



(12) **EUROPEAN PATENT APPLICATION**
published in accordance with Art. 153(4) EPC

(43) Date of publication:
09.01.2019 Bulletin 2019/02

(51) Int Cl.:
F04C 18/52 (2006.01) F25B 1/047 (2006.01)

(21) Application number: **16892504.8**

(86) International application number:
PCT/JP2016/056265

(22) Date of filing: **01.03.2016**

(87) International publication number:
WO 2017/149659 (08.09.2017 Gazette 2017/36)

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
MA MD

(72) Inventors:
• **KAMIKAWA, Masaaki**
Tokyo 100-8310 (JP)
• **SHIMOJI, Mihoko**
Tokyo 100-8310 (JP)
• **NAGATA, Hideaki**
Tokyo 100-8310 (JP)

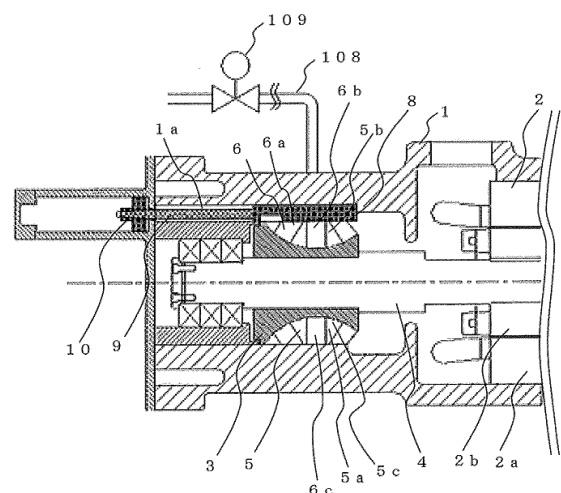
(71) Applicant: **Mitsubishi Electric Corporation**
Chiyoda-ku
Tokyo 100-8310 (JP)

(74) Representative: **Pfenning, Meinig & Partner mbB**
Patent- und Rechtsanwälte
Theresienhöhe 11a
80339 München (DE)

(54) **SCREW COMPRESSOR AND REFRIGERATION CYCLE DEVICE**

(57) A screw compressor according to an embodiment of the present invention includes an electric motor an rotation speed of which can be changed, a screw rotor including a plurality of screw grooves on an outer circumferential surface, a screw shaft to transmit a driving force of the electric motor to the screw rotor and rotate the screw rotor, a first gate rotor and a second gate rotor respectively disposed on both sides of the screw rotor point-symmetrically with respect to the screw shaft and including, in outer circumferential portions, a plurality of teeth meshed with the screw grooves, a casing having a cylindrical shape to house the screw rotor inside a cylinder, a bypass device to cause a first compression chamber, which is a space surrounded by the first gate rotor, the screw groove, and the casing, and a low-pressure chamber having a suction pressure atmosphere to communicate, and an economizer port provided in the casing to cause fluid flowing from an outside to flow into the first compression chamber.

FIG. 2



Description

Citation List

Technical Field

Patent Literature

[0001] The present invention relates to, for example, a screw compressor and a refrigeration cycle apparatus that perform refrigerant compression. The present invention relates to, in particular, a screw compressor or the like including economizer ports.

5 **[0005]** Patent Literature 1: Japanese Patent No. 1551204

Summary of Invention

Background Art

10 Technical Problem

[0002] There is a conventional refrigeration cycle apparatus including, as a device configuring a refrigerant circuit, an intermediate cooler to perform heat exchange between refrigerant and refrigerant to increase, for example, a capacity and improve performance and a coefficient of performance (a ratio of a refrigeration capacity to a compressor input) of the refrigeration cycle. Some refrigeration cycle apparatus including the intermediate cooler can perform economizer operation for leading gaseous refrigerant (hereinafter referred to as economizer gas) after cooling of liquid refrigerant in the intermediate cooler to a compressor intermediate unit.

[0006] While there is the screw compressor that moves the slide valve to adjust the area of opening of the bypass port and perform capacity control as explained above, there is a screw compressor that changes rotation speed of an electric motor to adjust a capacity according to control by an inverter device to reduce a loss caused by bypassing compressed gaseous refrigerant. For example, in a screw compressor that adjusts a capacity by inverter control, a ratio of a leak to a discharge amount is large and performance is deteriorated during low-rotation speed operation. Therefore, the slide valve is moved relative to one compression chamber to adjust the area of opening of the bypass port. Cylinder partial disuse operation that opens the bypass port to bring one compression chamber into a no-load state and reduces area of opening of a suction volume of the compressor to approximately a half is performed to reduce the suction volume and a seal length at which a refrigerant gas leaks. By performing the cylinder partial disuse operation, it is possible to increase the rotation speed of the compressor to obtain a predetermined capacity. The ratio of a leak to a discharge amount decreases. It is possible to improve performance in a partial load.

[0003] In such a refrigeration cycle apparatus, the intermediate cooler is disposed between a condenser and an evaporator of the refrigerant circuit. The refrigeration cycle apparatus includes an economizer pipe branching from a main refrigerant circuit halfway between the evaporator and the condenser. An expansion valve for intermediate cooling is set in the economizer pipe. The refrigeration cycle apparatus includes a screw compressor including economizer ports to which the economizer pipe is connected.

25 **[0007]** In the screw compressor that changes the rotation speed of the electric motor to adjust the capacity as explained above, because it changes the rotation speed to adjust the capacity, duration of an operation mode for opening the bypass port to adjust the capacity decreases, and it can improve the performance during the partial load. However, in the screw compressor to which the economizer pipe is connected and in which the economizer ports are provided, there is a problem when the economizer operation is stopped. The economizer ports are usually provided respectively in two compression chambers, in which case there is a problem when the economizer operation is stopped. Still, even when the economizer port is provided only in one compression chamber, there is the same problem as follows. When the economizer port is provided in the compression chamber on a side where the bypass port is not opened as in Patent Literature 1, under a condition that an operation pressure difference (a difference between high and low pressures of the refrigeration cycle) is small under a low-load condition, the economizer gas less easily flows in, a cycle becomes unstable, an improvement effect of a refrigeration capacity by an economizer cycle is not obtained, and a coefficient of performance is deteriorat-

[0004] The screw compressor includes a screw rotor, a casing to house the screw rotor, a bypass port to allow a low-pressure chamber and a suction side of a compression chamber to communicate, and a slide valve slid in a rotation axis direction of the screw rotor to close a part or the whole of bypass port and adjust the size of an opening port portion of the bypass port. Some screw compressor includes at least two compression chambers among an inner surface of a casing, a screw rotor, and a gate rotor. In the conventional techniques, the economizer port described above is provided only in one compression chamber. For example, a controller moves, first, the slide valve of the other compression chamber in which the economizer port is not provided, adjusts the opening port portion of the bypass port, and adjusts the capacity of a compressor. At this time, the economizer gas does not flow into a suction side through the bypass port. Hindrance of refrigerant to be sucked is prevented (see, for example, Patent Literature 1).

55

ed. Therefore, disadvantageously, when the economizer operation is stopped, the coefficient of performance is deteriorated. This is caused by, for example, a volume portion of the economizer ports and channels becomes a dead volume to cause a recompression loss and act as a leak channel.

[0008] To overcome the problems described above, an object of the present invention is to provide a screw compressor and a refrigeration cycle apparatus that can realize a high coefficient of performance in a wide operation range and improve performance. Solution to Problem

[0009] A screw compressor according to an embodiment of the present invention includes: an electric motor configured to operate at a variable rotation speed; a screw rotor including a plurality of screw grooves on an outer circumferential surface; a screw shaft configured to transmit a driving force of the electric motor to the screw rotor and rotate the screw rotor; a first gate rotor and a second gate rotor, the first gate rotor being disposed on one side of the screw rotor, the second gate rotor being disposed on an other side of the screw rotor, the first gate rotor and the second gate rotor being disposed point-symmetrically with respect to the screw shaft and including, in outer circumferential portions, a plurality of teeth meshed with the screw grooves; a casing having a cylindrical shape to house the screw rotor inside a cylinder; a bypass device configured to allow a first compression chamber and a low-pressure chamber to communicate with each other, the low-pressure chamber being configured to have atmosphere of a suction pressure, the first compression chamber being a space surrounded by the first gate rotor, the screw groove, and the casing; and an economizer port provided in the casing and configured to allow fluid flowing from an outside to flow into the first compression chamber.

[0010] A refrigeration cycle apparatus according to another embodiment of the present invention is a refrigeration cycle apparatus in which the screw compressor described above, a condenser, a high-pressure side channel of an intermediate cooler, a decompression device, and an evaporator are connected in order by refrigerant pipes to configure a refrigerant circuit that circulates refrigerant, which is fluid, the refrigeration cycle apparatus comprising an economizer pipe branching from a pipe between the intermediate cooler and the decompression device and connected to an economizer port included in the screw compressor via an expansion device for the intermediate cooler and an intermediate-pressure side channel of the intermediate cooler.

Advantageous Effects of Invention

[0011] According to the embodiments of the present invention, the economizer port and the bypass device are provided on the first compression chamber side. Therefore, for example, economizer operation is performed and an economizer effect is obtained during high-

load operation. During low-load operation, the rotation speed can be increased by bringing the first compression chamber into the no-load state. Further, even when the economizer is switched to stop operation, it is possible to reduce a loss due to a dead volume. Therefore, it is possible to obtain a screw compressor and other devices that can realize a high coefficient of performance in a wide operation range and improve performance.

Brief Description of Drawings

[0012]

Fig. 1 is a diagram illustrating the configuration of a refrigeration cycle apparatus 100 including a screw compressor 102 according to Embodiment 1 of the present invention.

Fig. 2 is a diagram for explaining the internal configuration in the screw compressor 102 according to Embodiment 1 of the present invention.

Fig. 3 is a diagram illustrating a relation between a casing 1, a screw rotor 3, and a gate rotor 6 and a compression chamber 5 in the screw compressor 102 according to Embodiment 1 of the present invention.

Fig. 4 is a diagram illustrating a compression principle of the screw compressor 102 according to Embodiment 1 of the present invention.

Fig. 5 is a schematic diagram illustrating a state at the time when a suction-side bypass port 1d is not opened in the screw compressor 102 according to Embodiment 1 of the present invention.

Fig. 6 is a development of the inner cylinder surface of the casing 1 and the screw rotor 3 at the time when the suction-side bypass port 1d is not opened in the screw compressor 102 according to Embodiment 1 of the present invention.

Fig. 7 is a schematic diagram illustrating a state at the time when the suction-side bypass port 1d is opened in the screw compressor 102 according to Embodiment 1 of the present invention.

Fig. 8 is a development of the inner cylinder surface of the casing 1 and the screw rotor 3 at the time when the suction-side bypass port 1d is opened in the screw compressor 102 according to Embodiment 1 of the present invention.

Fig. 9 is a diagram illustrating the configuration of the refrigeration cycle apparatus 100 including the screw compressor 102 according to Embodiment 2 of the present invention.

Fig. 10 is a schematic diagram illustrating a state at the time when the suction-side bypass port 1d is not opened in the screw compressor 102 according to Embodiment 2 of the present invention.

Fig. 11 is a development of the inner cylinder surface of the casing 1 and the screw rotor 3 at the time when the suction-side bypass port 1d is not opened in the screw compressor 102 according to Embodiment 2

of the present invention.

Fig. 12 is a schematic diagram illustrating a state at the time when the suction-side bypass port 1d is opened in the screw compressor 102 according to Embodiment 2 of the present invention.

Fig. 13 is a development of the inner cylinder surface of the casing 1 and the screw rotor 3 at the time when the suction-side bypass port 1d is opened in the screw compressor 102 according to Embodiment 2 of the present invention. Description of Embodiments

[0013] Embodiments of the present invention will be explained below with reference to the drawings. In the drawings referred to below, components denoted by the same reference numerals and signs are the same or equivalent components and are common throughout the descriptions of embodiments described below. Embodiments of constituent elements described throughout the specification are only illustrations and are not limited to these descriptions. In particular, combinations of the constituent elements are not limited to only combinations in each embodiment. Elements described in other embodiments can be applied to different embodiments as appropriate. High and low pressures are not particularly decided in a relation with absolute values and are relatively decided in states, operations, and the like in a system, a device, and the like. When it is not particularly necessary to distinguish or specify devices and the like of a plurality of types, distinguished by suffixes, such suffixes and the like may be omitted.

Embodiment 1.

[0014] Fig. 1 is a diagram illustrating the configuration of a refrigeration cycle apparatus 100 including a screw compressor 102 according to Embodiment 1 of the present invention. In the following explanation, the screw compressor 102 is a device constituting a refrigerant circuit. Therefore, fluid sucked, compressed, and discharged by the screw compressor 102 in Embodiment 1 and other embodiments is explained as being refrigerant.

[0015] The refrigeration cycle apparatus 100 of Embodiment 1 includes a main refrigerant circuit configured by connecting, with refrigerant pipes, the screw compressor 102 supplied with electric power from an inverter device 101 to be driven, a condenser 103, a high-pressure side channel of an intermediate cooler 104, an expansion valve 105, which is a decompression device, and an evaporator 106 in order. The refrigeration cycle apparatus 100 further includes an economizer pipe 108, one end of which branches from a pipe in which mainstream refrigerant flows between the intermediate cooler 104 and the expansion valve 105. The other end of the economizer pipe 108 is connected to the screw compressor 102 via an intermediate-cooler expansion valve 107 and an intermediate-pressure side channel of the intermediate cooler 104. In the economizer pipe 108, a solenoid

valve 109 serving as a valve that allows refrigerant to pass or prevents the refrigerant from passing the economizer pipe 108 is provided.

[0016] The inverter device 101 controls electric power supply to the screw compressor 102 and controls rotation speed of the screw compressor 102. The screw compressor 102 will be explained below. The condenser 103 cools and condenses a discharge gas, which is gaseous refrigerant, discharged from the screw compressor 102. The expansion valve 105 decompresses and expands the mainstream refrigerant flowing out from the high-pressure side channel of the intermediate cooler 104. Further, the evaporator 106 evaporates the refrigerant flowing out from the expansion valve 105. The intermediate cooler 104 causes high-pressure side refrigerant, which is the mainstream refrigerant, and intermediate-pressure refrigerant to exchange heat. The high-pressure side refrigerant is refrigerant flowing in the high-pressure side channel between the condenser 103 and the expansion valve 105. The intermediate-pressure refrigerant is refrigerant obtained by decompressing a part of the high-pressure side refrigerant by the intermediate-cooler expansion valve 107 and flowing in the intermediate-pressure side channel. The high-pressure side refrigerant is cooled by the heat exchange. The intermediate-pressure refrigerant is heated to be an economizer gas.

[0017] The refrigeration cycle apparatus 100 further includes a controller 110. The controller 110 controls the inverter device 101, the expansion valve 105, the intermediate-cooler expansion valve 107, and other devices. In particular, in Embodiment 1, the controller 110 includes a bypass control device 111 and a valve control device 112. As explained below, the bypass control device 111 performs position control and other kinds of control of a slide valve 8 included in the screw compressor 102. The valve control device 112 controls opening and closing of the solenoid valve 109.

(Screw compressor)

[0018] Fig. 2 is a diagram for explaining the internal configuration in the screw compressor 102 according to Embodiment 1 of the present invention. Fig. 3 is a diagram illustrating a relation between a casing 1, a screw rotor 3, and a gate rotor 6 and a compression chamber 5 in the screw compressor 102 according to Embodiment 1 of the present invention. The screw compressor 102 according to Embodiment 1 of the present invention will be explained below with reference to Fig. 2 and Fig. 3.

[0019] As illustrated in Fig. 2, the screw compressor 102 of Embodiment 1 includes the casing 1, the screw rotor 3, the gate rotor 6, an electric motor 2 to drive to rotate the screw rotor 3, the slide valve 8 and other devices. The casing 1 having a cylindrical shape houses the screw rotor 3, the gate rotor 6, the electric motor 2, the slide valve 8, and other devices inside a cylinder. The electric motor 2 includes a stator 2a fixed in contact with

the casing 1 and a motor rotor 2b disposed inside the stator 2a. The electric motor 2 is driven at rotation speed based on electric power supplied from the inverter device 101.

[0020] The screw rotor 3 is disposed in the casing 1. Both the screw rotor 3 and the motor rotor 2b are disposed and fixed around a screw shaft 4 serving as a rotating shaft. A plurality of spiral screw grooves 5a are formed on an outer circumferential surface of the screw rotor 3. The screw rotor 3 rotates by rotation of the motor rotor 2b fixed to the screw shaft 4. The screw compressor 102 of Embodiment 1 includes two gate rotors 6. The two gate rotors 6 are disposed in positions point-symmetrical with respect to the screw shaft 4 and on both sides of the screw rotor 3. One of the gate rotors 6 is referred to as a first gate rotor 6b and the other is referred to as a second gate rotor 6c. The gate rotors 6 are formed in a disk-like shape. A plurality of teeth 6a are provided on outer circumferential surfaces of the gate rotors 6 along a circumferential direction. The teeth 6a of the gate rotors 6 are meshed with the screw grooves 5a. Spaces surrounded by the teeth 6a of the gate rotors 6, the screw grooves 5a, and a cylinder inner surface side of the casing 1 are the compression chambers 5.

[0021] As illustrated in Fig. 3, a plurality of the compression chambers 5 are formed in positions point-symmetrical with respect to a radial direction center of the screw rotor 3. In Embodiment 1, the compression chamber 5 surrounded by the casing 1, the screw rotor 3, and the teeth 6a of the first gate rotor 6b is referred to as a first compression chamber 5b. The compression chamber 5 surrounded by the casing 1, the screw rotor 3, and the teeth 6a of the second gate rotor 6c is referred to as a second compression chamber 5c. When it is unnecessary to distinguish the first compression chamber 5b and the second compression chamber 5c from each other, the first compression chamber 5b and the second compression chamber 5c are explained as the compression chamber 5.

[0022] Inside of the screw compressor 102 is partitioned into a low-pressure side serving as a suction side of the refrigerant and a high-pressure side serving as a discharge side of the refrigerant by a partition wall (not illustrated in the figure). A space on the low-pressure side is a low-pressure chamber (not illustrated in the figure) configured to have atmosphere of a suction pressure. A space on the high-pressure side is a high-pressure chamber having a discharge pressure atmosphere (not illustrated in the figure). In the casing 1, a discharge port 7 (see Fig. 4 referred to below) to cause the high-pressure chamber and the compression chamber 5 to communicate is provided in a position on the high-pressure side of the compression chamber 5.

[0023] Further, inside the casing 1, a slide groove 1a extending in a rotation axis direction of the screw rotor 3 is formed in a position corresponding to the first compression chamber 5b. In the slide groove 1a, the slide valve 8 serving as a bypass device is housed such that

it can slide along the slide groove 1a. A part of the wall of the slide valve 8 is integrated with a part of the casing 1 to form the first compression chamber 5b in conjunction with the casing 1. In Embodiment 1, the slide valve 8 is provided only on one compression chamber 5 of the two compression chambers 5. In Fig. 2, the slide valve 8 serving as the bypass device is provided only in the first compression chamber 5b. In Embodiment 1, the screw compressor 102 in which the slide groove 1a and the slide valve 8 are provided only on the first compression chamber 5b side is explained. However, the slide groove 1a and the slide valve 8 may be present only on the second compression chamber 5c side. In this case, the second compression chamber 5c is a first compression chamber.

[0024] The slide valve 8 is connected to a bypass driving device 10 such as a piston via a coupling bar 9. The bypass driving device 10 is driven, and thereby the slide valve 8 moves in the rotation axis direction of the screw rotor 3 in the slide groove 1a. The bypass control device 111 of the controller 110 sends, to the bypass driving device 10, an instruction for locating the slide valve 8 in a position where a discharge amount of fluid discharged from the discharge port 7 provided to the first compression chamber 5b is smaller than a discharge amount of fluid discharged from a discharge port provided to the second compression chamber 5c and performs capacity control operation of the screw compressor 102. A power source of driving of the bypass driving device 10 that drives the slide valve 8 is not limited. The power source is, for example, a power source that drives the slide valve 8 with a gas pressure, a power source that drives the slide valve 8 with a hydraulic pressure, or a power source that drives the slide valve 8 with a motor or the like separately from a piston.

[0025] The casing 1 includes an economizer gas channel 1b for leading the economizer gas flowing out from the intermediate cooler 104 to the first compression chamber 5b. The economizer gas channel 1b communicates with the first compression chamber 5b via an economizer port 1c. The economizer pipe 108 is connected to the economizer gas channel 1b. The economizer gas flowing out and branching from the intermediate cooler 104 and cooling mainstream refrigerant liquid flows into the first compression chamber 5b through the economizer pipe 108, the economizer gas channel 1b, and the economizer port 1c.

[0026] The economizer gas channel 1b and the economizer port 1c for leading the economizer gas from the intermediate cooler 104 communicate with the first compression chamber 5b and are provided only on the first compression chamber 5b side as explained above. Some economizer gas channel 1b in the casing 1 includes a space for preventing pulsation at the time when a refrigerant gas flows (not illustrated in the figure) is provided, and through this space, the economizer gas channel 1b communicates with the first compression chamber 5b.

(Operation example of refrigerant circuit)

[0027] Operation of the refrigeration cycle apparatus 100 of Embodiment 1 will be explained with reference to Fig. 1 to Fig. 3.

[0028] The screw compressor 102 sucks and compresses a refrigerant gas, which is gaseous refrigerant, and thereafter discharges the refrigerant gas. The discharge gas discharged from the screw compressor 102 is cooled by the condenser 103. Refrigerant cooled by the condenser 103 flows into the high-pressure side channel of the intermediate cooler 104. The intermediate cooler 104 causes high-pressure side refrigerant passing the high-pressure side channel and intermediate-pressure refrigerant branching after passing the intermediate cooler 104, decompressed by the intermediate-cooler expansion valve 107, and passing the intermediate-pressure side channel to exchange heat. The high-pressure side refrigerant is supercooled by the heat exchange with the intermediate-pressure refrigerant. Since the refrigerant is supercooled, a refrigeration effect in the evaporator 106 increases. The supercooled refrigerant is heated by the evaporator 106 to be a refrigerant gas. The refrigerant gas flowing out from the evaporator 106 is sucked by the screw compressor 102.

[0029] On the other hand, the intermediate-pressure refrigerant passing the intermediate-pressure side channel of the intermediate cooler 104 changes to an economizer gas after cooling the high-pressure side refrigerant and passes the economizer pipe 108 and the economizer gas channel 1b. According to pressure differences between the high pressure and the intermediate pressure of the economizer gas and pressure in the first compression chamber 5b, the economizer gas is injected into the first compression chamber 5b from the economizer port 1c provided in the casing 1. The injected economizer gas is mixed with the refrigerant gas being compressed and is discharged from the screw compressor 102.

(Operation explanation of screw compressor 102)

[0030] Fig. 4 is a diagram illustrating a compression principle of the screw compressor 102 according to Embodiment 1 of the present invention. The operation of the screw compressor 102 according to Embodiment 1 will be explained. For example, when the screw rotor 3 is rotated by the electric motor 2 illustrated in Fig. 2 via the screw shaft 4 illustrated in Fig. 2, as illustrated in Fig. 4, the teeth 6a of the gate rotor 6 relatively move in the compression chamber 5 (the screw grooves 5a). At this time, in the compression chamber 5, a suction stroke, a compression stroke, and a discharge stroke are sequentially performed. The suction stroke, the compression stroke, and the discharge stroke together form one cycle of the compression operation and the cycle is repeated. Each stroke will be explained focusing on the compression chamber 5 indicated by dot hatching in Fig. 4.

[0031] Fig. 4(a) illustrates a state of the compression

chamber 5 in the suction stroke. The screw rotor 3 is driven by the electric motor 2 to rotate in a direction of a solid line arrow. When the screw rotor 3 rotates, a volume of the compression chamber 5 decreases as illustrated in Fig. 4(b).

[0032] When the screw rotor 3 continuously rotates, as illustrated in Fig. 4(c), the compression chamber 5 communicates with the outside via the discharge port 7. Consequently, a high-pressure refrigerant gas compressed in the compression chamber 5 is discharged to the outside from the discharge port 7. The same compression is performed in the back of the screw rotor 3.

[0033] In Fig. 4, concerning the economizer port 1c, the slide valve 8, and the slide groove 1a are not shown in the drawings. During economizer operation, in the compression stroke, an economizer gas flows into the compression chamber 5 via the economizer port 1c. The economizer gas flowing into the compression chamber 5 is compressed together with the refrigerant gas and discharged to the outside in the discharge stroke.

[0034] In the screw compressor 102 of Embodiment 1, the economizer port 1c is provided in only the compression chamber 5 on one side (in an example of Embodiment 1, the first compression chamber 5b). The screw compressor 102 performs economizer operation. In the economizer operation, the screw compressor 102 further has an object of preventing the economizer port 1c from becoming a dead volume during low-load operation for operation in a low-load state. The screw compressor 102 will be explained in detail below. To clarify characteristics in the screw compressor 102 of Embodiment 1, operation during the compression stroke will be explained, by comparing the relation between suction bypass control and the economizer port 1c during the high-load operation and the relation between those during the low-load operation. The low load is a predetermined load set by the controller 110 as a determination standard for operation of the screw compressor 102. In general, the screw compressor 102 is driven at low rotation speed of approximately 20 Hz to 30 Hz or less. Low-pressure difference operation is often performed in the refrigerant circuit. The low-load operation is operation under the low load. In the high-load operation, in general, the screw compressor 102 is driven at high rotation speed. The inside of the refrigerant circuit is often in a high-pressure difference state.

[0035] First, the compression stroke and the economizer circuit in the case in which, in the high-load operation, the suction-side bypass port 1d present between the low-pressure chamber and the compression chambers 5 does not open and compression is performed in both of the compression chambers 5. To secure a capacity during the high-load operation, the suction-side bypass port 1d is closed not to be opened. The refrigerant is compressed in the two compression chambers 5.

[0036] Fig. 5 is a schematic diagram illustrating a state at the time when the suction-side bypass port 1d is not opened in the screw compressor 102 according to Em-

bodiment 1 of the present invention. Fig. 6 is a development of an inner cylinder surface of the casing 1 and the screw rotor 3 at the time when the suction-side bypass port 1d is not opened in the screw compressor 102 according to Embodiment 1 of the present invention.

[0037] During the high-load operation, the economizer operation is performed to improve a refrigeration effect, a coefficient of performance, and the like. When the economizer operation is performed, the bypass control device 111 of the controller 110 moves the slide valve 8 to the suction side (the right side in Fig. 5 and Fig. 6) as indicated by white arrows in Fig. 5 and Fig. 6. The slide valve 8 is moved to a position (a first position) where the suction-side bypass port 1d is not opened. Since the suction-side bypass port 1d is not opened, the economizer gas channel 1b provided in the casing 1 and the first compression chamber 5b communicate via the economizer port 1c but do not communicate with the low-pressure chamber.

[0038] During the compression stroke, while the economizer port 1c is positioned in the first compression chamber 5b, the economizer gas passing through the economizer gas channel 1b is injected into the first compression chamber 5b from the economizer port 1c. While the economizer port 1c is positioned in the first compression chamber 5b, when a pressure (an intermediate pressure) of the refrigerant in the first compression chamber 5b rises, a capacity expansion effect by the economizer operation decreases. When the economizer gas flows into the first compression chamber 5b in a state in which closing of the first compression chamber 5b is not completed, the economizer gas flows out from the first compression chamber 5b to the low-pressure chamber side and hinders the refrigerant gas from flowing into the screw groove 5a. Therefore, the economizer port 1c is disposed in a position where the economizer gas flows as much as possible into a low-pressure portion of the first compression chamber 5b in a range in which the economizer gas does not hinder the refrigerant gas from flowing into the compression chamber 5.

[0039] In this way, the suction-side bypass port 1d that causes the low-pressure chamber and the first compression chamber 5b to communicate is not opened. Consequently, the two compression chambers 5 are formed in the screw compressor 102. The economizer gas flows into the first compression chamber 5b via the economizer pipe 108 and other pipes. Therefore, it is possible to secure a necessary refrigeration capacity during the high-load operation. Further, it is possible to realize a high coefficient of performance with an economizer effect.

[0040] For example, concerning the low-load operation, the compression stroke and the economizer circuit in the case in which the suction-side bypass port 1d of the first compression chamber 5b is opened will be explained. When the suction-side bypass port 1d is in an opened state, the first compression chamber 5b and the low-pressure chamber communicate. Compression is not performed in the first compression chamber 5b.

Therefore, a suction volume in the screw compressor 102 decreases to approximately a half (1/2). Single chamber operation (one-side operation) in which the first compression chamber 5b is in a no-load state is performed.

[0041] Fig. 7 is a schematic diagram illustrating a state at the time when the suction-side bypass port 1d is opened in the screw compressor 102 according to Embodiment 1 of the present invention. Fig. 8 is a development of the inner cylinder surface of the casing 1 and the screw rotor 3 at the time when the suction-side bypass port 1d is opened in the screw compressor 102 according to Embodiment 1 of the present invention.

[0042] For example, during the low-load operation, the rotation speed is reduced to adjust a capacity. However, when the rotation speed is low, a ratio of a leak to a discharge amount increases and performance is deteriorated. Therefore, in Embodiment 1, the slide valve 8 is moved to the discharge side and moved to a position where the suction-side bypass port 1d of the low-pressure chamber and the first compression chamber 5b is opened. Since the suction-side bypass port 1d is opened, the compression stroke is not performed in the first compression chamber 5b. The first compression chamber 5b comes into a no-load state. Since the compression stroke is performed only in the second compression chamber 5c, a displacement volume is approximately a half (1/2) with respect to a case in which the suction-side bypass port 1d is not opened. Therefore, to attain the displacement volume being the same as that in the case of compression by using the two compression chambers 5 and secure a refrigeration capacity, the screw compressor 102 is driven with an increased rotation speed. Since the rotation speed is increased, it is possible to prevent deterioration in the ratio of a leak to a discharge amount.

[0043] For example, in a water cooled chiller, in general, in the case of the low-load operation, a suction pressure or a pressure in the compression chambers 5 and a discharge pressure are often in a low-pressure difference state. Therefore, the economizer effect is small even if the economizer operation is performed. Further, the economizer gas less easily flows into the compression chambers 5. Therefore, the economizer port 1c is a dead volume and a recompression loss and a leak loss occur. The dead volume refers to a wastefully compressed volume portion.

[0044] In the low-load operation, the economizer gas less easily flows into the compression chambers 5 even if the economizer operation is performed. A refrigeration cycle falls into an unstable state. Therefore, in the controller 110, the valve control device 112 closes the solenoid valve 109 present in the economizer pipe 108 and stops the economizer operation.

[0045] Therefore, in Embodiment 1, the economizer port 1c and the suction-side bypass port 1d are provided on the first compression chamber 5b side. During the low-load operation, the bypass control device 111 moves the slide valve 8, opens the suction-side bypass port 1d,

and performs cylinder partial disuse operation.

[0046] The bypass control device 111 of the controller 110 moves the slide valve 8 to the discharge side (the left side in Fig. 7 and Fig. 8) as indicated by white arrows in Fig. 7 and Fig. 8. The slide valve 8 moves to a position (a second position) where the suction-side bypass port 1d is opened. Since the first compression chamber 5b is disused for compression, the compression stroke is not performed in the first compression chamber 5b. Therefore, the economizer port 1c and the economizer gas channel 1b cannot be the dead volume.

[0047] In this way, in a state in which the slide valve 8 is moved to open the suction-side bypass port 1d, the economizer port 1c and the economizer gas channel 1b are formed in the first compression chamber 5b in which the suction-side bypass port 1d is opened. Therefore, even during the low-load operation, it is possible to secure a leak loss prevention effect by the increased rotation speed at which the rotor rotates when the single one of the two compression chamber is used. Since there is no influence of a space to be a dead volume, it is possible to reduce a recompression loss and a leak loss. Consequently, the screw compressor 102 of Embodiment 1 is a compressor that achieves a high coefficient of performance.

[0048] As explained above, in the screw compressor 102 of Embodiment 1, the economizer port 1c and the economizer gas channel 1b are provided in the first compression chamber 5b, while the suction-side bypass port 1d and the slide valve 8 are provided in the first compression chamber 5b. With this configuration, by opening the suction-side bypass port 1d and performing the single chamber operation that can reduce a suction volume to approximately a half, it is possible to reduce a leak loss and further reduce a loss due to a dead volume, and it is possible to improve a coefficient of performance. Hence, in the refrigeration device of Embodiment 1, it is possible to obtain an economizer effect in the high-load operation and reduce a dead volume loss and a leak loss in the low-load operation in the screw compressor 102 and the refrigeration cycle apparatus 100. Therefore, it is possible to realize a high coefficient of performance in a wide operation range.

Embodiment 2.

[0049] Fig. 9 is a diagram illustrating the configuration of the refrigeration cycle apparatus 100 including the screw compressor 102 according to Embodiment 2 of the present invention. Differences from the refrigeration cycle apparatus 100 of Embodiment 1 will be explained. The refrigeration cycle apparatus 100 of Embodiment 2 is different from the refrigeration cycle apparatus 100 of Embodiment 1 in the configurations of the screw compressor 102 and the controller 110.

(Screw compressor)

[0050] The screw compressor 102 in Embodiment 2 includes a first slide valve 8a and a second slide valve 8b. The first slide valve 8a is set in the first compression chamber 5b. Like the slide valve 8 explained in Embodiment 1, the first slide valve 8a performs the operation of a bypass device.

[0051] In the screw compressor 102 in Embodiment 2, compared with the screw compressor 102 of Embodiment 1, the second slide valve 8b is set not only on the first compression chamber 5b side but also on the second compression chamber 5c side. The second slide valve 8b is set to be movable in an axial direction of the screw rotor 3. An internal-volume-ratio changing mechanism 11 to change a position of the second slide valve 8b is set. The internal volume ratio means a ratio of a volume of the compression chamber 5 at suction completion (compression start) time and a volume of the compression chamber 5 immediately before discharge. A change of the internal volume ratio is performed by adjusting timing when the refrigerant is discharged from the discharge port 7. Specifically, during the low-load operation, the second slide valve 8b is positioned on the suction side. The position of the second slide valve 8b is changed to set opening timing of the discharge port 7 to early timing and reduce a volume ratio. During the high-load operation, the second slide valve 8b is positioned on the discharge side. The position of the second slide valve 8b is changed to set the opening timing of the discharge port 7 to later timing and increase the volume ratio.

[0052] In this way, the second slide valve 8b configures a part of the discharge port 7. Therefore, the internal-volume-ratio changing mechanism 11 can adjust timing of discharge and change the internal volume ratio by moving the second slide valve 8b. Therefore, insufficient compression during the high-load operation and excessive compression during the low-load operation are prevented to improve performance.

[0053] The controller 110 of Embodiment 2 further includes an internal-volume-ratio control device 113. The internal-volume-ratio control device 113 sends an instruction to the internal-volume-ratio changing mechanism 11 and performs control for locating the second slide valve 8b based on the internal volume ratio.

[0054] To clarify characteristics of Embodiment 2, as in Embodiment 1, position control of the first slide valve 8a and the second slide valve 8b and a relation of the economizer port 1c during the high-load operation and during the low-load operation are compared and operation during the compression stroke will be explained.

[0055] Fig. 10 is a schematic diagram illustrating a state at the time when the suction-side bypass port 1d is not opened in the screw compressor 102 according to Embodiment 2 of the present invention. Fig. 11 is a development of the inner cylinder surface of the casing 1 and the screw rotor 3 at the time when the suction-side bypass port 1d is not opened in the screw compressor

102 according to Embodiment 2 of the present invention. The operation and the like of the screw compressor 102 during the high-load operation will be explained with reference to Fig. 10 and Fig. 11.

[0056] During the high-load operation, economizer operation is performed to improve a refrigeration effect, a coefficient of performance, and the like. When the economizer operation is performed, as in Embodiment 1, the bypass control device 111 of the controller 110 moves the first slide valve 8a to the suction side (the right side in Fig. 10 and Fig. 11) as indicated by white arrows in Fig. 10 and Fig. 11. The first slide valve 8a moves to a position (a first position) for not opening the suction-side bypass port 1d.

[0057] On the other hand, the internal-volume-ratio control device 113 of the controller 110 sends an instruction to the internal-volume-ratio changing mechanism 11 and locates the second slide valve 8b such that an internal volume ratio is the same and timing when the refrigerant is discharged from the discharge port 7 is the same in the first compression chamber 5b and the second compression chamber 5c. Specifically, as indicated by the white arrows in Fig. 10 and Fig. 11, the internal-volume-ratio control device 113 moves, for example, the second slide valve 8b to the discharge side (the left side in Fig. 10 and Fig. 11).

[0058] In this way, the suction-side bypass port 1d to cause the low-pressure chamber and the first compression chamber 5b to communicate is not opened, whereby the two compression chambers 5 are formed in the screw compressor 102. Since the economizer gas flows into the first compression chamber 5b via the economizer pipe 108 and other pipes, it is possible to secure a necessary refrigeration capacity during the high-load operation. Further, it is possible to realize a high coefficient of performance to properly adjust the economizer effect and the internal volume ratio.

[0059] Then, the compression stroke and the operations of the first slide valve 8a and the second slide valve 8b in opening the suction-side bypass port 1d of the first compression chamber 5b will be explained. In the low-load operation of Embodiment 2, as in Embodiment 1, the first compression chamber 5b is brought into the cylinder halt state to perform the single chamber operation.

[0060] Fig. 12 is a schematic diagram illustrating a state at the time when the suction-side bypass port 1d is opened in the screw compressor 102 according to Embodiment 2 of the present invention. Fig. 13 is a development of the inner cylinder surface of the casing 1 and the screw rotor 3 at the time when the suction-side bypass port 1d is opened in the screw compressor 102 according to Embodiment 2 of the present invention.

[0061] In Embodiment 2, the economizer operation is not performed under a low-load operation condition. Therefore, the valve control device 112 of the controller 110 closes the solenoid valve 109 to prevent an economizer gas from flowing into the first compression chamber 5b. The bypass control device 111 of the controller

110 moves the slide valve 8 to the discharge side (the left side in Fig. 12 and Fig. 13) as indicated by white arrows in Fig. 12 and Fig. 13. The slide valve 8 moves to a position (a second position) where the suction-side bypass port 1d is opened. Since the first compression chamber 5b is halted, the compression stroke is not performed in the first compression chamber 5b.

[0062] On the other hand, the internal-volume-ratio control device 113 of the controller 110 sends an instruction to the internal-volume-ratio changing mechanism 11 to move the second slide valve 8b to a position suitable for operation. Specifically, as indicated by the white arrows in Fig. 12 and Fig. 13, for example, the internal-volume-ratio control device 113 moves the second slide valve 8b to the suction side (the right side in Fig. 12 and Fig. 13), which is a direction in which the internal volume ratio is reduced.

[0063] As explained above, with the screw compressor 102 of Embodiment 2, in a state in which the first slide valve 8a is moved to open the suction-side bypass port 1d, the economizer port 1c and the economizer gas channel 1b are formed in the first compression chamber 5b in which the suction-side bypass port 1d is opened. Therefore, even during the low-load operation, by performing the single chamber operation, it is possible to secure a leak loss prevention effect according to an increase in the rotation speed. Since there is no influence of a space to be a dead volume, it is possible to reduce a recompression loss and a leak loss. Therefore, as the screw compressor 102 of Embodiment 2, it is possible to obtain the screw compressor 102 that realizes a high coefficient of performance. Since timing for discharging the refrigerant from the discharge port 7 is adjusted by causing the internal-volume-ratio changing mechanism 11 to move the second slide valve 8b, it is possible to properly set the internal volume ratio in the second compression chamber 5c. Therefore, it is possible to prevent a power loss due to insufficient compression and excessive compression. It is possible to realize a higher coefficient of performance in a wide operation range.

Third Embodiment.

[0064] Although not particularly limited in Embodiment 2 explained above, for example, the control concerning the movement of the second slide valve 8b in the screw compressor 102 performed by the controller 110 may be continuous or may be stepwise.

Reference Signs List

[0065] 1 casing 1a slide groove 1b economizer gas channel 1c economizer port 1d suction-side bypass port 2 electric motor 2a stator 2b motor rotor 3 screw rotor 4 screw shaft 5 compression chamber 5a screw groove 5b first compression chamber 5c second compression chamber 6 gate rotor 6a teeth 6b first gate rotor 6c second gate rotor 7 discharge port 8 slide valve 8a first slide valve

8b second slide valve 9 coupling bar 10 bypass driving device 11 internal-volume-ratio changing mechanism 100 refrigeration cycle apparatus 101 inverter device 102 screw compressor 103 condenser 104 intermediate cooler 105 expansion valve 106 evaporator 107 expansion valve for intermediate cooler 108 economizer pipe 109 solenoid valve 110 controller 111 bypass control device 112 valve control device 113 internal-volume-ratio control device.

Claims

1. A screw compressor comprising:

an electric motor configured to operate at a variable rotation speed;
 a screw rotor including a plurality of screw grooves on an outer circumferential surface;
 a screw shaft configured to transmit a driving force of the electric motor to the screw rotor and rotate the screw rotor;
 a first gate rotor and a second gate rotor, the first gate rotor being disposed on one side of the screw rotor, the second gate rotor being disposed on an other side of the screw rotor, the first gate rotor and the second gate rotor being disposed point-symmetrically with respect to the screw shaft and including, in outer circumferential portions, a plurality of teeth meshed with the screw grooves;
 a casing having a cylindrical shape to house the screw rotor inside a cylinder;
 a bypass device configured to allow a first compression chamber and a low-pressure chamber to communicate with each other, the low-pressure chamber being configured to have atmosphere of a suction pressure, the first compression chamber being a space surrounded by the first gate rotor, the screw groove, and the casing; and
 an economizer port provided in the casing and configured to allow fluid flowing from an outside to flow into the first compression chamber.

2. The screw compressor of claim 1, wherein the screw compressor

includes a first slide valve configured to slide in a direction of the screw shaft, and is configured to position the first slide valve in a position where a discharge amount of fluid discharged from a discharge port included in the first compression chamber is smaller than a discharge amount of fluid discharged from a discharge port included in the second compression chamber, which is a space surrounded by the

second gate rotor, the screw groove, and the casing.

3. The screw compressor of claim 1 or 2, wherein the bypass device includes a first slide valve configured to slide in a longitudinal direction of the screw shaft, and the screw compressor is configured to move the first slide valve to a position where the first compression chamber comes into a no-load state in which a pressure of the fluid in the first compression chamber does not rise.

4. The screw compressor of any one of claims 1 to 3, further comprising:

a second slide valve provided to outer circumferential surface of a second compression chamber, which is a space surrounded by the second gate rotor, the screw groove, and the casing, and configured to slide in a direction of the screw shaft; and
 an internal-volume-ratio changing mechanism configured to slide the second slide valve.

5. The screw compressor of claim 4, wherein, when a load of the refrigeration cycle apparatus is smaller than a predetermined load, the internal-volume-ratio changing mechanism is configured to move the second slide valve in a direction in which an internal volume ratio is reduced.

6. A refrigeration cycle apparatus in which the screw compressor of any one of claims 1 to 5, a condenser, a high-pressure side channel of an intermediate cooler, a decompression device, and an evaporator are connected in order by refrigerant pipes to configure a refrigerant circuit that circulates refrigerant, which is fluid,
 the refrigeration cycle apparatus comprising an economizer pipe branching from a pipe between the intermediate cooler and the decompression device and connected to an economizer port included in the screw compressor via an expansion device for the intermediate cooler and an intermediate-pressure side channel of the intermediate cooler.

7. The refrigeration cycle apparatus of claim 6, further comprising a valve that prevents the refrigerant from passing the economizer pipe when the refrigeration cycle apparatus determines that a load of the refrigeration cycle apparatus is smaller than a predetermined load.

FIG. 1

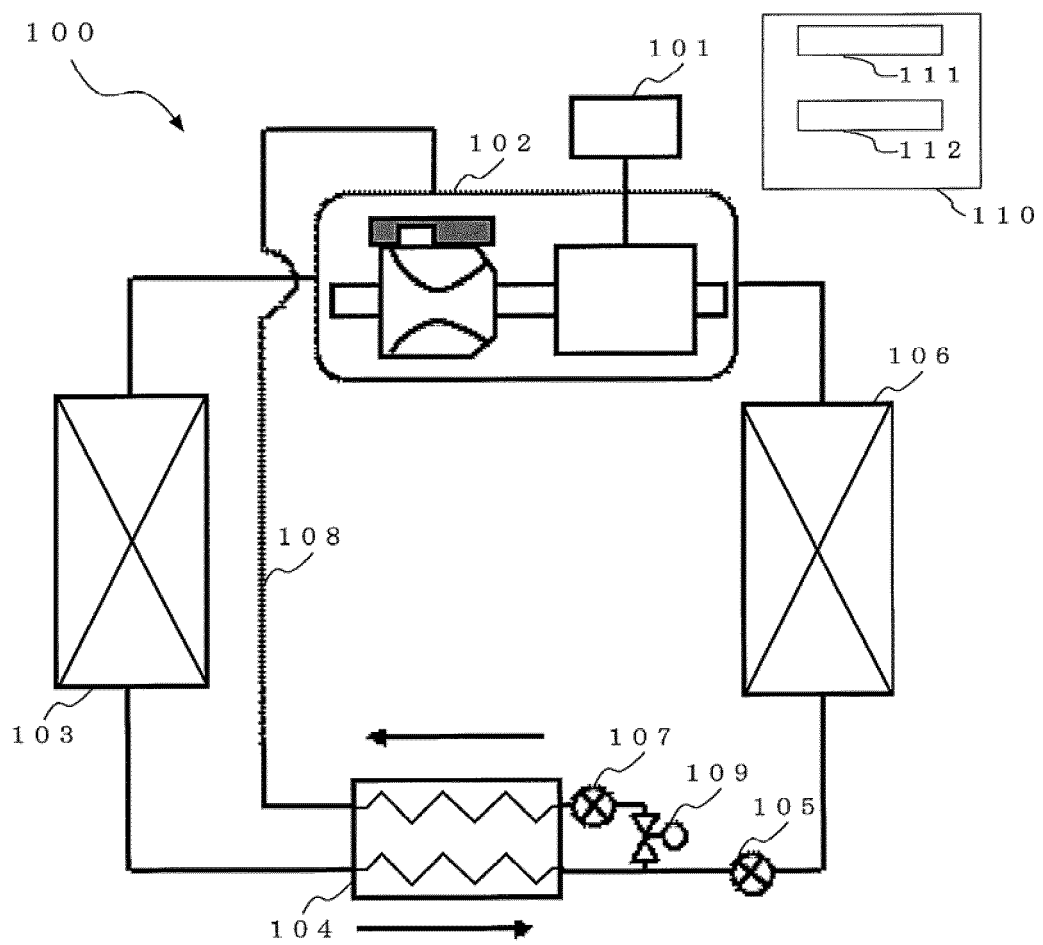


FIG. 2

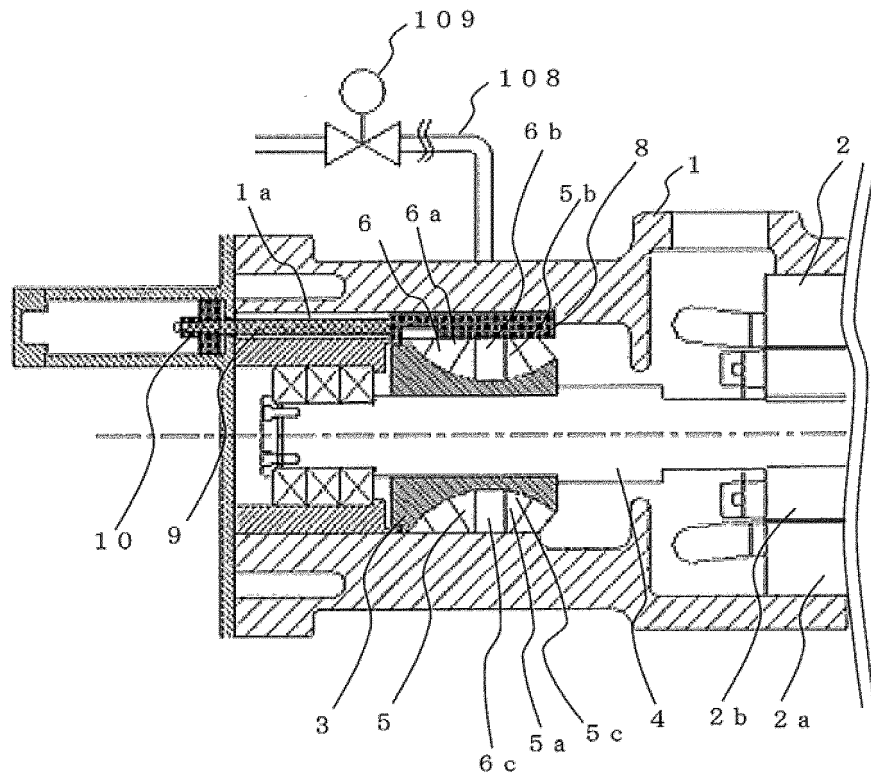


FIG. 3

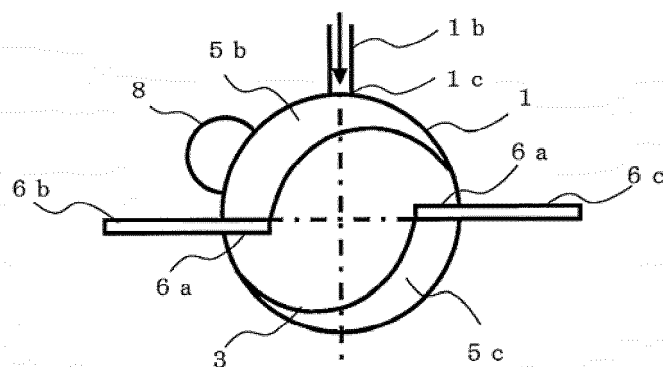


FIG. 4

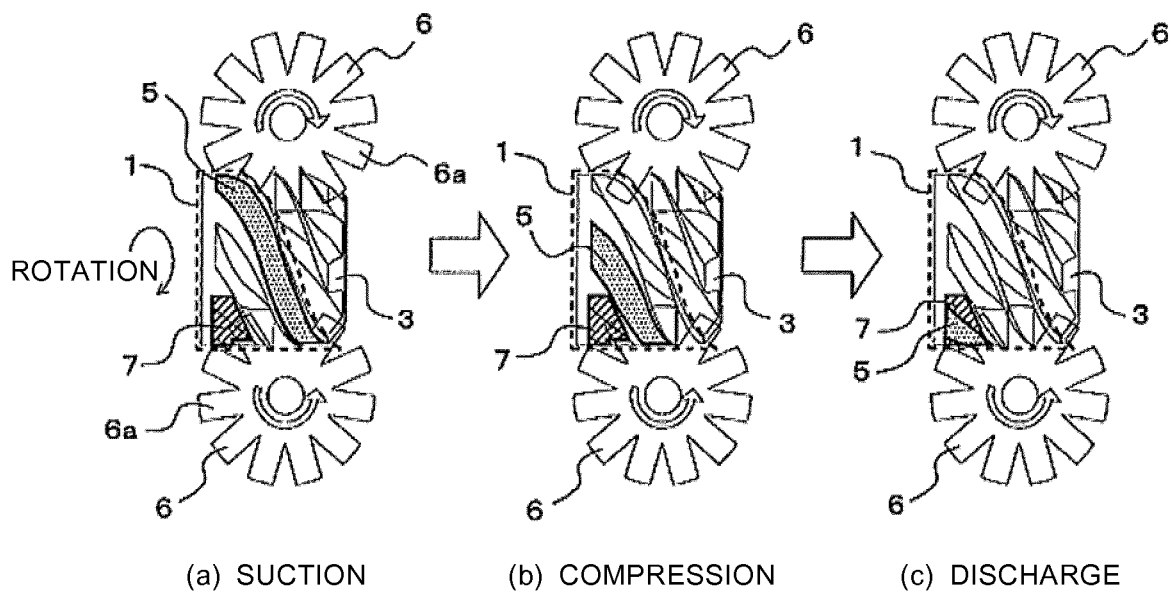


FIG. 5

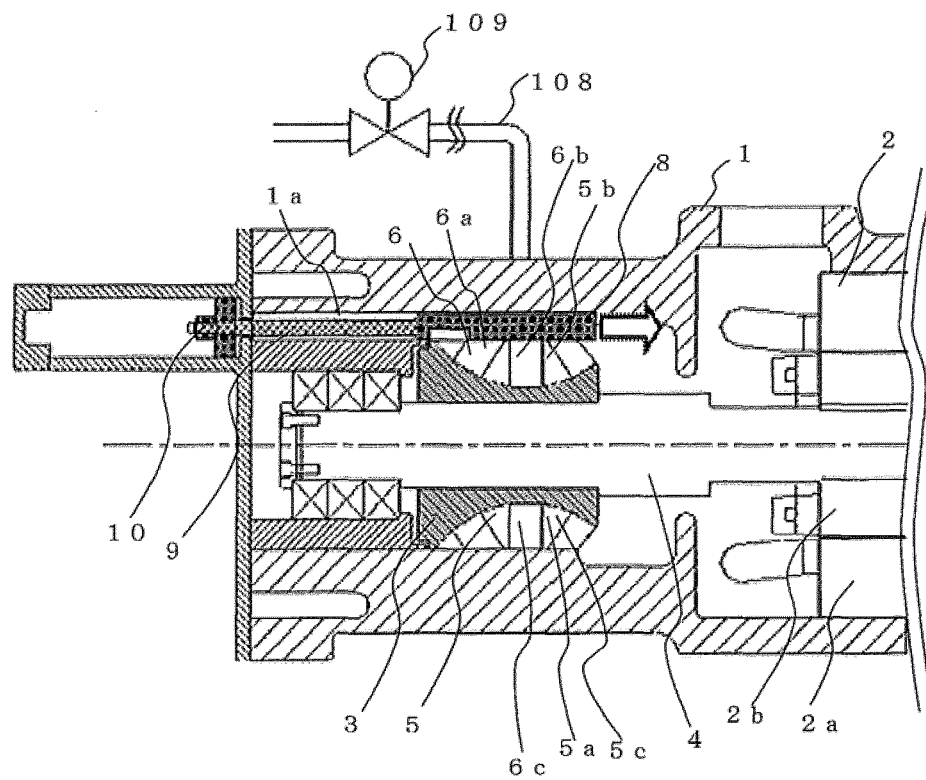


FIG. 6

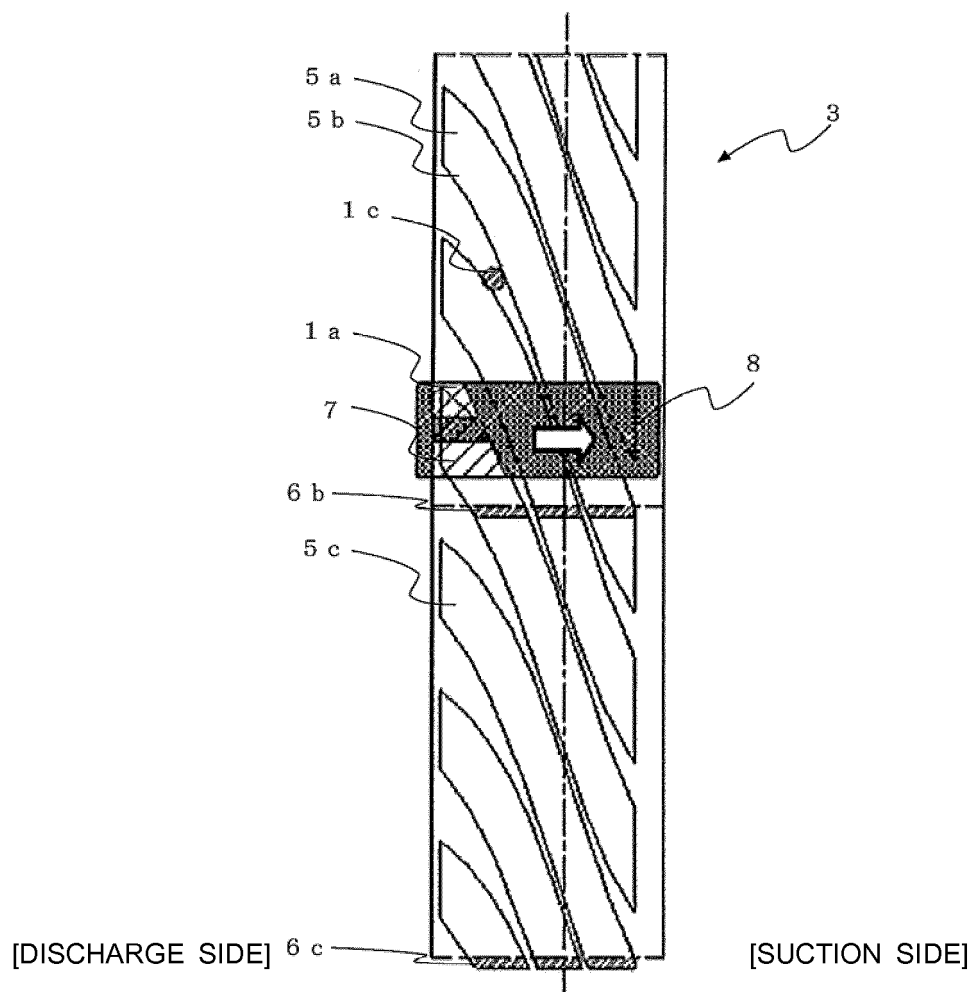


FIG. 7

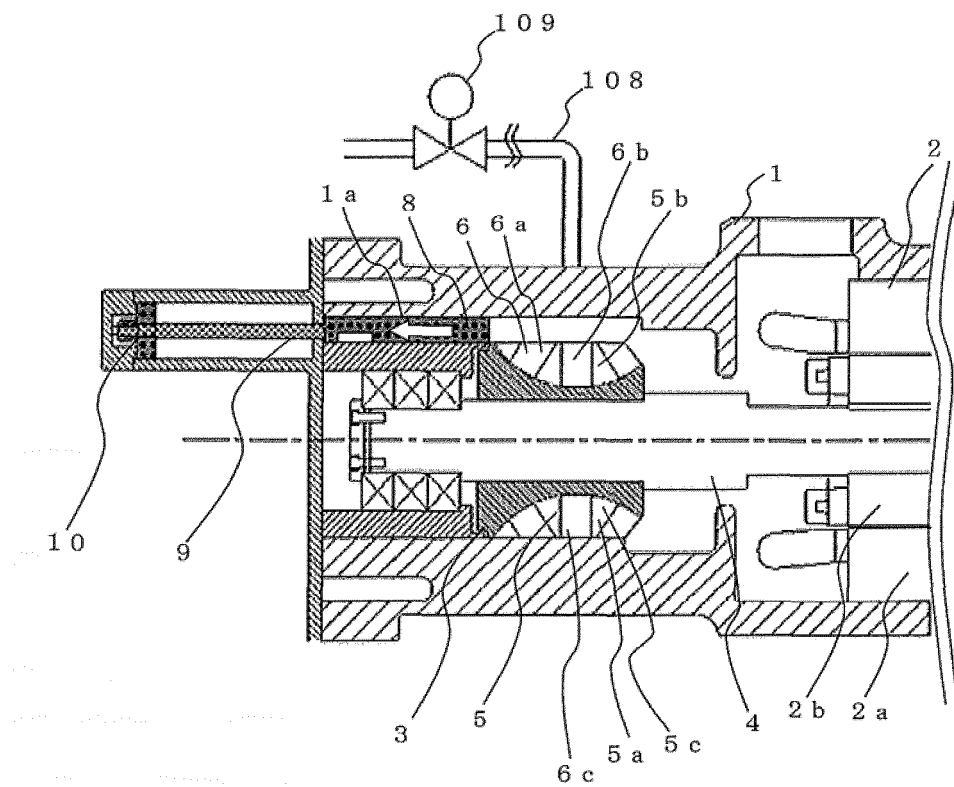


FIG. 8

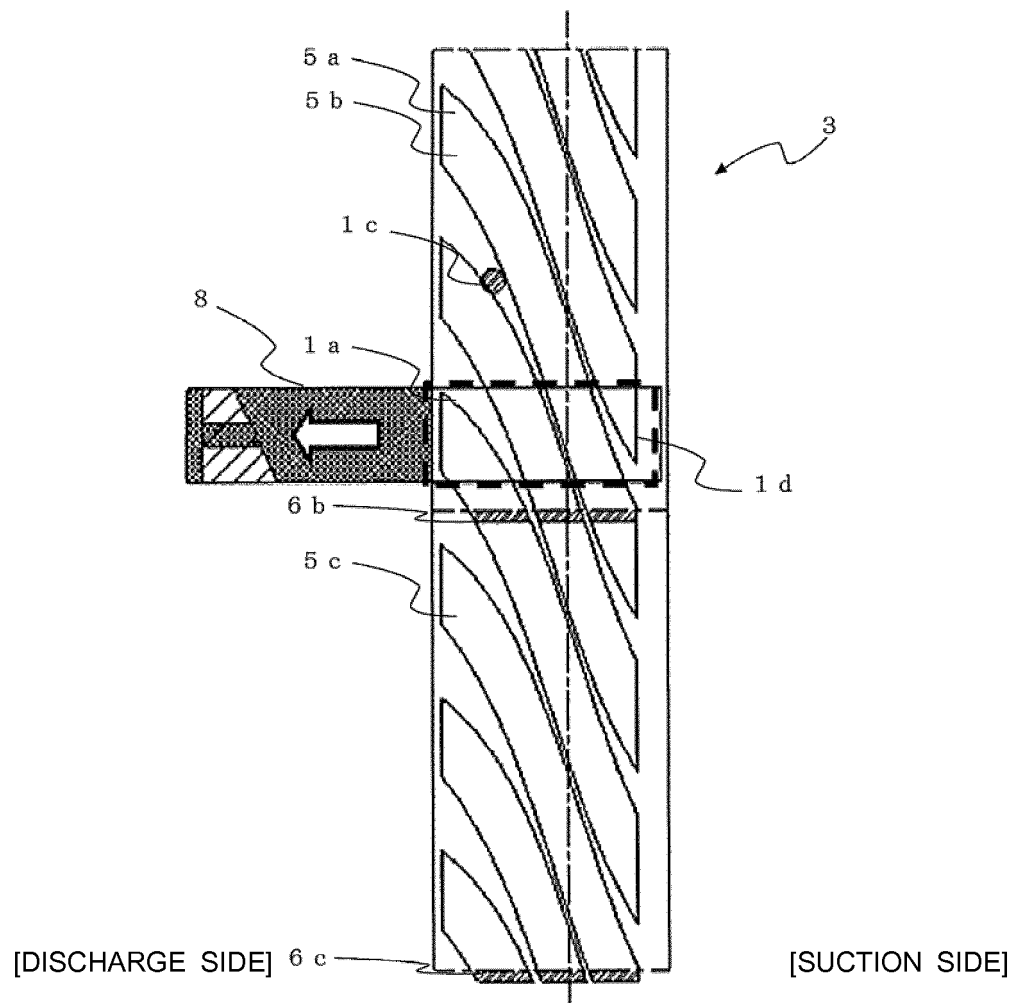


FIG. 9

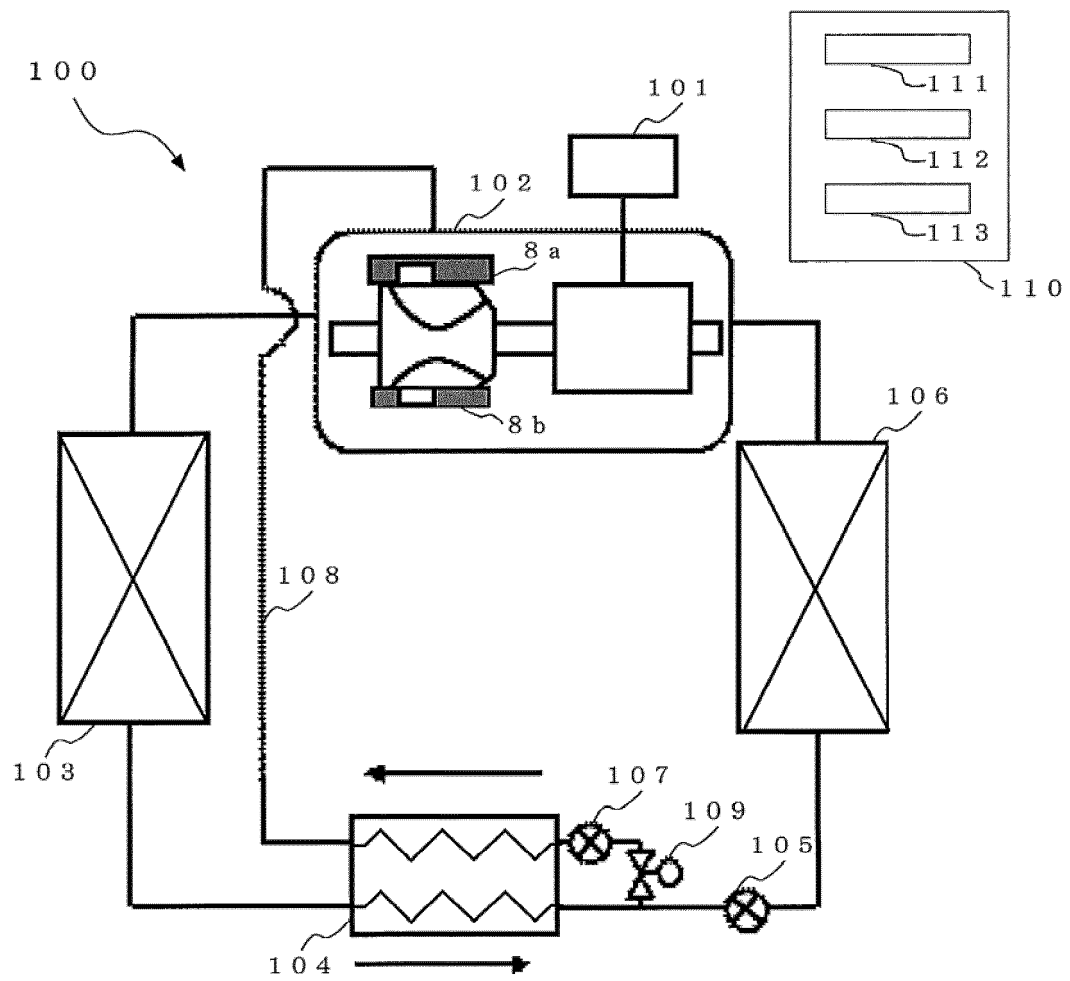


FIG. 10

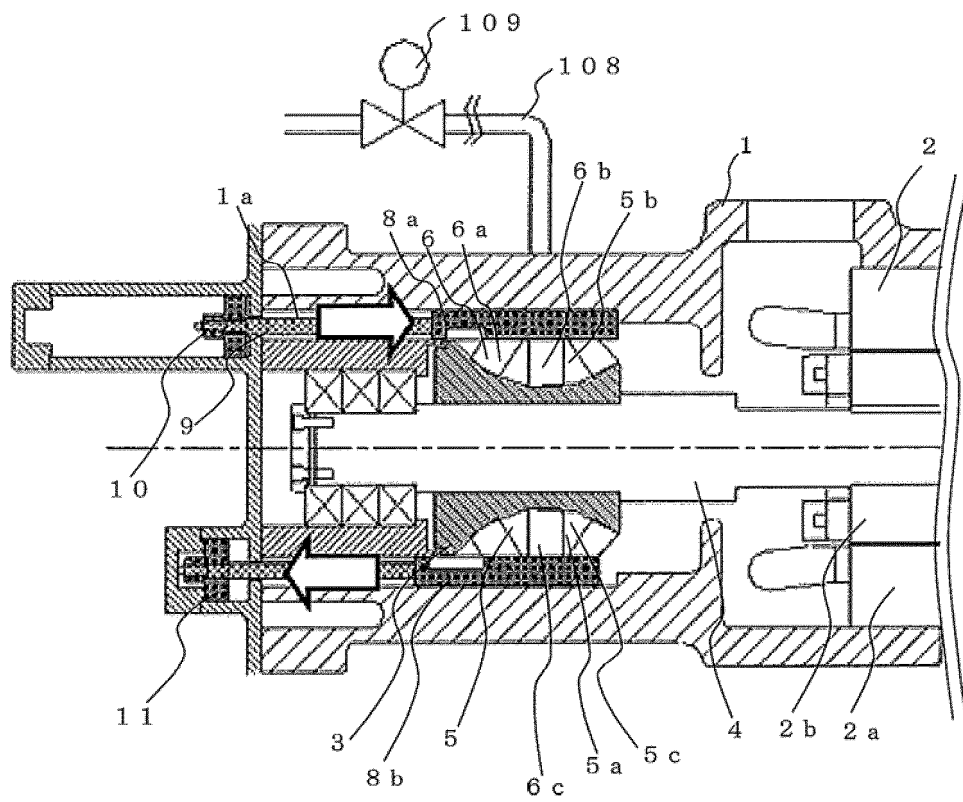


FIG. 11

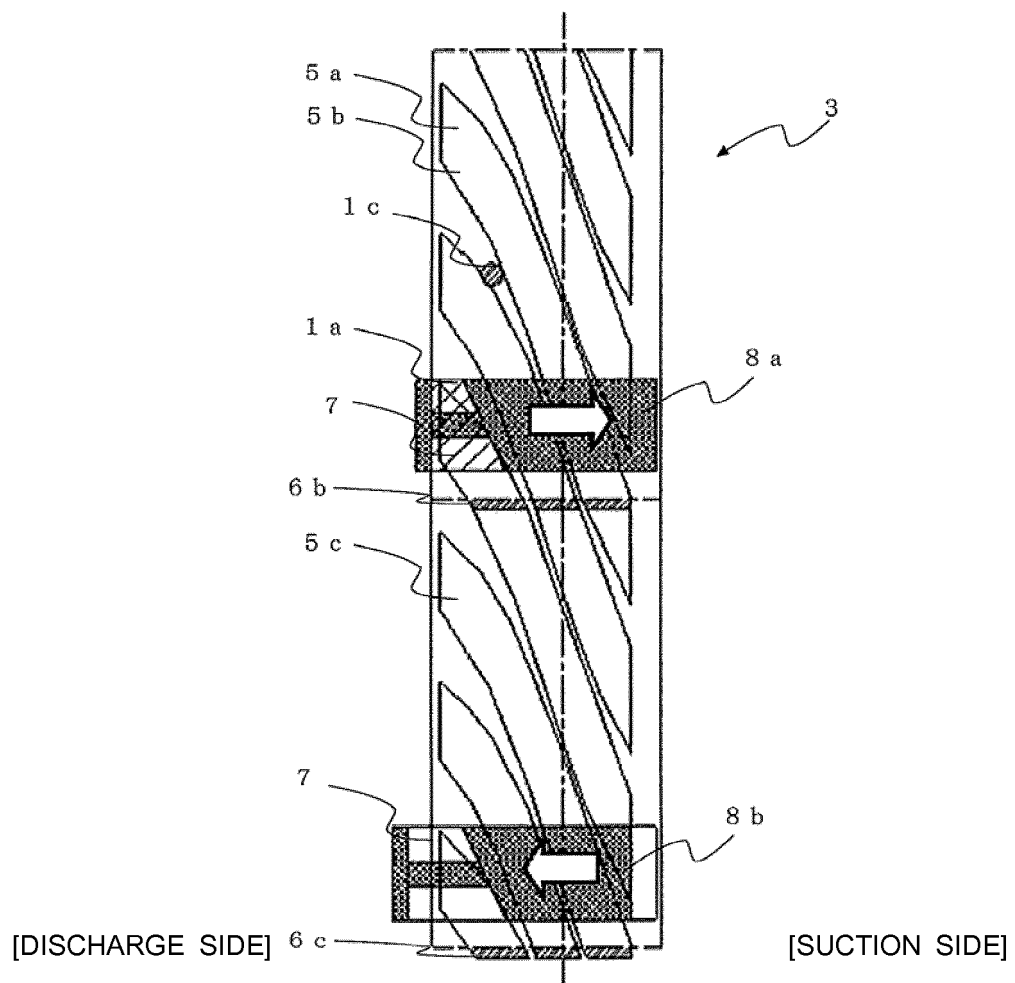


FIG. 12

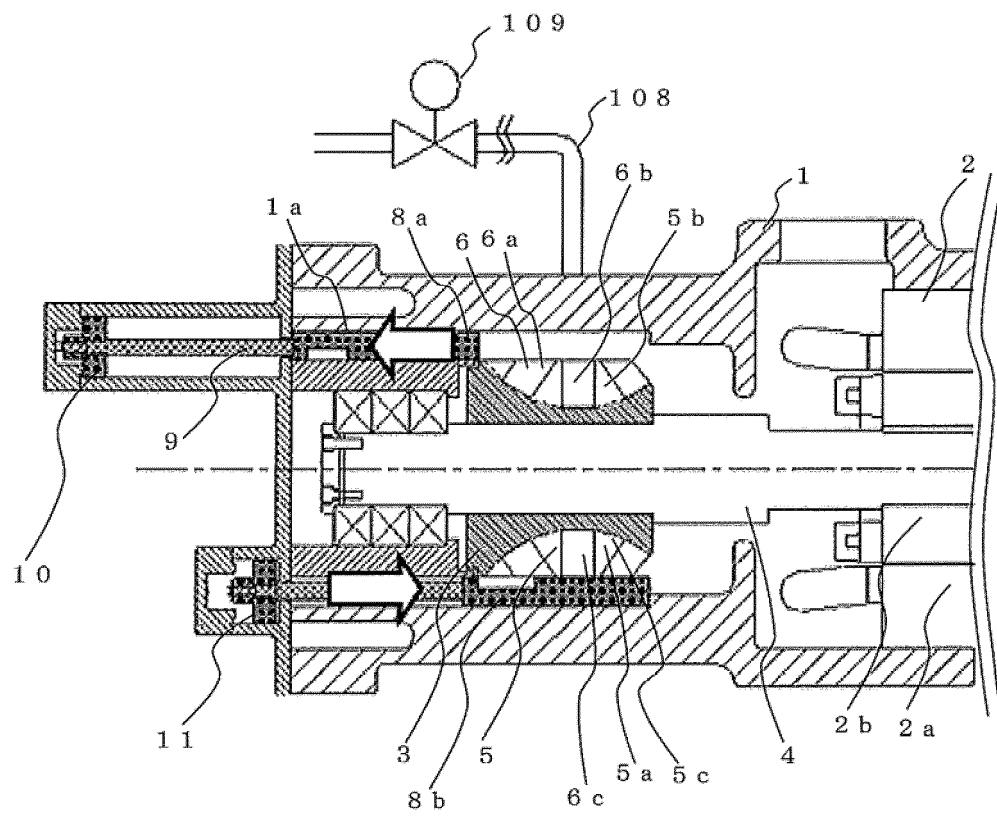
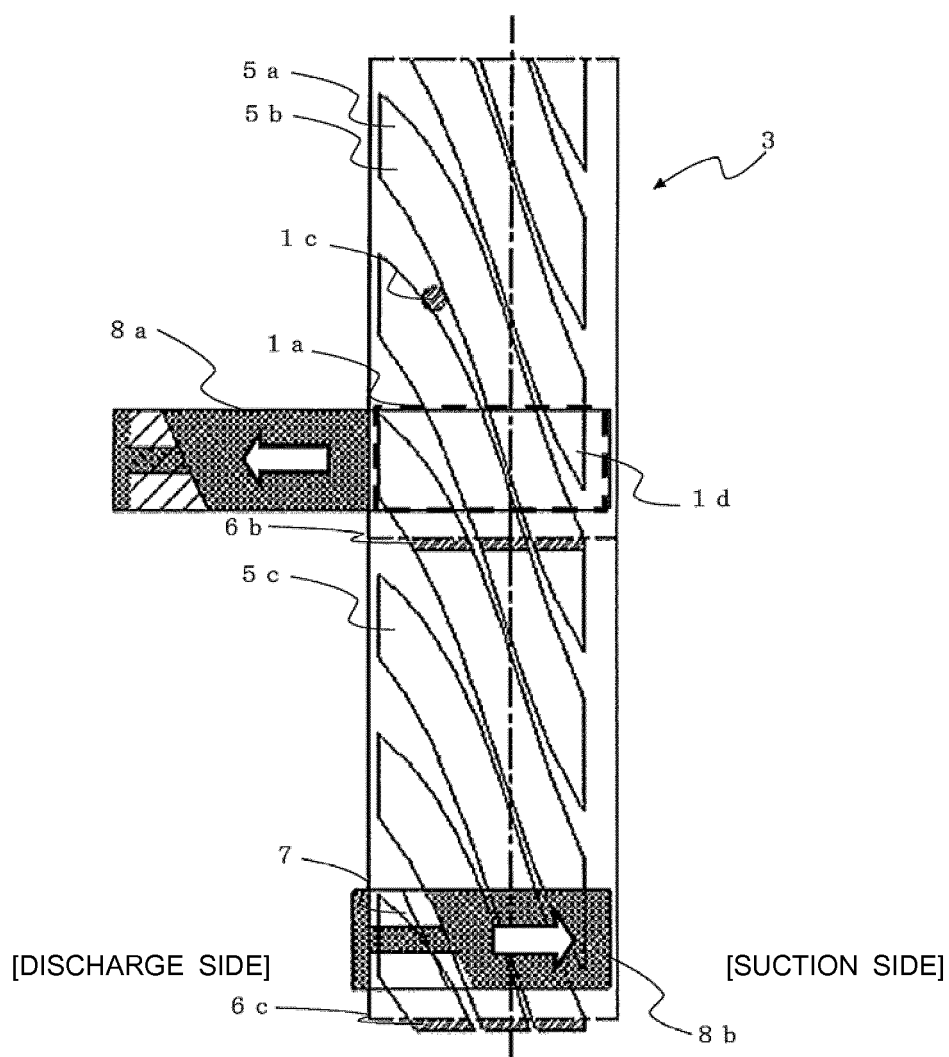


FIG. 13



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2016/056265

A. CLASSIFICATION OF SUBJECT MATTER

F04C18/52(2006.01)i, F25B1/047(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

F04C18/52, F25B1/047

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 1996-2016

Kokai Jitsuyo Shinan Koho 1971-2016 Toroku Jitsuyo Shinan Koho 1994-2016

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 2012-107613 A (Daikin Industries, Ltd.), 07 June 2012 (07.06.2012), paragraphs [0037] to [0079]; fig. 1 to 7 & US 2013/0216418 A1 paragraphs [0049] to [0094] & WO 2012/056728 A1 & EP 2634432 A1 & CN 103189652 A	1-7
Y	WO 2014/192898 A1 (Mitsubishi Electric Corp.), 04 December 2014 (04.12.2014), paragraphs [0016] to [0042]; fig. 1 to 6 & CN 105247217 A	1-7

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

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search
20 May 2016 (20.05.16)Date of mailing of the international search report
31 May 2016 (31.05.16)Name and mailing address of the ISA/
Japan Patent Office
3-4-3, Kasumigaseki, Chiyoda-ku,
Tokyo 100-8915, Japan

Authorized officer

Telephone No.

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

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2016/056265

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 7-6509 B2 (Vilter Manufacturing Corp.), 30 January 1995 (30.01.1995), claim 1; page 5, left column, line 23 to right column, line 20; fig. 5 to 7 & US 4610613 A column 6, line 60 to column 7, line 54; column 9, line 57 to column 11, line 2 & GB 2176244 A & DE 3617133 A1 & FR 2582742 A1	3-7
Y	JP 5-10614 A (Daikin Industries, Ltd.), 19 January 1993 (19.01.1993), paragraphs [0015], [0026] to [0027]; fig. 1 (Family: none)	7
A	US 2014/0083130 A1 (PICOUE, Jean-Louis), 27 March 2014 (27.03.2014), entire text; all drawings & WO 2014/052192 A2 & CA 2885727 A1 & CN 104838144 A	1-9

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

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- JP 1551204 A [0005]