum driving force.

[0166] In addition, in each of the above-described fourteenth to sixteenth embodiments, spaces receiving vaporized low-temperature fluid in these embodiments can be vacuumed.
By doing so, not only is an increase in the temperature of the cylinder blocks suppressed, but also an increase in the temperature of low-temperature fluid flowing into the compression chambers is suppressed.
In this case, the pipes 931 and 1138 and the pressure regulator 1139 shown in Figs. 21, 24, and 26 are omitted.

[0167] Furthermore, in the above-described embodiments, it is more preferable that an vacuumed space be formed between the piston rods 322 and 1122 and the cylinder blocks 323 and 1123.
For example, in the fifteenth embodiment shown in Fig. 24, a bellows (same as the bellows 1141) for separating a space adjacent to the inner circumferential side from a space adjacent to the outer circumferential side of the piston rod 1122 is provided between the lower surface of the other end portion 328b of the piston rod 1122 and the upper surface of the bottom of the inner space 329.
More specifically, the space between the cylinder block 1123 and the piston rod 1122 is vacuumed to prevent heat from the piston rod 1122 (i.e., heat moving from the driving source 1111 side to the piston rod 1122 side) from being transmitted to the cylinder block 1123.
By doing so, not only is an increase in the temperature of the cylinder block 1123 suppressed, but also an increase in the temperature of low-temperature fluid flowing into the compression chambers 1126a is suppressed.

[0168] In the current description, the term "low temperature" designates temperatures of about -273°C to 0°C, and the term "high pressure" designates pressures of about 0.2 MPa to 200 MPa.
The word "fluid" used in the current description includes "liquid," "gas," and "colloid."

Claims

1. A booster pump comprising:

a piston having a piston head and a piston rod; and
a cylinder having a compression chamber that accommodates the piston head so that a fluid is compressed by one end surface of the piston head,

wherein the piston head is provided with a bellows for separating a space adjacent to the piston rod from a space adjacent to the cylinder in the compression chamber.

2. The booster pump according to Claim 1, wherein a filler filling a space between an outer surface of the bellows and an inner circumferential surface of the cylinder is provided.

3. The booster pump according to Claim 1 or 2, wherein a ring-shaped sealing member is provided at one end portion, adjacent to the piston head, of the bellows.

4. The booster pump according to one of Claims 1 to 3, wherein the piston rod has a heat-insulating vacuum structure that is hollow and vacuumed.

5. A booster comprising at least two of the booster pumps according to one of Claims 1 to 4, wherein multistage compression is performed with the booster pumps.

6. A low-temperature-fluid storage tank for storing a low-temperature fluid in a low-temperature state, comprising:

the booster pump according to one of Claims 1 to 4 or the booster according to Claim 5;
a low-temperature-fluid reservoir reserving the low-temperature fluid; and
a low-temperature container for accommodating the booster pump or the booster and the low-temperature-fluid reservoir.

7. The low-temperature-fluid storage tank according to Claim 6, wherein the booster pump or the booster is disposed downstream of the low-temperature-fluid reservoir and outside the low-temperature-fluid reservoir.

8. The low-temperature-fluid storage tank according to Claim 6 or 7, wherein a low-temperature slush fluid in a solid/liquid two-phase state is reserved in the low-temperature-fluid reservoir.

9. The low-temperature-fluid storage tank according to Claim 8, wherein a mesh is provided at an outlet of the low-temperature-fluid reservoir.

10. The low-temperature-fluid storage tank according to Claim 9, wherein a heater is provided in the low-temperature-fluid reservoir.

11. The low-temperature-fluid storage tank according to one of Claims 6 to 10, wherein a heat exchanger is disposed downstream of the booster pump or the booster.

12. The low-temperature-fluid storage tank according to one of Claims 6 to 11, wherein a radiation shield plate is provided on an inner surface of the low-temperature container.

13. A low-temperature-fluid boosting pump comprising a cylinder block having therein a compression chamber; and a piston head that is accommodated in the compression chamber and reciprocates in the compression chamber so that a low-temperature fluid is compressed by one end surface of the piston head, wherein a flexible partition for separating a space adjacent to an inner circumferential side from a space adjacent to an outer circumferential side of the piston head is provided between the one end surface of the piston head and an inner surface of the compression chamber which faces the one end surface.

14. The low-temperature-fluid boosting pump according to Claim 13, wherein a pressure-boosted fluid resides on an outer side of the partition.

15. The low-temperature-fluid boosting pump according to Claim 13, wherein an outer side of the partition is vacuumed.

16. A low-temperature-fluid boosting pump comprising:

a piston rod driven by a drive unit connected to a driving source;
a piston head that is connected to the piston rod and reciprocates with the piston rod; and
a cylinder having a compression chamber that accommodates the piston head so that a low-temperature fluid is compressed by one end surface of the piston head,
wherein the drive unit is disposed adjacent to the one end surface of the piston head, and a shank of the piston rod is subjected to a tensile force in a direction substantially equal to a direction in which the shank extends when the low-temperature fluid is to be compressed.

17. The low-temperature-fluid boosting pump according to Claim 16, wherein the piston head is divided into at least two concentric subsections to achieve a multistage compression structure where the low-temperature fluid is gradually increased to a desired pressure by sequentially passing through the one end surface of the divided piston head.

18. The low-temperature-fluid boosting pump according to Claim 16 or 17, wherein a flexible partition for separating a space adjacent to the piston rod from a space adjacent to the cylinder in the compression chamber is provided adjacent to the one end surface and adjacent to the other end surface of the piston head.

19. The low-temperature-fluid boosting pump according to Claim 16 or 17, wherein a flexible partition for separating a space adjacent to the piston rod from a space adjacent to the cylinder in the compression chamber is provided adjacent to the other end surface of the piston head.

20. The low-temperature-fluid boosting pump according to one of Claims 16 to 19, wherein a precooling layer is formed in the cylinder.

21. The low-temperature-fluid boosting pump according to one of Claims 16 to 20, wherein the drive unit is linked to the piston rod via a heat-insulating connection section.

22. The low-temperature-fluid boosting pump according to one of Claims 16 to 21, wherein the piston head is linked to the piston rod via a heat insulator.

23. The low-temperature-fluid boosting pump according to one of Claims 16 to 22, wherein a guiding member for guiding the shank of the piston rod is provided between the cylinder block and the piston rod.

24. The low-temperature-fluid boosting pump according to one of Claims 16 to 23, wherein a space between the cylinder block and the shank of the piston rod is a vacuum.

25. The low-temperature-fluid boosting pump according to one of Claims 16 to 24, wherein the cylinder is immersed in low-temperature fluid stored in a low-temperature-fluid storage tank and is attachable to and detachable from the low-temperature-fluid storage tank.

26. The low-temperature-fluid boosting pump according to one of Claims 16 to 24, wherein the drive unit and the cylinder are immersed in low-temperature fluid stored in a low-temperature-fluid storage tank and are attachable to and detachable from the low-temperature-fluid storage tank.

27. A low-temperature-fluid feeder comprising:

the low-temperature-fluid boosting pump according to one of Claims 16 to 26;
a chamber for reserving a low-temperature fluid whose pressure has been increased by the low-temperature-fluid boosting pump; and
a fuel injector supplied with the low-temperature fluid from the chamber.

28. The low-temperature-fluid feeder according to Claim 27, wherein a booster-fluid feeding unit for liquefying or vaporizing the low-temperature fluid in the chamber and supplying the low-temperature fluid into the cylinder disposed adjacent to the other end surface of the piston head of the low-temperature-fluid boosting pump is provided.

29. The low-temperature-fluid feeder according to Claim 27, wherein a heat exchanger for vaporizing liquid hydrogen is provided between the chamber and the fuel injector, and a booster-fluid feeding unit for adjusting the pressure of the vaporized hydrogen and supplying the hydrogen into the cylinder disposed adjacent to the other end surface of the piston head of the low-temperature-fluid boosting pump is provided.

30. The low-temperature-fluid feeder according to one of Claims 27 to 29, wherein the chamber is provided with a relief valve.

31. A low-temperature-fluid boosting pump comprising a cylinder block having therein a compression chamber; and a piston head that is accommodated in the compression chamber and reciprocates in the compression chamber so that a low-temperature fluid is compressed by one end surface of the piston head, wherein a flexible partition for separating a space adjacent to an inner circumferential side from a space adjacent to an outer circumferential side in the compression chamber is provided adjacent to the other end surface of the piston head.

32. The low-temperature-fluid boosting pump according to Claim 31, wherein a pressure-boosted fluid resides on an inner side of the partition.

33. The low-temperature-fluid boosting pump according to Claim 31, wherein an inner side of the partition is vacuumed.

34. The low-temperature-fluid boosting pump according to one of Claims 16 to 26 and 31 to 33, wherein a guiding member for guiding the piston head is provided between the cylinder block and the piston head.

35. The low-temperature-fluid boosting pump according to one of Claims 13 to 15 and 31 to 34, wherein the cylinder block is immersed in low-temperature fluid stored in a low-temperature-fluid storage tank and is attachable to and detachable from the low-temperature-fluid storage tank.

FIG. 1

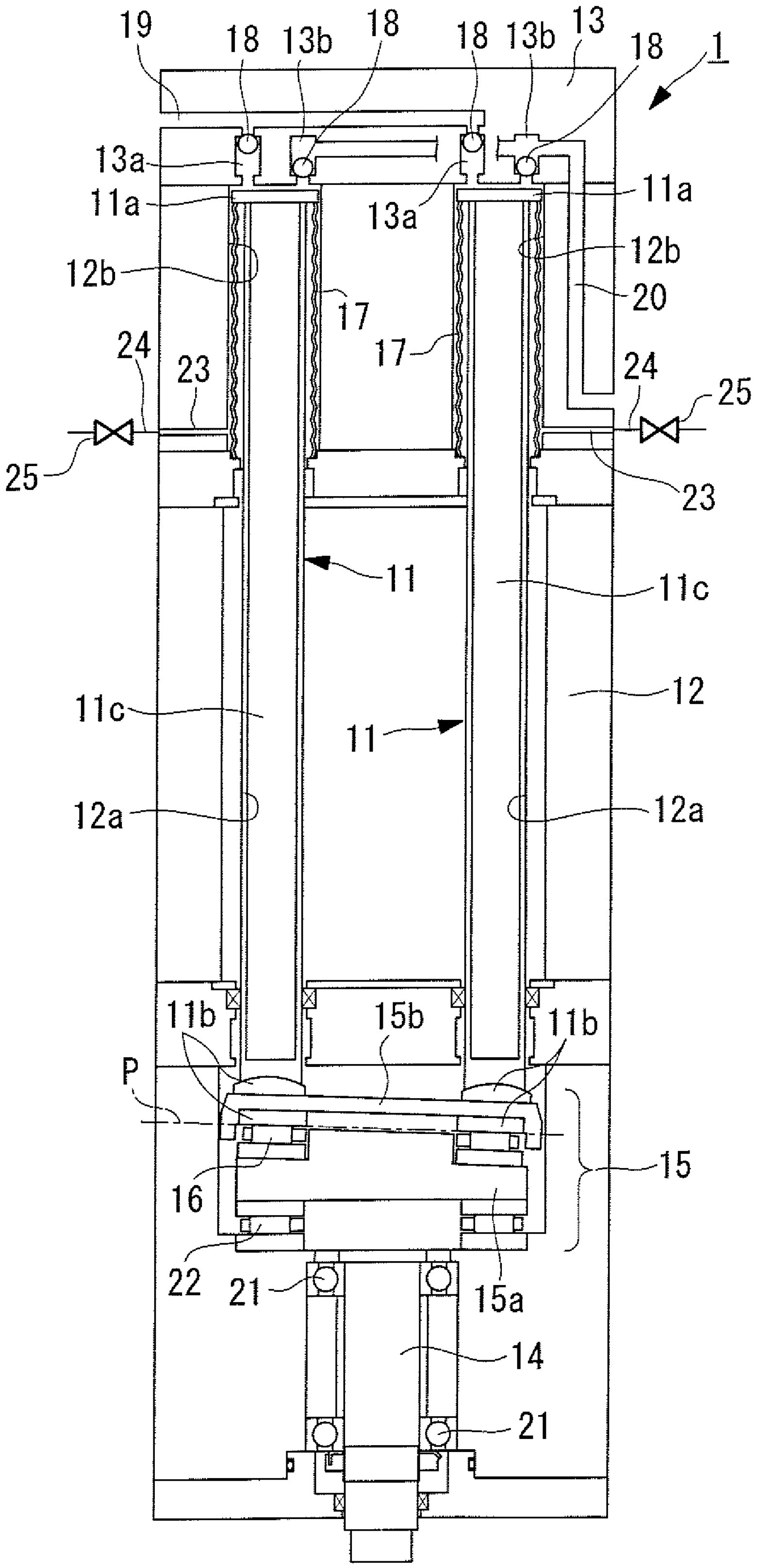
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FIG. 2

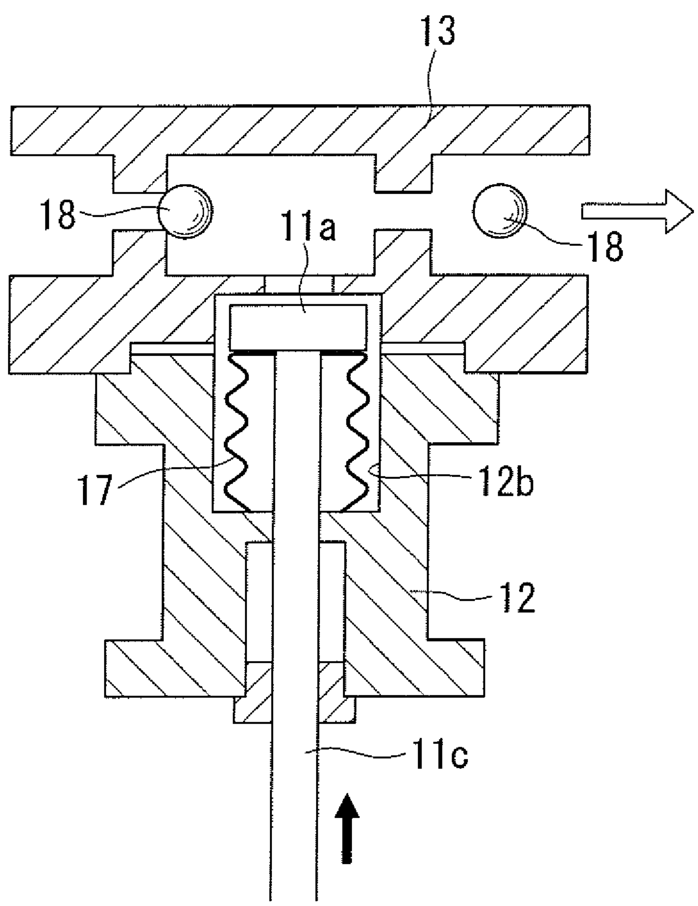

FIG. 3

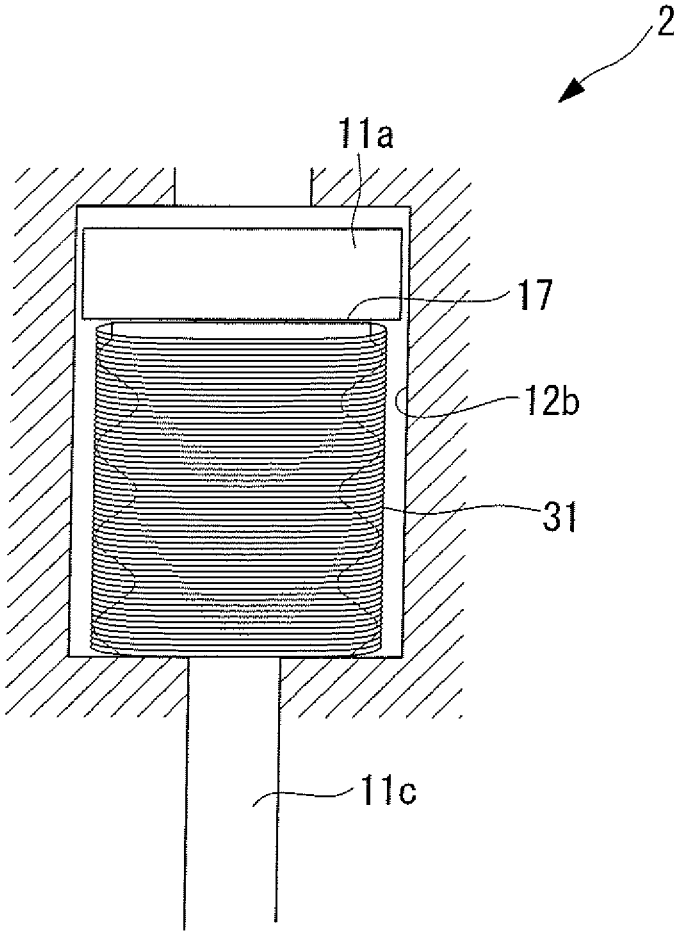

FIG. 4

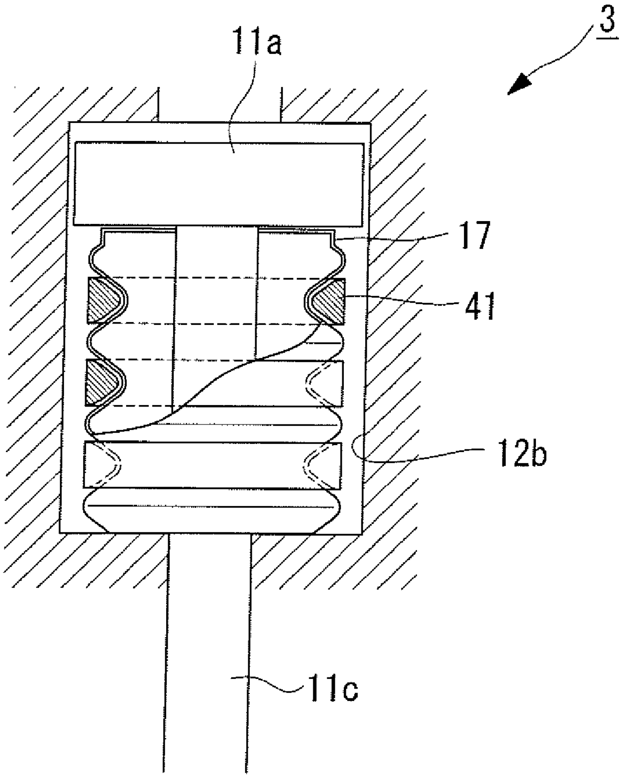

FIG. 5

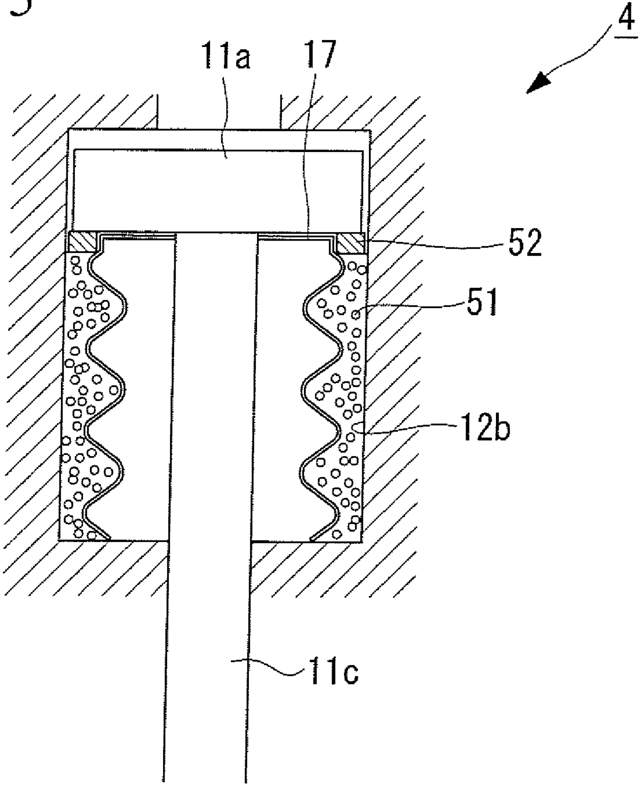

FIG. 6

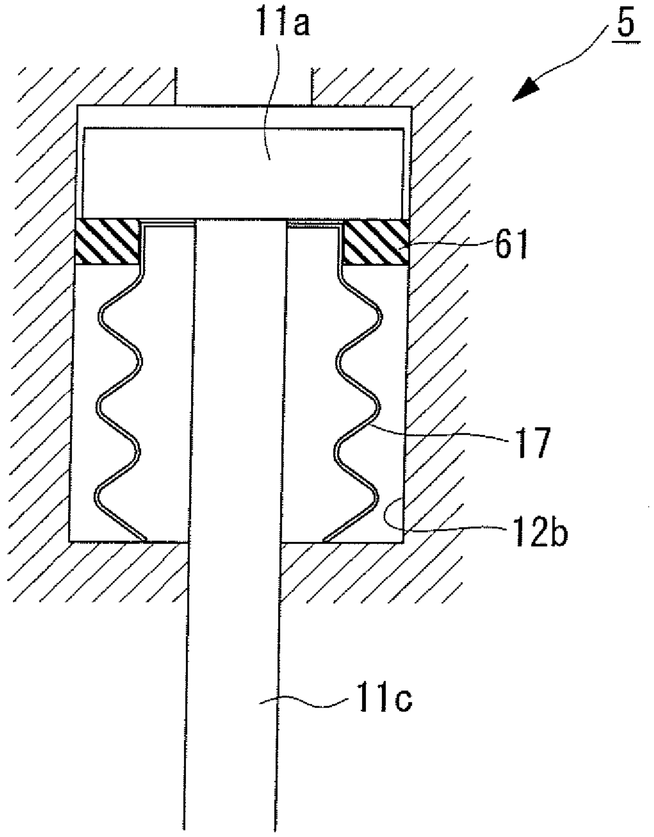

FIG. 7

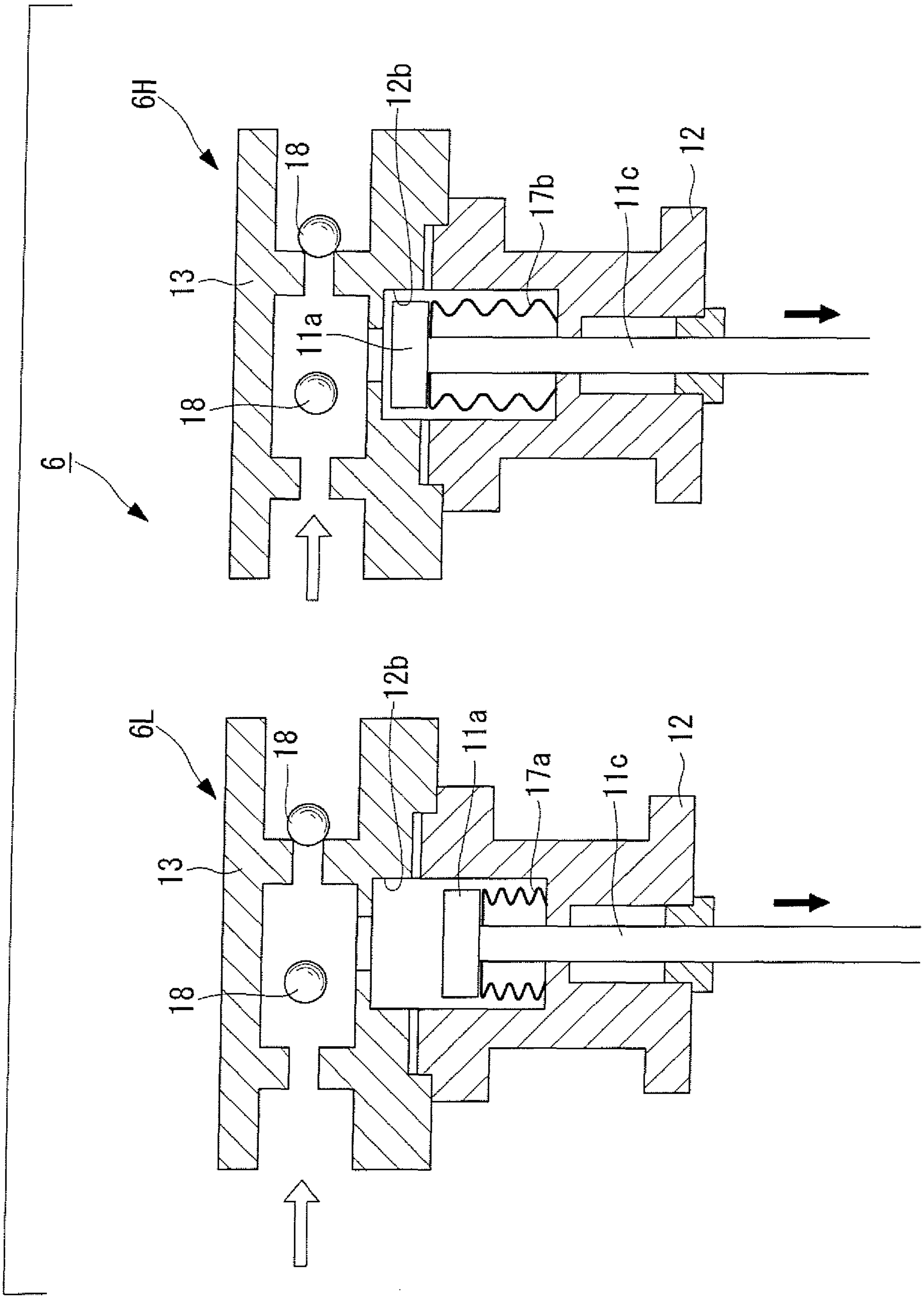

FIG. 8

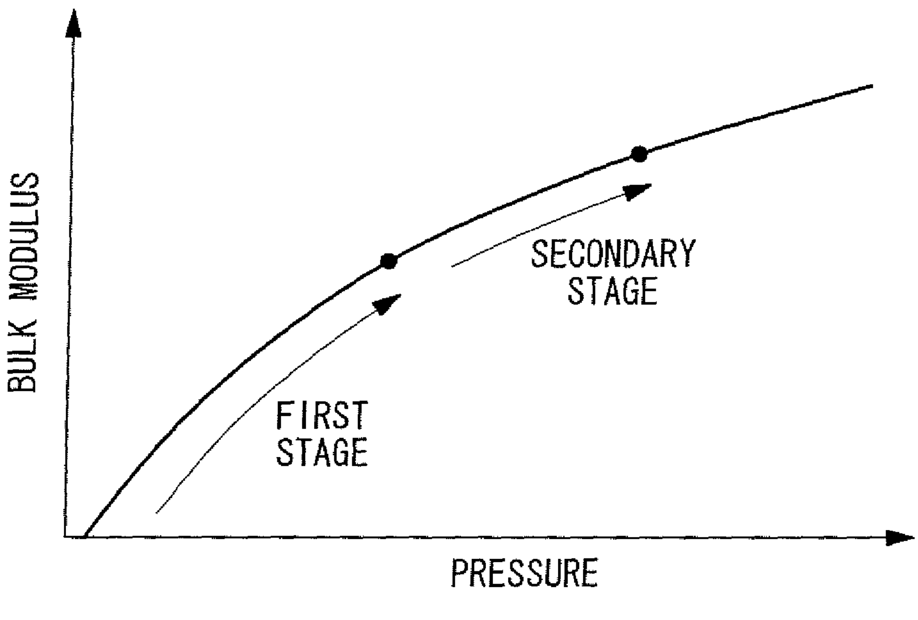

FIG. 9

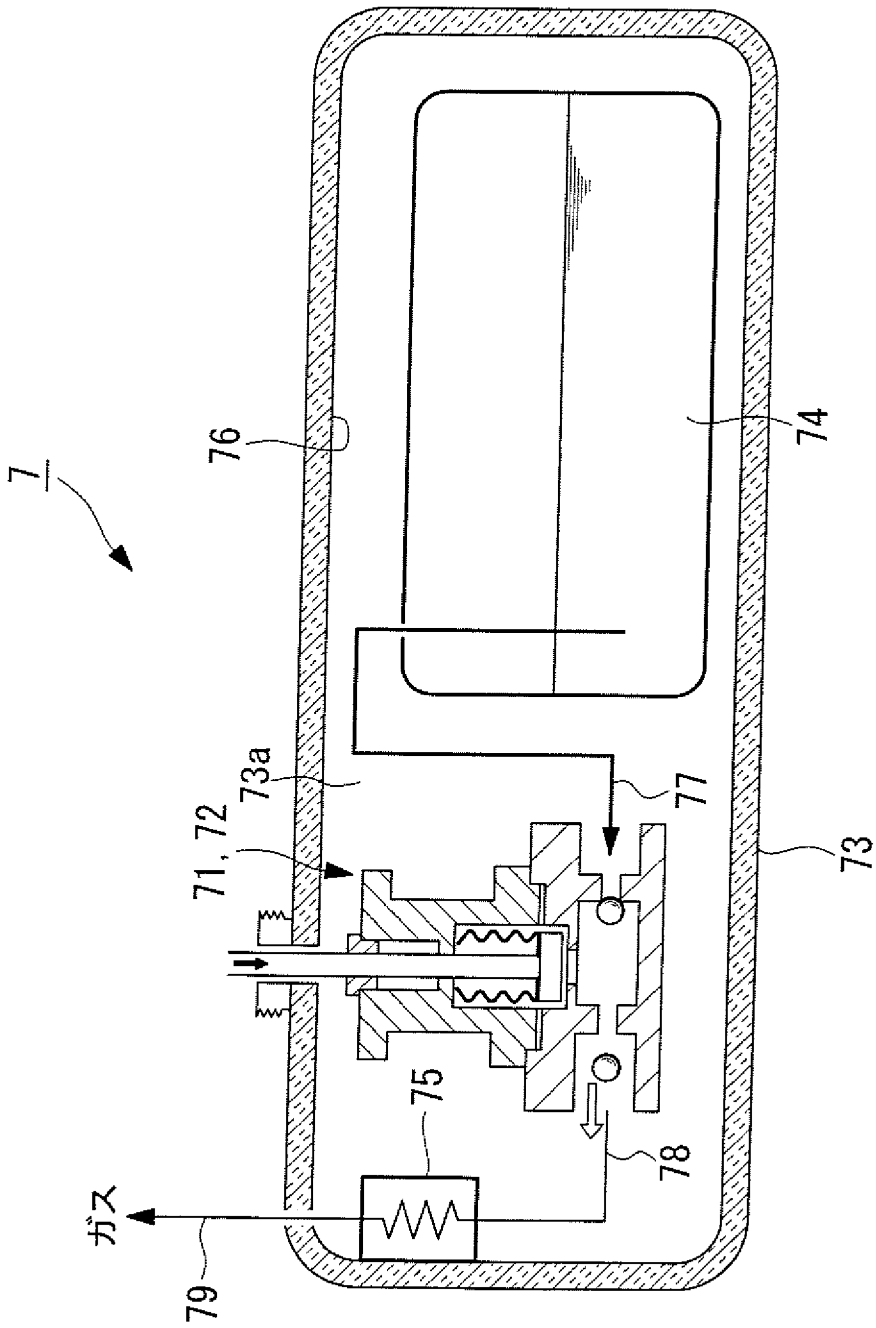

FIG. 10

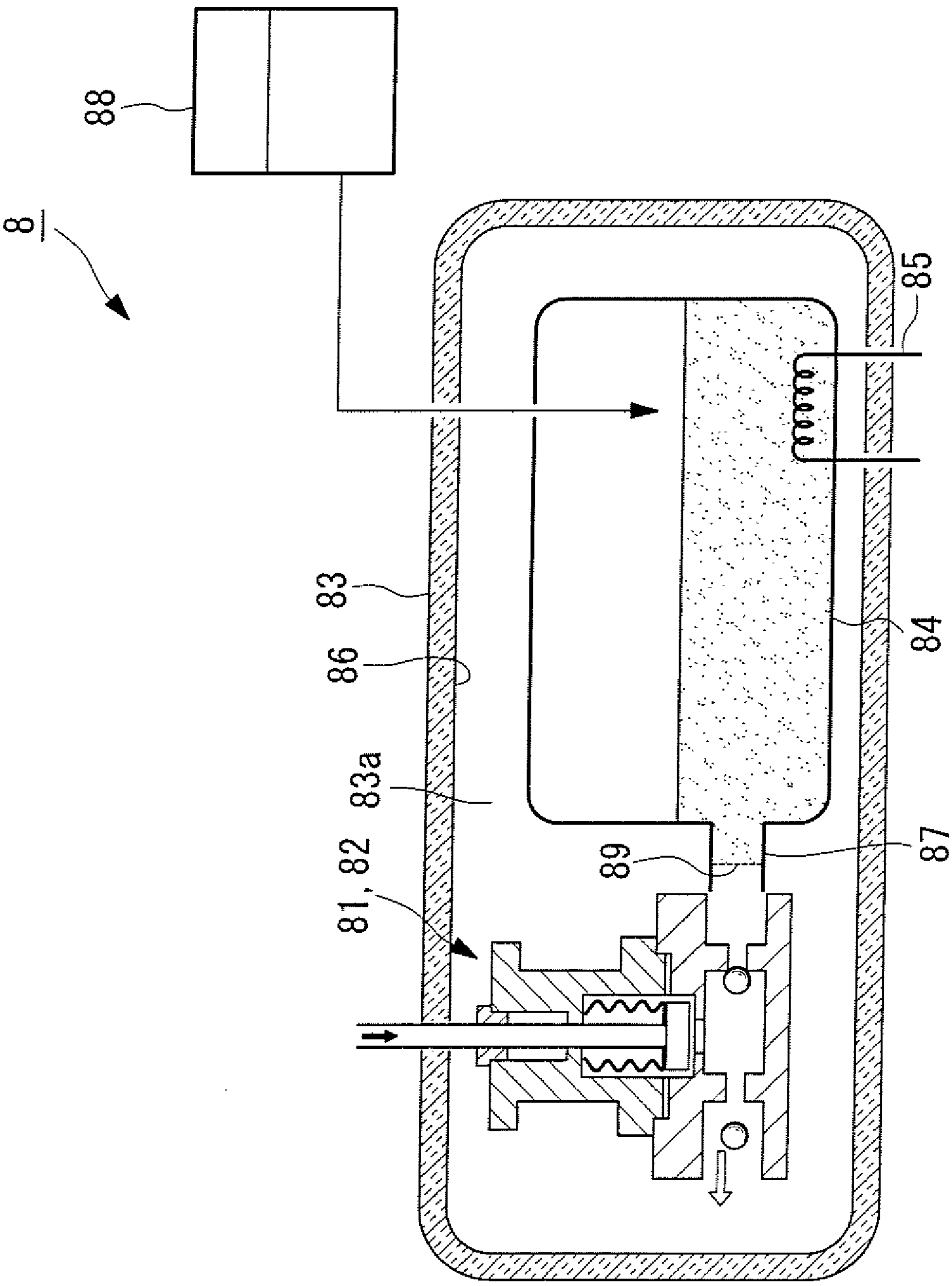

FIG. 11

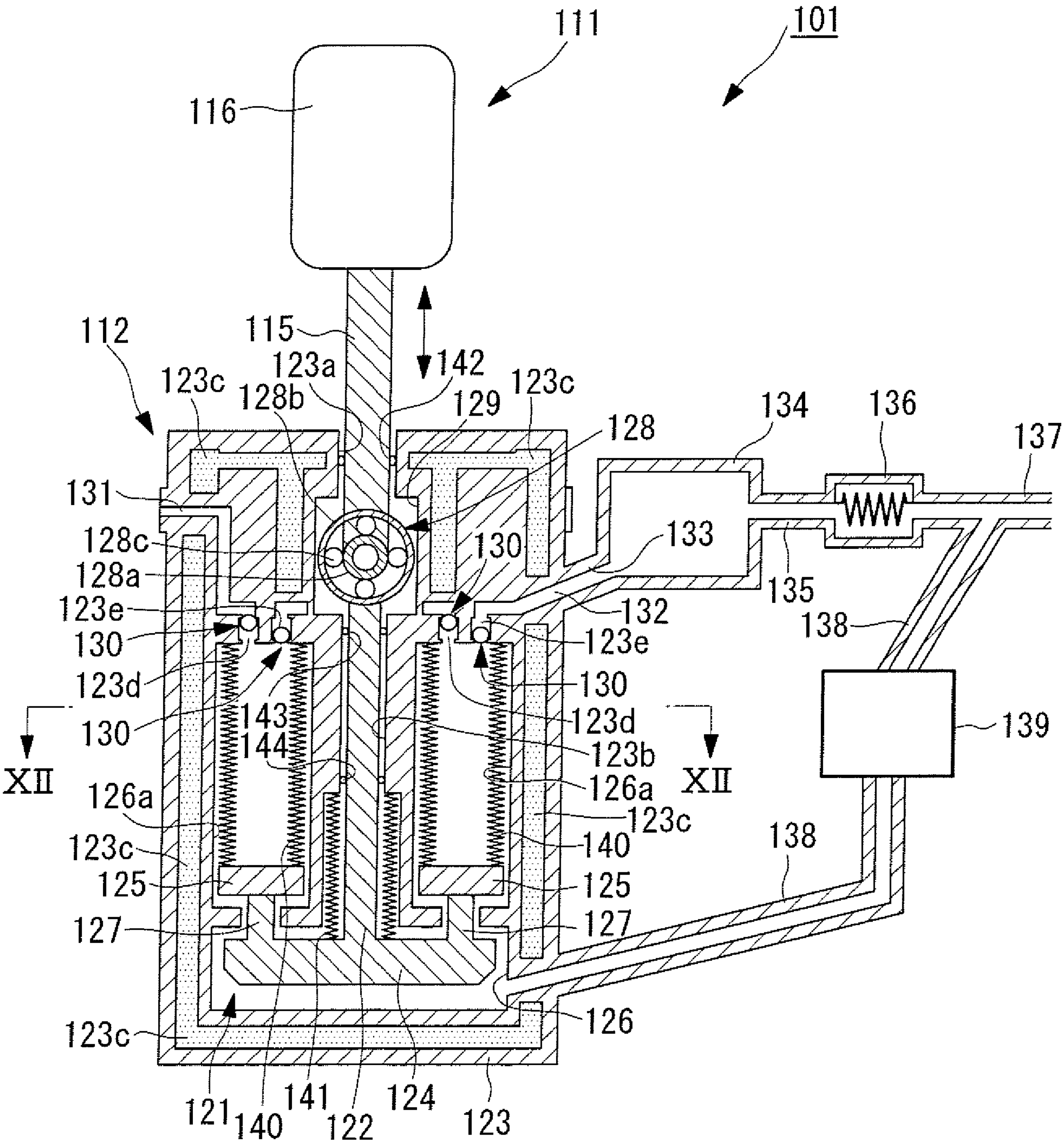

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FIG. 12

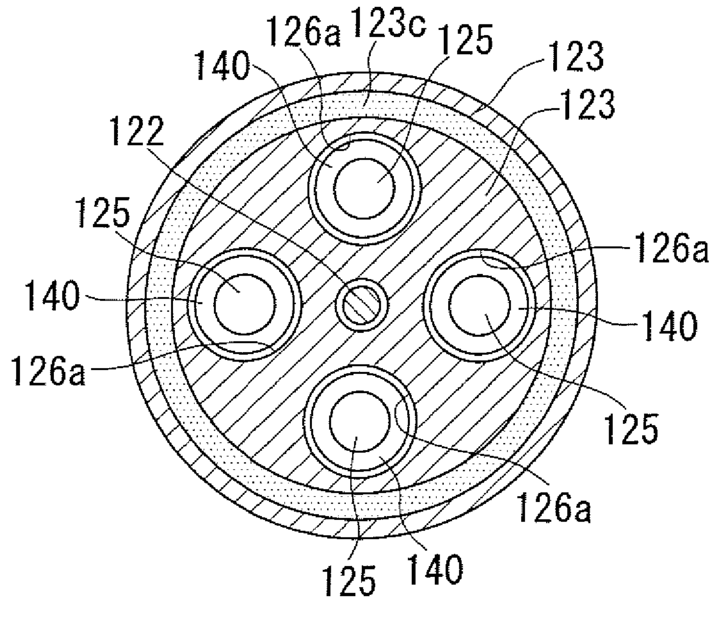
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FIG. 13

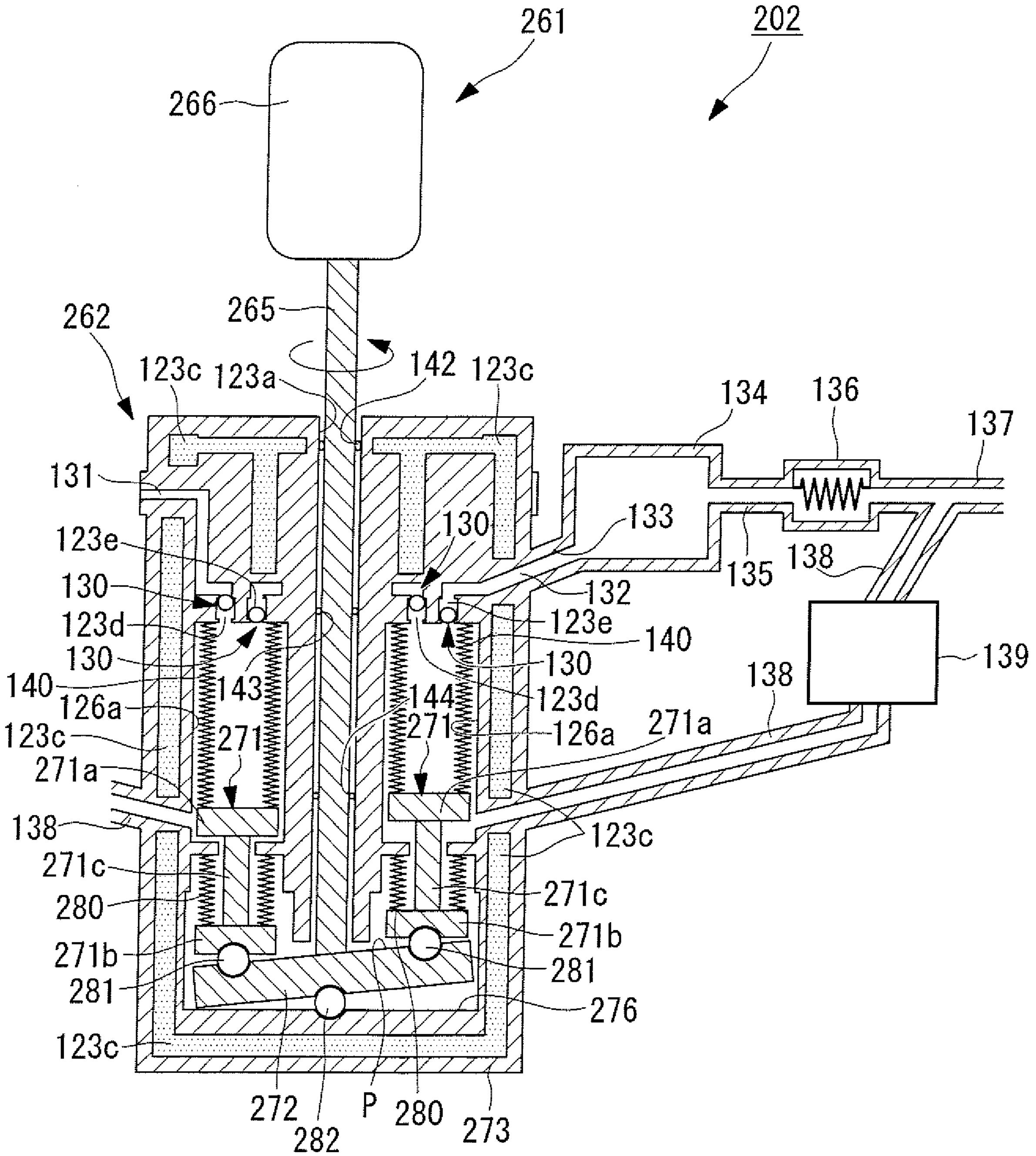
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FIG. 14

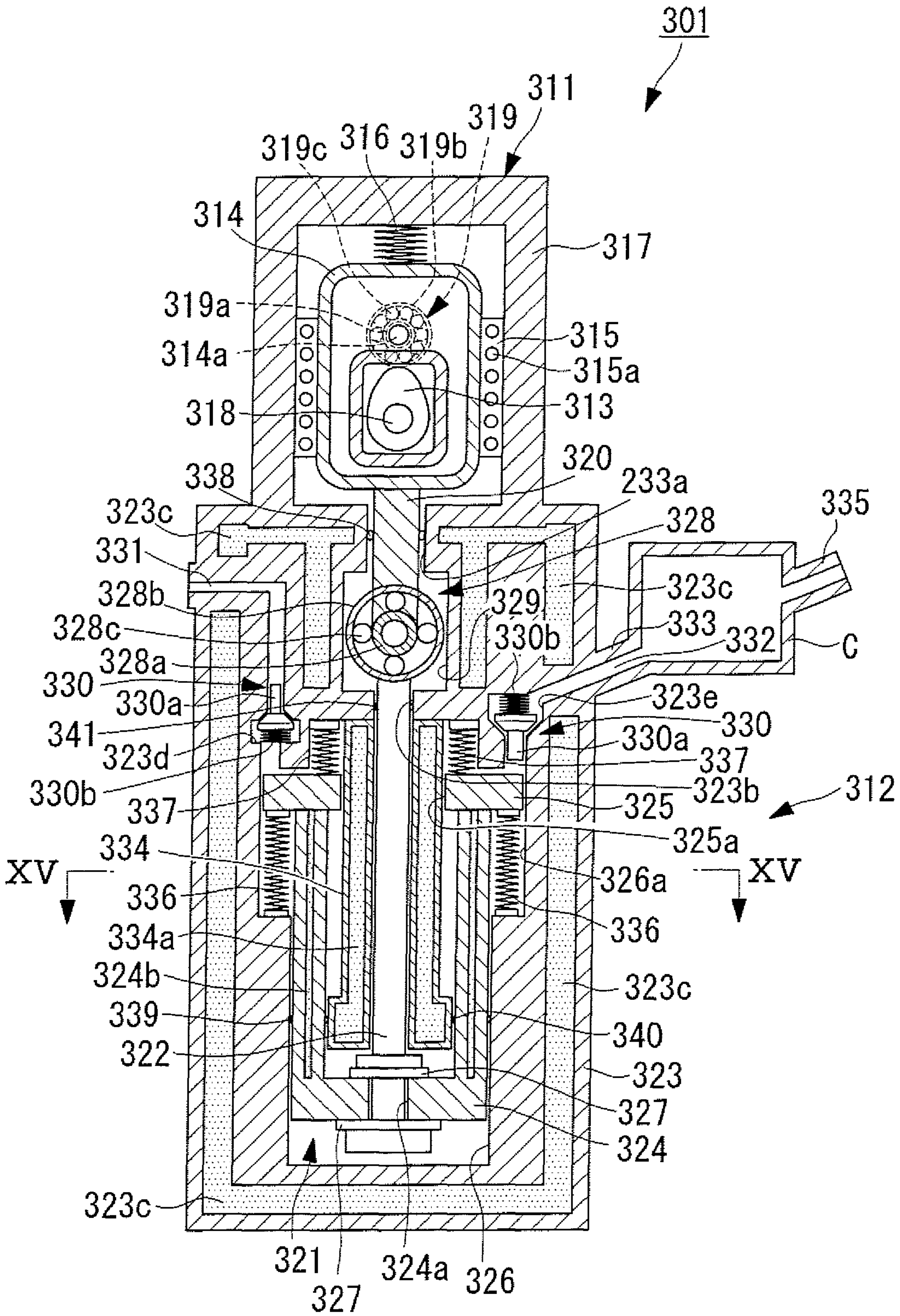
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FIG. 15

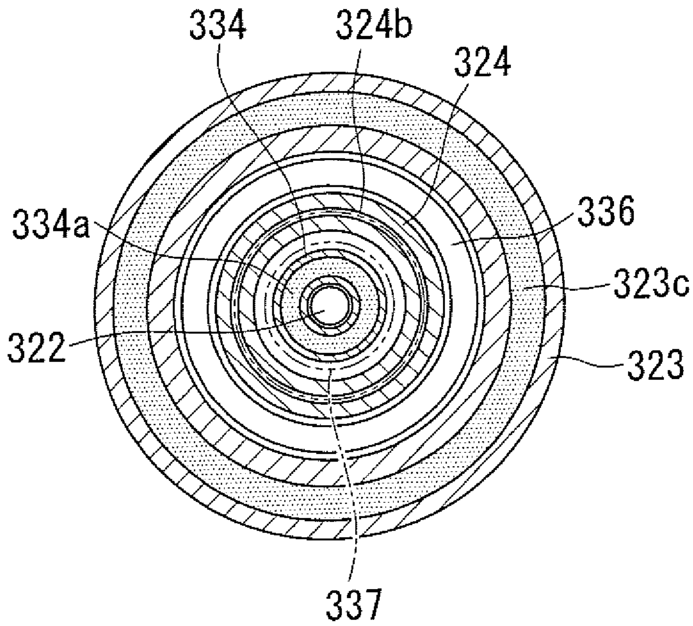

FIG. 16

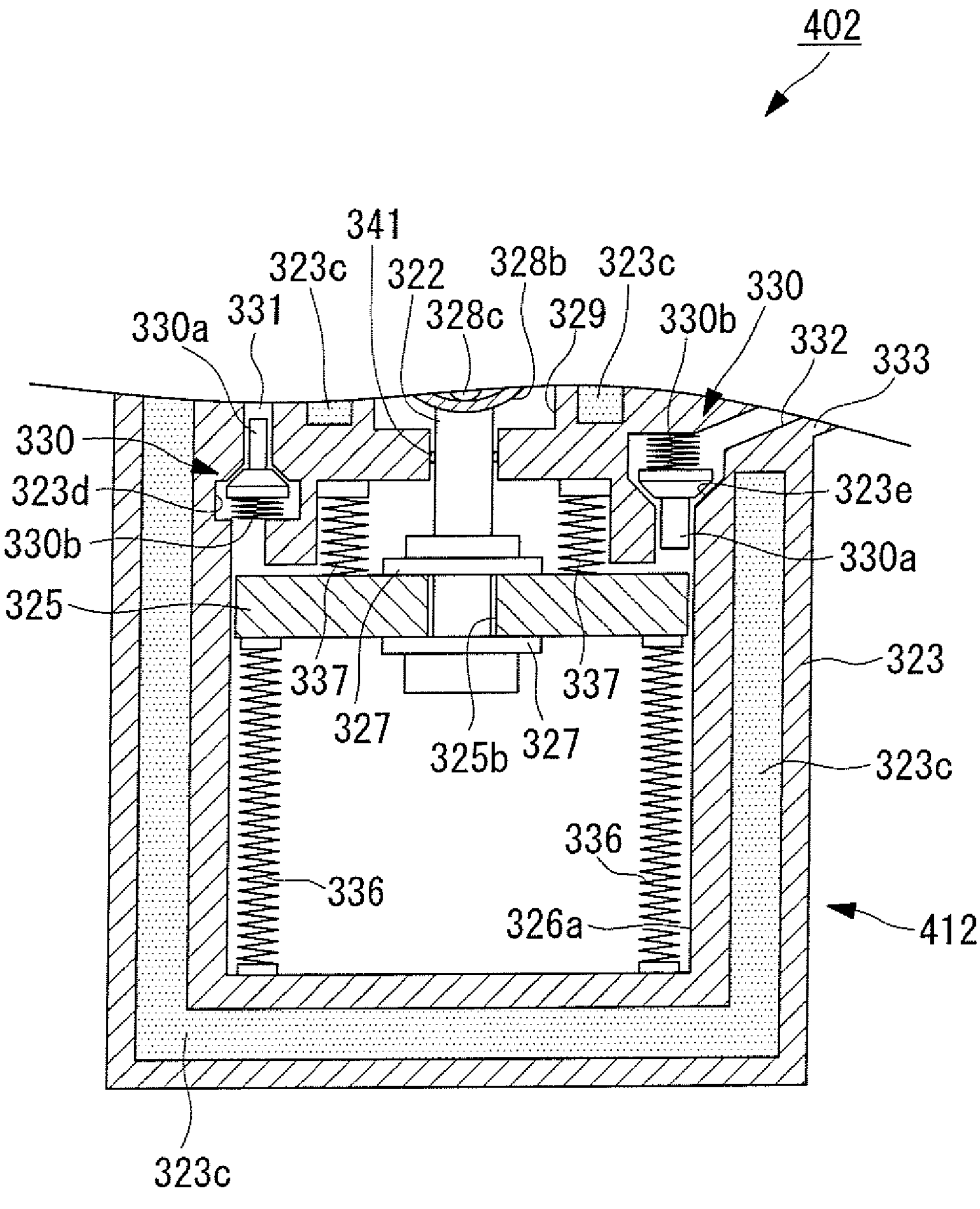
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FIG. 17

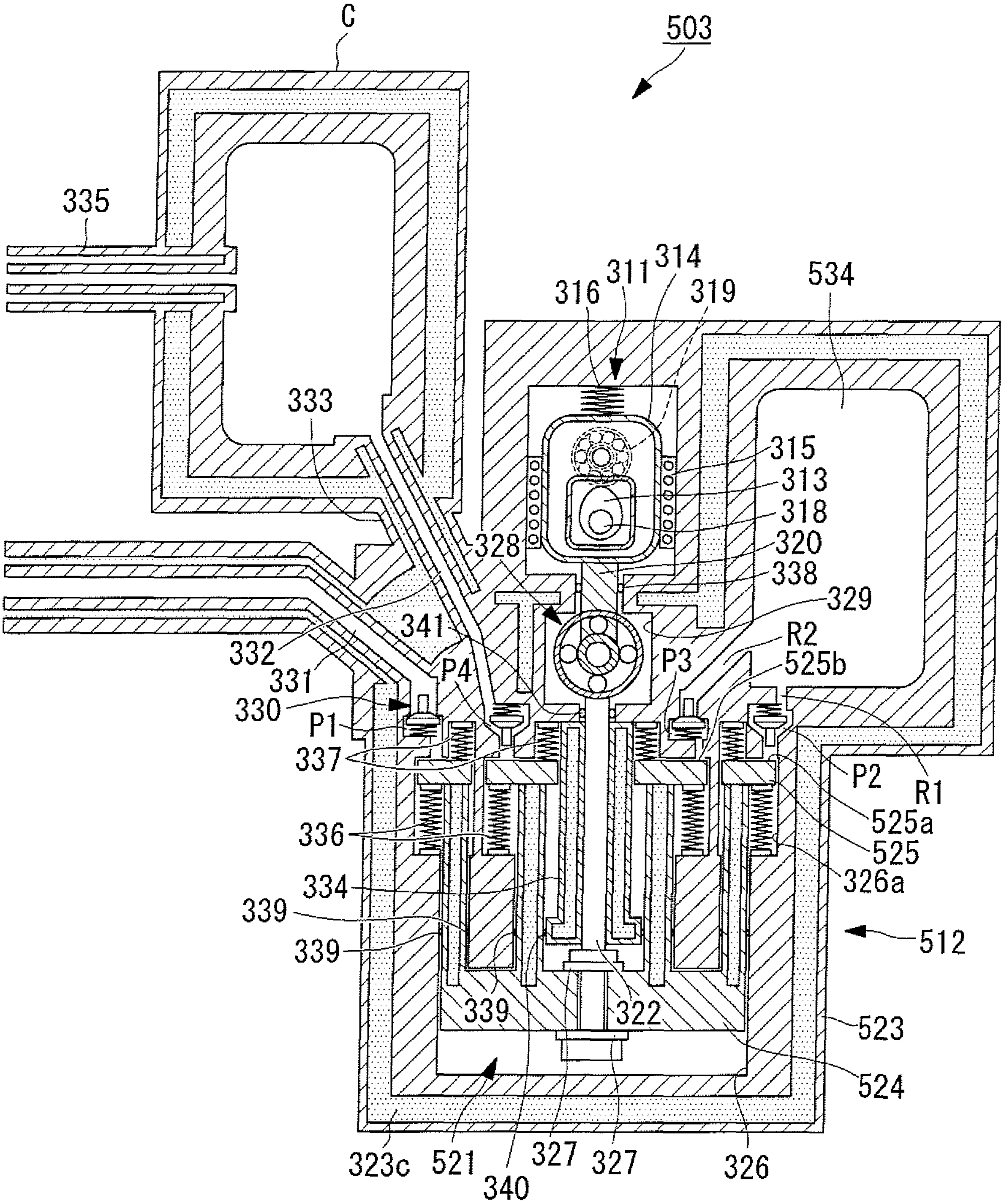
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FIG. 18

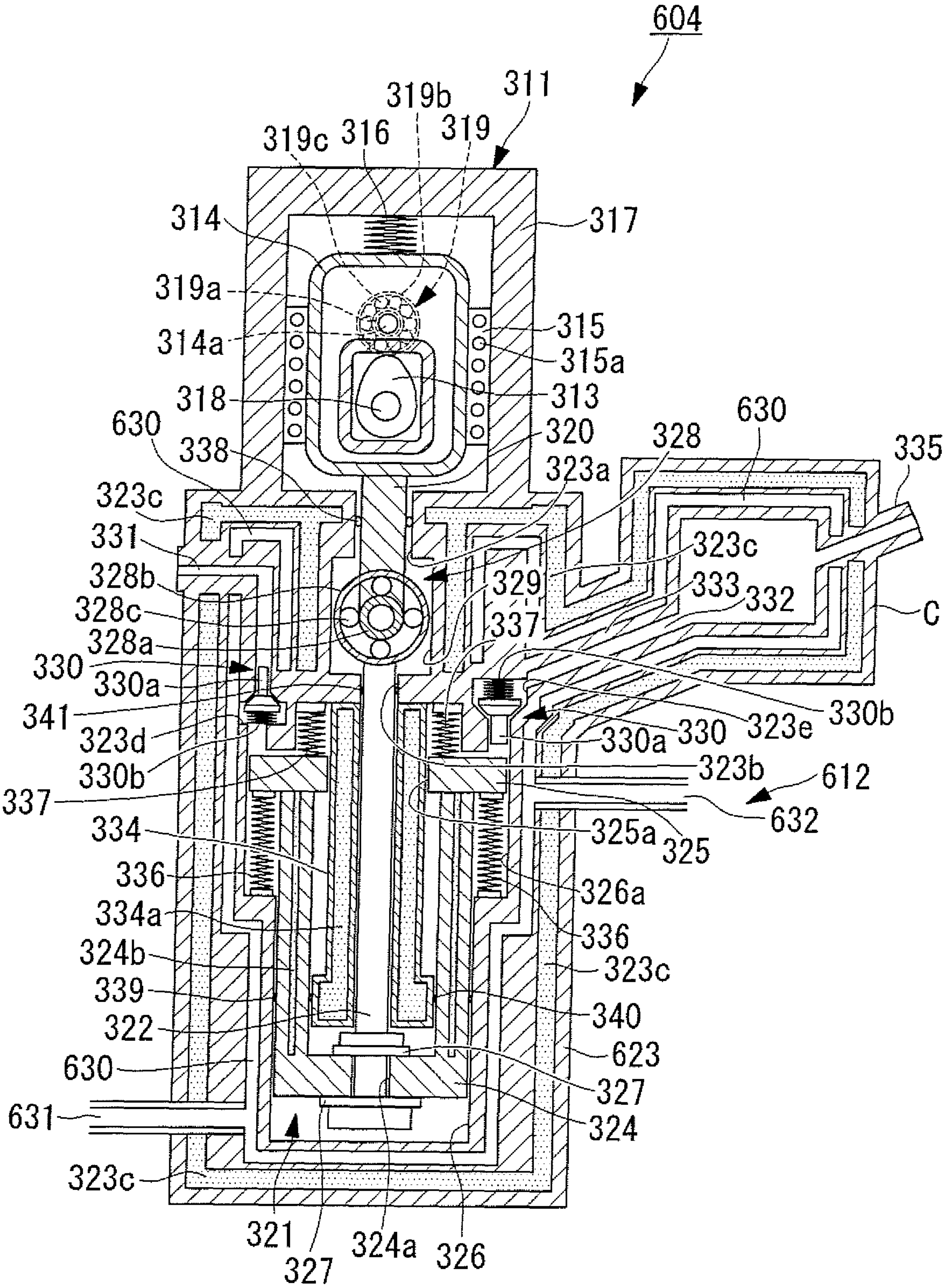

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FIG. 19

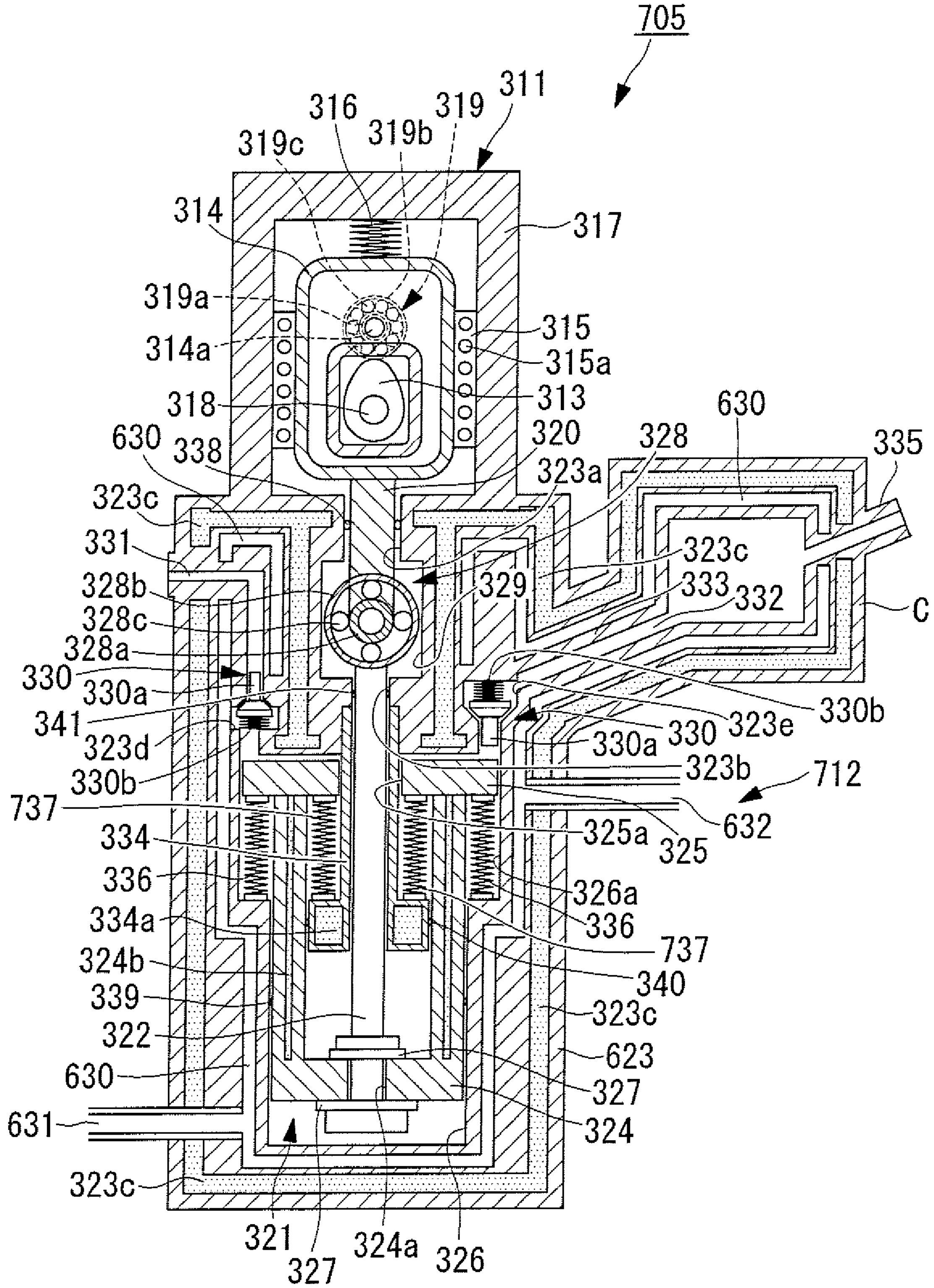
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FIG. 20

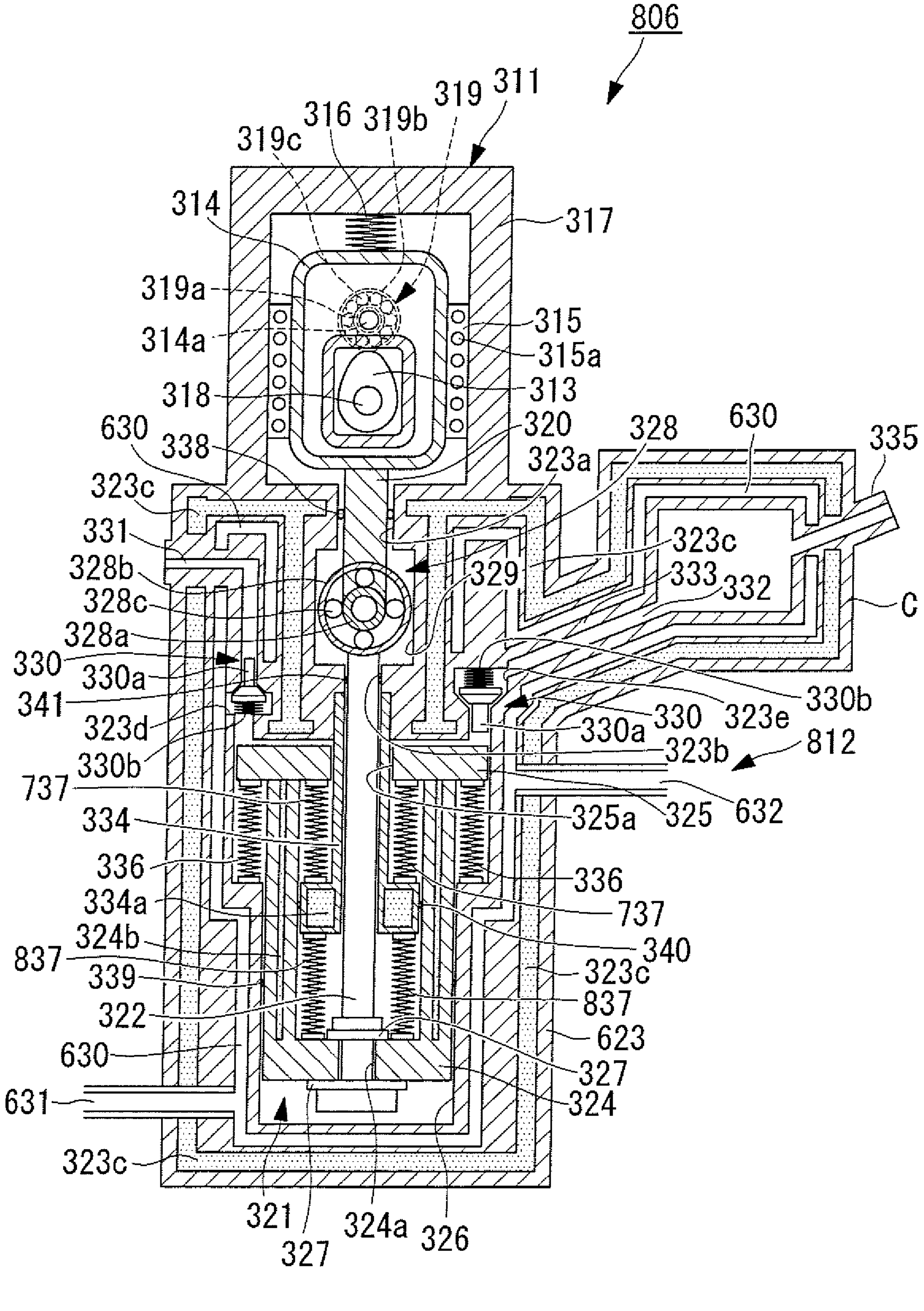
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FIG. 21

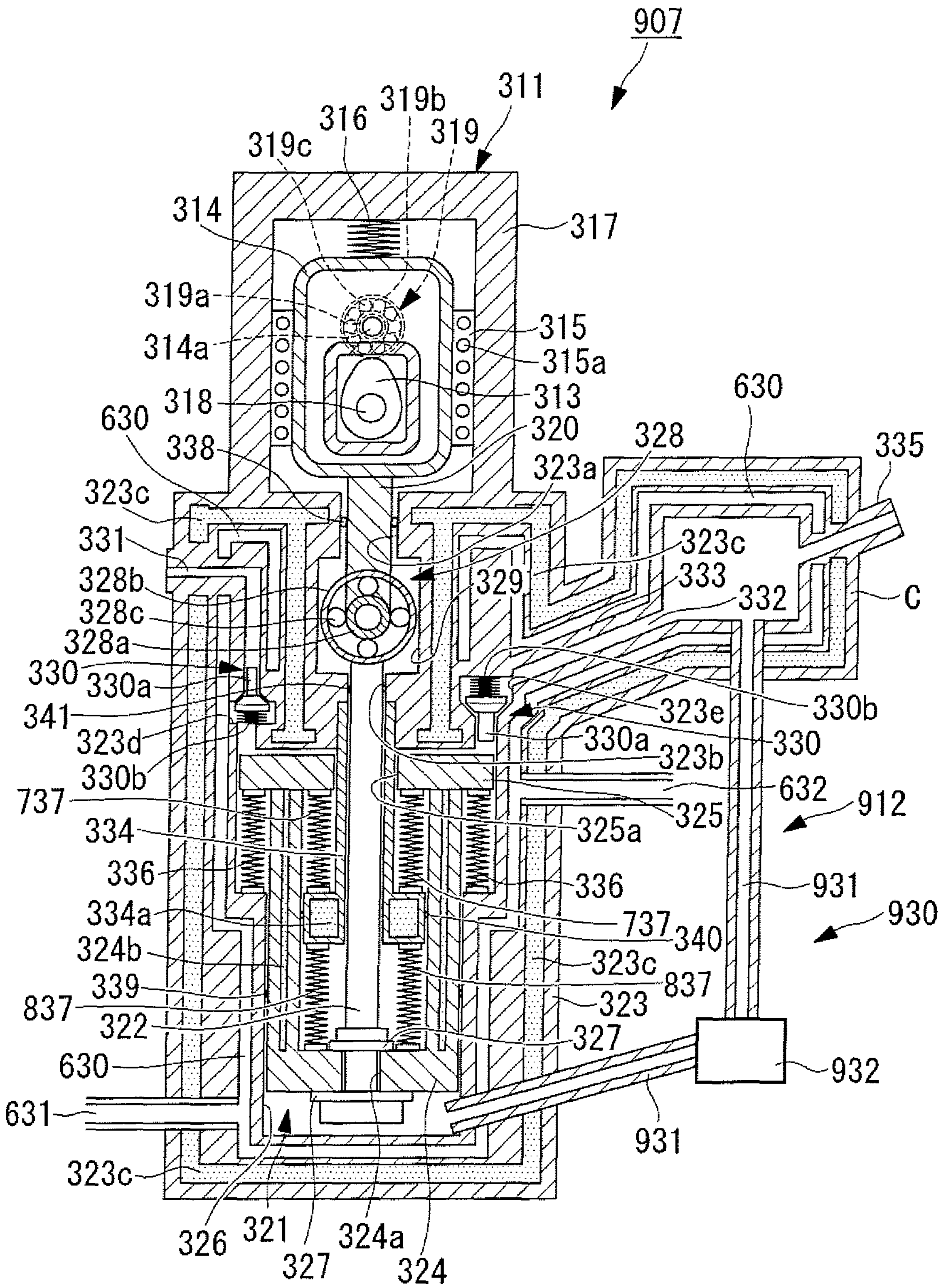
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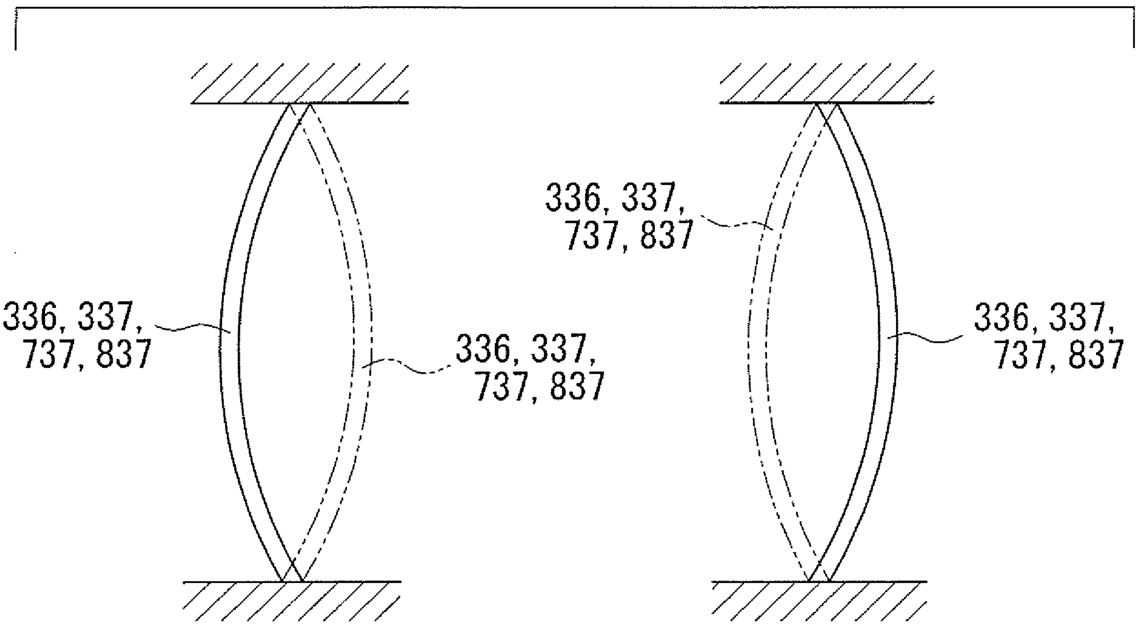
FIG. 22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336, 337,
737, 837

FIG. 23

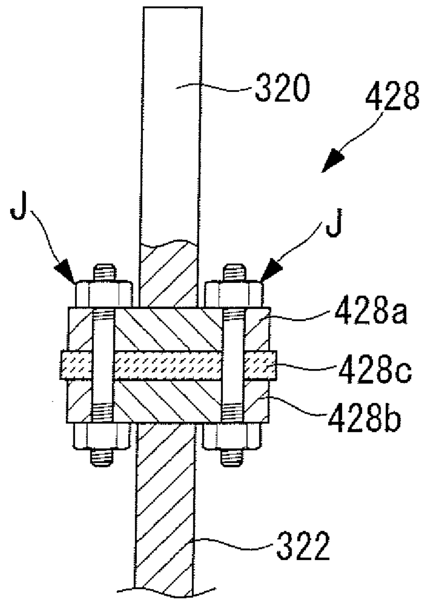

320
428
J
J
428a
428c
428b
322

FIG. 24

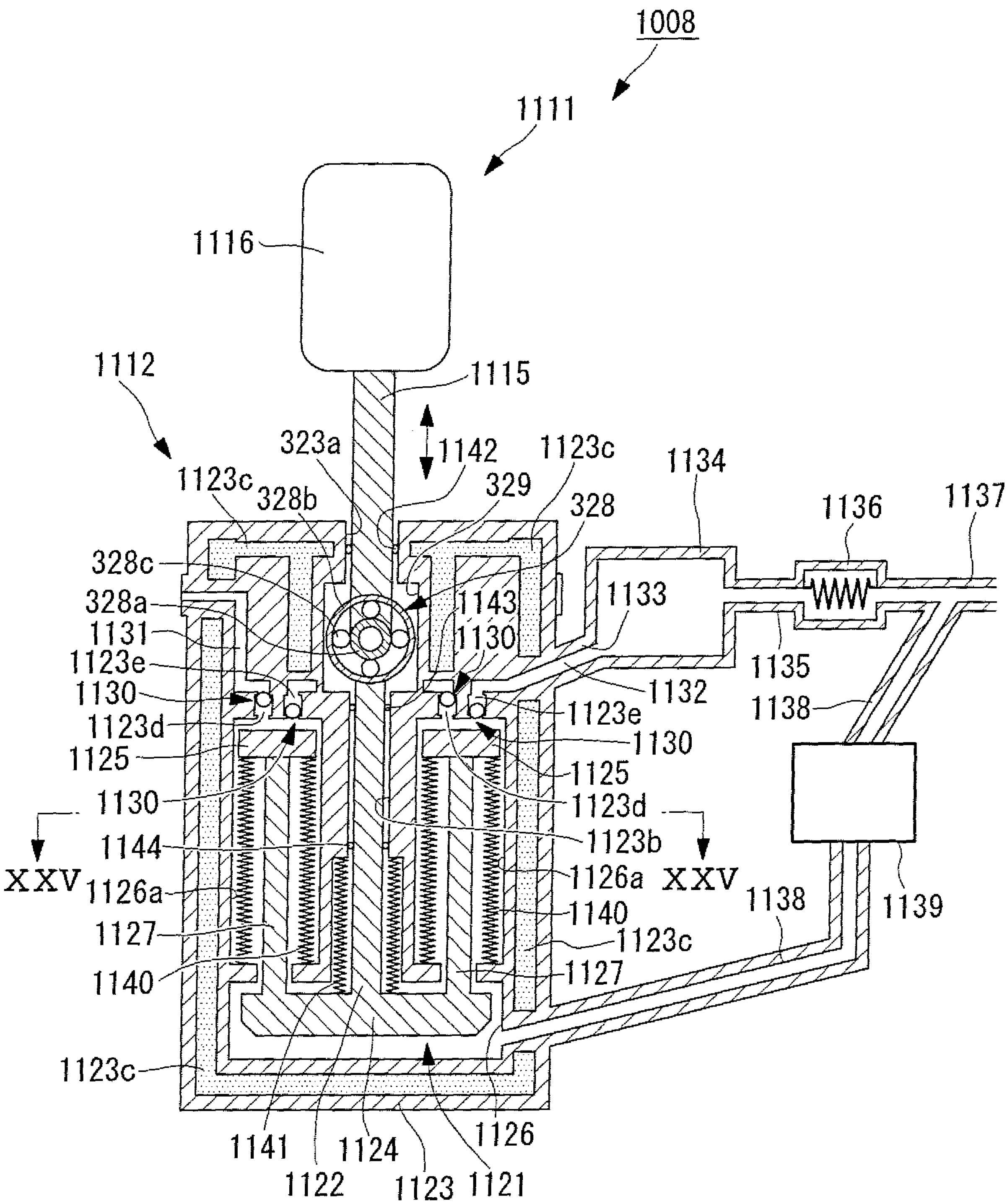

1008
1111
1116
1112
1115
323a
1142
1123c
1134
1136
1137
328b
329
328
328c
1143
1133
328a
1130
1131
1123e
1135
1132
1138
1123d
1125
1144
1126a
1140
1127
1139
XXV
1123b
1141
1124
1122
1123
1121
1126

FIG. 25

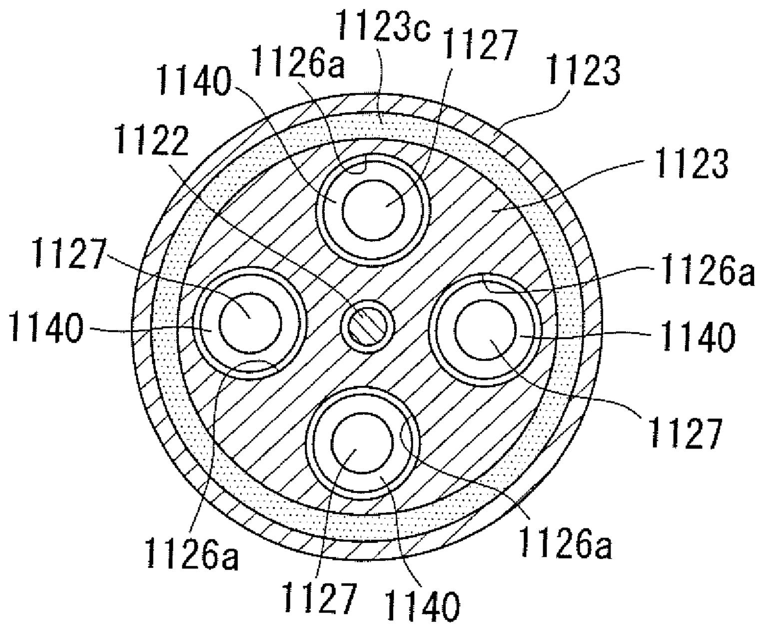
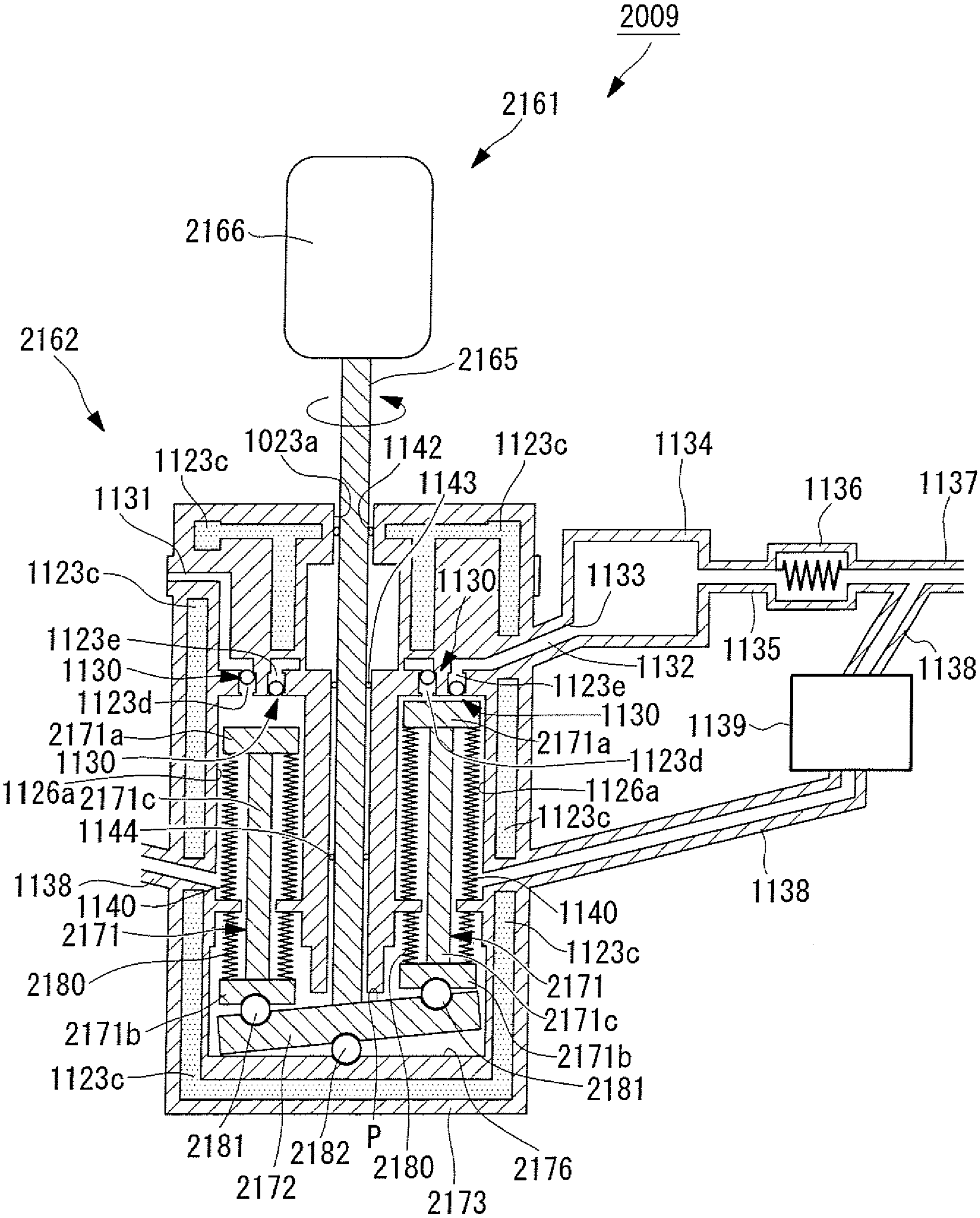

1123c
1127
1123
1140
1126a
1122
1123
1127
1126a
1140
1140
1127
1126a
1126a
1127
1140

FIG. 26


2009
2161
2166
2162
2165
1023a
1142
1123c
1134
1136
1137
1131
1143
1123c
1130
1133
1123e
1130
1123d
2171a
1130
1126a
2171c
1144
1138
1140
2171
2180
2171b
1123c
1132
1135
1138
1123e
1130
1139
2171a
1123d
1126a
1123c
1138
1140
1123c
2171
2171c
2171b
2181
2181
2172
2182
P
2180
2173
2176

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2005/011783

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl^7 F04B53/02, 15/06, 23/02

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^7 F04B53/02, 15/06, 23/02

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	1996-2005
Kokai Jitsuyo Shinan Koho	1971-2005	Toroku Jitsuyo Shinan Koho	1994-2005

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	Microfilm of the specification and drawings annexed to the request of Japanese Utility Model Application No. 140964/1985(Laid-open No. 47782/1987) (Kabushiki Kaisha Tokushu Pisuton Seisakusho), 24 March, 1987 (24.03.87), Full text; all drawings (Family: none)	1-5 6-12,19, 31-33
X Y	JP 2003-148326 A (TAKAKO INDUSTRIES, INC.), 21 May, 2003 (21.05.03), Par. No. [0025]; all drawings (Family: none)	1-5 6-12,19, 31-33

☒ 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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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
27 September, 2005 (27.09.05)	11 October, 2005 (11.10.05)
Name and mailing address of the ISA/ Japanese Patent Office Facsimile No.	Authorized officer Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No. PCT/JP2005/011783

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	JP 2003-287310 A (Sanyo Electric Co., Ltd.), 10 October, 2003 (10.10.03), Full text; all drawings (Family: none)	1-5 6-12,19, 31-33
X Y	Microfilm of the specification and drawings annexed to the request of Japanese Utility Model Application No. 55778/1982(Laid-open No. 158173/1983) (Nippon Fuida Kogyo Kabushiki Kaisha), 21 October, 1983 (21.10.83), Full text; all drawings (Family: none)	1-5 6-12,19, 31-33
Y A	JP 2001-522968 A (Westport Research Inc.), 20 November, 2001 (20.11.01), Full text; all drawings & US 5884488 A & US 2002/85921 A1 & US 2004/105759 A1 & WO 1999/024714 A1 & WO 2003/031817 A1 & GB 2396891 A & CA 2460869 A	6-17,19-35 18
Y	CD-ROM of the specification and drawings annexed to the request of Japanese Utility Model Application No. 59651/1993(Laid-open No. 25281/1995) (Yugen Kaisha Emu Ai Tekuno), 12 May, 1995 (12.05.95), Full text; all drawings (Family: none)	13-15
Y	JP 2003-286961 A (Sanyo Electric Co., Ltd.), 10 October, 2003 (10.10.03), Full text; all drawings (Family: none)	13-15
Y	JP 10-159976 A (NHK Spring Co., Ltd.), 16 June, 1998 (16.06.98), Full text; all drawings (Family: none)	13-15
Y A	Microfilm of the specification and drawings annexed to the request of Japanese Utility Model Application No. 12847/1977(Laid-open No. 107306/1978) (Nippondenso Co., Ltd.), 29 August, 1978 (29.08.78), Full text; all drawings (Family: none)	16-17,19-30 18

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REFERENCES CITED IN THE DESCRIPTION

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Non-patent literature cited in the description

- **TAKUYA ENDO et al.** Shin Enerugii Jidousha. *Sankaido,* January 1995, 221-222 **[0002]**