



(11) **EP 2 587 188 A1**

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

(43) Date of publication:
01.05.2013 Bulletin 2013/18

(21) Application number: **11797842.9**

(22) Date of filing: **21.06.2011**

(51) Int Cl.:
F25B 1/00 (2006.01) **F01C 1/356** (2006.01)
F01C 13/04 (2006.01) **F25B 5/04** (2006.01)
F25B 11/02 (2006.01)

(86) International application number:
PCT/JP2011/003536

(87) International publication number:
WO 2011/161953 (29.12.2011 Gazette 2011/52)

(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**

(30) Priority: **23.06.2010 JP 2010143046**

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(54) **REFRIGERATION CYCLE APPARATUS**

(57) A refrigeration cycle apparatus 100 includes a compressor 2, a radiator 3, a positive displacement fluid machine 4, an evaporator 7 and an injection flow passage 10f. The positive displacement fluid machine 4 performs (i) a step of drawing, at a first pressure, a refrigerant into a working chamber, (ii) a step of expanding the drawn refrigerant to a second pressure lower than the first pressure and overexpanding further the refrigerant to a third pressure lower than the second pressure, (iii) a step of supplying, through an injection port 30, the refrigerant having the third pressure to the working chamber so as to mix the supplied refrigerant with the overexpanded refrigerant, (iv) a step of recompressing, in the working chamber, the mixed refrigerant to the second pressure by using power recovered from the refrigerant in the step (ii), and (v) a step of discharging the recompressed refrigerant from the working chamber.

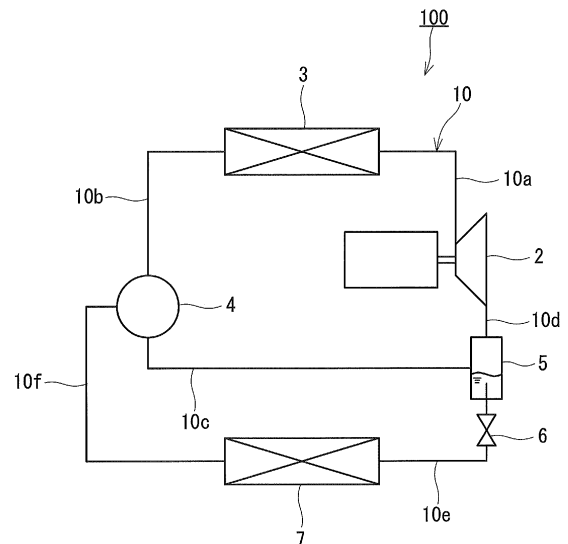


FIG.1

Description

TECHNICAL FIELD

[0001] The present invention relates to a refrigeration cycle apparatus.

BACKGROUND ART

[0002] As described in Patent Literature 1, there has been known a refrigeration cycle apparatus including an expander for recovering power from a refrigerant and a sub compressor integrated with the expander. With reference to FIG. 12, the outline of the refrigeration cycle apparatus described in Patent Literature 1 is explained.

[0003] As shown in Fig. 12, the refrigeration cycle apparatus 500 described in Patent Literature 1 includes a main compressor 501, a radiator 502, an expander 503, an evaporator 504 and a sub compressor 505. The sub compressor 505 is coupled to the expander 503 by a shaft 506.

[0004] A refrigerant is compressed in the main compressor 501 so as to be in a high temperature and high pressure state. The compressed refrigerant is cooled in the radiator 502 and then expanded in the expander 503. The expanded refrigerant changes from a liquid phase to a gaseous phase in the evaporator 504. The gaseous phase refrigerant is compressed from a low pressure to an intermediate pressure in the sub compressor 505 and drawn into the main compressor 501 again.

[0005] The sub compressor 505 is driven by the power that the expander 503 has recovered from the refrigerant. Since the sub compressor 505 compresses preliminarily the refrigerant on an upstream of the main compressor 501, the load on a motor 501a of the main compressor 501 is reduced. As a result, the COP (coefficient of performance) of the refrigeration cycle apparatus 500 is enhanced.

CITATION LIST

Patent Literature

[0006]

PTL 1: JP 2004-325019 A

PTL 2: JP 2006-046257 A

SUMMARY OF INVENTION

Technical Problem

[0007] The refrigeration cycle apparatus 500 shown in FIG. 12 needs two positive displacement fluid machines, which are the expander 503 and the sub compressor 505. This tends to increase the cost of the refrigeration cycle apparatus 500 to be higher than that of a common refrigeration cycle apparatus in which an expansion valve

is used. As described in Patent Literature 2, an expander configured to transfer the recovered power directly to an compressor also is known, but the expander has a complicated structure and a considerable cost increase is inevitable.

[0008] The present invention is intended to provide a power recovery type refrigeration cycle apparatus having a simple structure.

10 Solution to Problem

[0009] That is, the present invention provides a refrigeration cycle apparatus including:

- 15 a compressor for compressing a refrigerant;
- a radiator for cooling the refrigerant compressed in the compressor;
- a positive displacement fluid machine having a working chamber and an injection port, and configured to perform (i) a step of drawing, at a first pressure, the refrigerant cooled in the radiator into the working chamber, (ii) a step of, in the working chamber, expanding the drawn refrigerant to a second pressure lower than the first pressure and overexpanding further the refrigerant to a third pressure lower than the second pressure, (iii) a step of supplying, through the injection port, the refrigerant having the third pressure to the working chamber so as to mix the supplied refrigerant with the overexpanded refrigerant, (iv) a step of recompressing, in the working chamber, the mixed refrigerant to the second pressure by using power recovered from the refrigerant in the step (ii), and (v) a step of discharging the recompressed refrigerant from the working chamber;
- 20 an evaporator for heating the refrigerant discharged from the positive displacement fluid machine; and
- an injection flow passage through which the refrigerant having the third pressure is supplied to the injection port of the positive displacement fluid machine.
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Advantageous Effects of Invention

- 45 **[0010]** According to the refrigeration cycle apparatus of the present invention, the following steps are performed in the positive displacement fluid machine. First, the refrigerant drawn into the working chamber is expanded and overexpanded. Subsequently, the refrigerant having the same pressure as that of the overexpanded refrigerant is injected into the working chamber through the injection flow passage so that the injected refrigerant is mixed with the overexpanded refrigerant in the working chamber. Furthermore, the mixed refrigerant is recompressed by using the power recovered during the expansion and overexpansion of the refrigerant.
- 50 Since the pressure of the refrigerant can be increased by the recovered power, the load on the compressor is reduced. This improves the COP of the refrigeration cycle
- 55

apparatus.

[0011] Particularly, in the present invention, the steps (ii), (iii) and (iv) are performed as a sequence of steps between a suction process and a discharge process. Thus, in the present invention, unlike in the refrigeration cycle apparatus described in Patent Literature 1, the expander and the sub compressor do not need to be provided independently. Therefore, in the present invention, it is possible to perform each step mentioned above by using the positive displacement fluid machine having a simpler structure. Thereby, the production cost of the refrigeration cycle apparatus can be suppressed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012]

FIG. 1 is a configuration diagram of a refrigeration cycle apparatus according to Embodiment 1 of the present invention.

FIG. 2 is a vertical cross-sectional view of a positive displacement fluid machine used in the refrigeration cycle apparatus shown in FIG. 1.

FIG. 3A is a transverse cross-sectional view of the positive displacement fluid machine shown in FIG. 2, taken along the line X-X.

FIG. 3B is a transverse cross-sectional view of the positive displacement fluid machine shown in FIG. 2, taken along the line Y-Y.

FIG. 4 is a diagram illustrating the operation principle of the positive displacement fluid machine shown in FIG. 2.

FIG. 5 is a graph showing a relationship between the rotation angle of a shaft and the volumetric capacity of a working chamber.

FIG. 6 is a graph showing a relationship between the rotation angle of the shaft and the pressure in the working chamber.

FIG. 7 is a P-V diagram showing a relationship between the pressure in the working chamber and the volumetric capacity of the working chamber.

FIG. 8 is a configuration diagram of a refrigeration cycle apparatus according to Embodiment 2 of the present invention.

FIG. 9 is a vertical cross-sectional view of a positive displacement fluid machine used in the refrigeration cycle apparatus shown in FIG. 8.

FIG. 10 is a transverse cross-sectional view of the positive displacement fluid machine shown in FIG. 9, taken along the line Z-Z.

FIG. 11 is a diagram illustrating the operation principle of the positive displacement fluid machine shown in FIG. 10.

FIG. 12 is a configuration diagram of a conventional refrigeration cycle apparatus.

DESCRIPTION OF EMBODIMENTS

[0013] Hereinafter, embodiments of the present invention are described with reference to the attached drawings. However, the present invention is not limited by the following embodiments. These embodiments can be combined with each other as long as they do not depart from the scope of the present invention.

10 (Embodiment 1)

[0014] FIG. 1 is a configuration diagram of a refrigeration cycle apparatus according to Embodiment 1. The refrigeration cycle apparatus 100 includes a compressor 2, a radiator 3, a positive displacement fluid machine 4, a gas-liquid separator 5, an expansion valve 6 and an evaporator 7. These components are connected to each other by flow passages 10a to 10f so as to form a refrigerant circuit 10. Typically, the flow passages 10a to 10f each are composed of a refrigerant pipe. The refrigerant circuit 10 is filled with a refrigerant, such as hydrofluorocarbon and carbon dioxide, as a working fluid. The flow passages 10a to 10f may be provided with another component such as an accumulator.

[0015] The compressor 2 is, for example, a positive displacement compressor such as a rotary compressor and a scroll compressor. The radiator 3 is a device for removing heat from the refrigerant compressed in the compressor 2, and typically is composed of a water-refrigerant heat exchanger or an air-refrigerant heat exchanger. The positive displacement fluid machine 4 has a function of expanding the refrigerant and a function of compressing the refrigerant. The gas-liquid separator 5 is a device for separating the refrigerant discharged from the positive displacement fluid machine 4 into a gas refrigerant and a liquid refrigerant. The gas-liquid separator 5 is provided with a liquid refrigerant outlet, a refrigerant inlet and a gas refrigerant outlet. The expansion valve 6 is a valve with a variable opening, such as an electric expansion valve. The evaporator 7 is a device for providing heat to the liquid refrigerant separated out in the gas-liquid separator 5, and typically is composed of an air-refrigerant heat exchanger.

[0016] The flow passage 10a connects the compressor 2 to the radiator 3 so that the refrigerant compressed in the compressor 2 is supplied to the radiator 3. The flow passage 10b connects the radiator 3 to the positive displacement fluid machine 4 so that the refrigerant that has flowed out of the radiator 3 is supplied to the positive displacement fluid machine 4. The flow passage 10c connects the positive displacement fluid machine 4 to the gas-liquid separator 5 so that the refrigerant discharged from the positive displacement fluid machine 4 is supplied to the gas-liquid separator 5. The flow passage 10d connects the gas-liquid separator 5 to the compressor 2 so that the gas refrigerant separated out in the gas-liquid separator 5 is supplied to the compressor 2. The flow passage 10e connects the gas-liquid separator 5 to the

evaporator 7 so that the liquid refrigerant separated out in the gas-liquid separator 5 is supplied to the evaporator 7. The flow passage 10f connects the evaporator 7 to the positive displacement fluid machine 4 so that the gas refrigerant that has flowed out of the evaporator 7 is supplied (injected) to the positive displacement fluid machine 4. The cycle explained in this description can be formed of the flow passages 10a to 10f and the components such as the compressor 2. Hereinafter, the flow passage 10f is referred to as "the injection flow passage 10f".

[0017] In the present embodiment, the expansion valve 6 is provided on the flow passage 10e connecting the gas-liquid separator 5 to the evaporator 7. The expansion valve 6 can lower the pressure of the refrigerant that has been separated out in the gas-liquid separator 5 and that is to be heated in the evaporator 7. Thereby, the refrigerant that has flowed out of the evaporator 7 can be drawn smoothly into the positive displacement fluid machine 4 through the injection flow passage 10f.

[0018] The compressor 2 draws the refrigerant and compresses the drawn refrigerant. The compressed refrigerant is cooled in the radiator 3 while remaining at a high pressure. The cooled refrigerant is decompressed to an intermediate pressure in the positive displacement fluid machine 4 to be turned into a gas-liquid two phase. The gas-liquid two phase refrigerant flows into the gas-liquid separator 5 and is separated into a gas refrigerant and a liquid refrigerant. The gas refrigerant is drawn into the compressor 2. The liquid refrigerant is decompressed by the expansion valve 6 and supplied to the evaporator 7. The refrigerant is heated and evaporated in the evaporator 7. The gas refrigerant that has flowed out of the evaporator 7 is drawn into the positive displacement fluid machine 4 and compressed preliminarily to an intermediate pressure. The gas refrigerant that has been compressed to the intermediate pressure passes again through the gas-liquid separator 5 to be drawn into the compressor 2. The pressure of the refrigerant drawn into the compressor 2 is increased to an intermediate pressure, so that the load on the compressor 2 is reduced. Thereby, the COP of the refrigeration cycle apparatus 100 is improved.

[0019] The cycle specified in the above stages is equivalent to a so-called "ejector cycle". In the ejector cycle well known to a person skilled in the art, an "ejector", which is a kind of non-positive-displacement fluid machine, is used. In contrast, the refrigeration cycle apparatus 100 of the present embodiment can constitute a cycle equivalent to the ejector cycle by including the positive displacement fluid machine 4.

[0020] FIG. 2 is a vertical cross-sectional view of the positive displacement fluid machine shown in FIG. 1. FIG. 3A and FIG. 3B are transverse cross-sectional views of the positive displacement fluid machine, taken along the line X-X and Y-Y, respectively. The positive displacement fluid machine 4 has a closed casing 23, a shaft 15, an upper bearing 18, a first cylinder 11, a first piston 13, a first vane 20, an intermediate plate 25, a second cylinder

12, a second piston 14, a second vane 21 and a lower bearing 19. The positive displacement fluid machine 4 is constituted as a two-stage rotary fluid machine. Parts, such as the cylinders, are accommodated in the closed casing 23.

[0021] As shown in Fig. 2, the shaft 15 has a first eccentric portion 15a and a second eccentric portion 15b. The first eccentric portion 15a and the second eccentric portion 15b each protrude radially outward. The shaft 15 extends through the first cylinder 11 and the second cylinder 12, and is supported rotatably by the upper bearing 18 and the lower bearing 19. The rotation axis of the shaft 15 coincides with the respective centers of the first cylinder 11 and the second cylinder 12. The second cylinder 12 is disposed concentrically with respect to the first cylinder 11, and separated from the first cylinder 11 by the intermediate plate 25. The first cylinder 11 is closed by the upper bearing 18 and the intermediate plate 25, and the second cylinder 12 is closed by the intermediate plate 25 and the lower bearing 19.

[0022] As shown in FIG. 3A, the first piston 13 has a ring shape in plan view, and is disposed inside the first cylinder 11 so as to form a crescent-shaped first space 16 between itself and the first cylinder 11. Inside the first cylinder 11, the first piston 13 is fitted around the first eccentric portion 15a of the shaft 15. A first vane groove 40 is formed in the first cylinder 11. The first vane 20 is placed slidably in the first vane groove 40. The first vane 20 partitions the first space 16 along the circumferential direction of the first piston 13. Thereby, a first suction space 16a and a first discharge space 16b are formed inside the first cylinder 11.

[0023] As shown in FIG. 3B, the second piston 14 has a ring shape in plan view, and is disposed inside the second cylinder 12 so as to form a crescent-shaped second space 17 between itself and the second cylinder 12. Inside the second cylinder 12, the second piston 14 is fitted around the second eccentric portion 15b of the shaft 15. A second vane groove 41 is formed in the second cylinder 12. The second vane 21 is placed slidably in the second vane groove 41. The second vane 21 partitions the second space 17 along the circumferential direction of the second piston 14. Thereby, a second suction space 17a and a second discharge space 17b are formed inside the second cylinder 12.

[0024] The second space 17 has a larger volumetric capacity than that of the first space 16. Specifically, in the present embodiment, the second cylinder 12 has a larger thickness than that of the first cylinder 11. Furthermore, the second cylinder 12 has a larger inner diameter than that of the first cylinder 11. The dimensions of each part are adjusted appropriately so that the second space 17 has a larger volumetric capacity than that of the first space 16.

[0025] With respect to the rotational direction of the shaft 15, the direction in which the first eccentric portion 15a protrudes coincides with the direction in which the second eccentric portion 15b protrudes. With respect to

the rotational direction of the shaft 15, the angular position at which the first vane 20 is disposed coincides with the angular position at which the second vane 21 is disposed. Thus, the timing at which the first piston 13 reaches its top dead center coincides with the timing at which the second piston 14 reaches its top dead center. The phrase "timing at which the piston reaches its top dead center" refers to the timing at which the vane is pressed maximally into the vane groove by the piston.

[0026] As shown respectively in FIG. 3A and FIG. 3B, a first spring 42 is disposed behind the first vane 20 and a second spring 43 is disposed behind the second vane 21. The first spring 42 and the second spring 43 press the first vane 20 and the second vane 21, respectively, toward the center of the shaft 15. A lubricating oil held in the closed casing 23 is supplied to the first vane groove 40 and the second vane groove 41. The first piston 13 and the first vane 20 may be formed of a single component, a so-called swing piston. The first vane 20 may be engaged with the first piston 13. This is also the case with the second piston 14 and the second vane 21.

[0027] As shown in Fig. 2, the positive displacement fluid machine 4 further has a suction pipe 22, a suction port 24, a discharge pipe 26, a discharge port 27, an injection port 30 and an injection suction pipe 29. The refrigerant can be supplied to the first space 16 (specifically, the first suction space 16a) through the suction port 24. The refrigerant can be discharged from the second space 17 (specifically, the second discharge space 17b) through the discharge port 27. The suction pipe 22 and the discharge pipe 26 are connected to the suction port 24 and the discharge port 27, respectively. The suction pipe 22 constitutes a part of the flow passage 10b in the refrigerant circuit 10 (FIG. 1). The discharge pipe 26 constitutes a part of the flow passage 10c in the refrigerant circuit 10. The discharge port 27 is provided with a discharge valve 28 (a check valve) for preventing backflow of the refrigerant from the flow passage 10c to the second discharge space 17b. Typically, the discharge valve 28 is a reed valve made of a metal thin plate. The discharge valve 28 is opened when the pressure in the second discharge space 17b exceeds the pressure in the discharge pipe 26 (the pressure in the flow passage 10c). When the pressure in the second discharge space 17b is equal to or lower than the pressure in the discharge pipe 26, the discharge valve 28 is closed.

[0028] The suction port 24 and the discharge port 27 are formed in the upper bearing 18 and the lower bearing 19, respectively. However, the suction port 24 may be formed in the first cylinder 11 and the discharge port 19 may be formed in the second cylinder 12.

[0029] The intermediate plate 25 is provided with a communication hole 25a (a communication flow passage). The communication hole 25a extends through the intermediate plate 25 in the thickness direction. The first discharge space 16b of the first cylinder 11 is in communication with the second suction space 17a of the second cylinder 12 through the communication hole 25a. There-

by, the first discharge space 16b, the communication hole 25a and the second suction space 17a can function as one working chamber. Since the volumetric capacity of the second space 17 is larger than the volumetric capacity of the first space 16, the refrigerant confined in the first discharge space 16b, the communication hole 25a and the second suction space 17a expands while rotating the shaft 15.

[0030] In the positive displacement fluid machine 4, the "working chamber" is formed of the first space 16, the second space 17 and the communication hole 25a. The working chamber increases its volumetric capacity to expand the refrigerant and reduces its volumetric capacity to compress the refrigerant. Specifically, the first suction space 16a functions as a working chamber into which the refrigerant is drawn. The first discharge space 16b, the communication hole 25a and the second suction space 17a function as a working chamber in which the refrigerant is expanded and overexpanded. The second discharge space 17b functions as a working chamber in which the refrigerant is recompressed and from which the refrigerant is discharged.

[0031] Particularly, in the present embodiment, the ratio (V_2/V_1) of a volumetric capacity V_2 of the second space 17 to a volumetric capacity V_1 of the first space 16 is adjusted to a value that allows the refrigerant drawn into the positive displacement fluid machine 4 to be expanded and overexpanded in the working chamber formed of the first discharge space 16b, the communication hole 25a and the second suction space 17a. That is, the volumetric capacity V_2 is far larger than the volumetric capacity V_1 . Specifically, the volumetric capacity ratio (V_2/V_1) is set to be almost equal to the ratio (V_{SEP}/V_{GC}) of a volumetric flow rate V_{SEP} of the refrigerant at the inlet of the gas-liquid separator 5 to a volumetric flow rate V_{GC} of the refrigerant at an outlet of the radiator 3.

[0032] The injection port 30 is formed at a position that allows the refrigerant to be supplied to the second suction space 17a through the injection port 30. Specifically, the injection port 30 is formed in the second cylinder 12. The injection port 30 is provided with a check valve 31 for preventing backflow of the refrigerant from the second suction space 17a or the second discharge space 17b to the injection flow passage 10f. Typically, the check valve 31 is a reed valve made of a metal thin plate.

[0033] Specifically, the second cylinder 12 is provided with a recessed portion 30a facing the second space 17. The injection port 30 opens into the recessed portion 30a. The check valve 31 is fixed to the recessed portion 30a so as to open and close the injection port 30. The check valve 31 is opened when the pressure in the second suction space 17a falls below the pressure in the injection suction pipe 29 (the pressure in the injection flow passage 10f). The check valve 31 is closed when the pressure in the second suction space 17a is equal to or higher than the pressure in the injection suction pipe 29.

[0034] In the present embodiment, the position where the second vane 21 is disposed (the position of the sec-

ond vane groove 41), with respect to the rotational direction of the shaft 15, is defined as a "reference position" having an angle of 0 degrees. Since the position at which the first vane 20 is disposed coincides with the position at which the second vane 21 is disposed, the position at which the first vane 20 is disposed also coincides with the reference position. The injection port 30 is provided at a position in the range of, for example, 45 to 135 degrees with respect to the rotational direction of the shaft 15. By providing the injection port 30 at a position in such a range, it is possible to prevent the high pressure refrigerant from flowing from the suction port 24 directly to the injection port 30 through a gap at the check valve 31. Moreover, it is possible to prevent the recovered power from decreasing due to expansion of the refrigerant in the recessed portion 30a. This is because when the high pressure drawn refrigerant enters into the recessed portion 30a that is a dead volume and is expanded in the recessed portion 30a, power cannot be recovered from the refrigerant expanded in the recessed portion 30a.

[0035] The suction port 24 is provided at a position in the range of, for example, 0 to 40 degrees. The communication hole 25a is provided at a position in the range of, for example, 0 to 40 degrees when viewed from the second cylinder 12 side. The discharge port 27 is provided at a position in the range of, for example, 320 to 360 degrees.

[0036] As can be understood from the positional relationship among the suction port 24, the communication hole 25a and the injection port 30, the injection port 30 is provided at a position that does not allow the injection port 30 to be in communication with the suction port 24 through the working chamber (the first space 16, the communication hole 25a and the second space 17). Such a configuration prevents the recovered power from decreasing due to the expansion of the refrigerant in the recessed portion 30a.

[0037] The opening area of the suction port 24, the opening area of the injection port 30 and the opening area of the discharge port 27 should be set appropriately taking into account the flow rate (volumetric flow rate) of the refrigerant passing through each of these ports. In the refrigeration cycle apparatus 100, the refrigerant flowing through the injection flow passage 10f has a very high volumetric flow rate. That is, the refrigerant passing through the injection port 30 has a very high volumetric flow rate. In contrast, the refrigerant passing through the suction port 24 has a relatively low volumetric flow rate because it is in a liquid phase (chlorofluorocarbon alternative) or in a supercritical state (CO₂). Therefore, it is desirable that the opening area of the injection port 30 is larger than that of the suction port 24, from the viewpoint of reducing the pressure loss.

[0038] Next, the operation of the positive displacement fluid machine is described in detail with reference to FIGs. 4 to 7. FIG. 4 is an a diagram illustrating the operation principle of the positive displacement fluid machine. The upper left diagram, upper right diagram, lower right dia-

gram and lower left diagram in FIG. 4 each show the positions of the first piston 13 and the second piston 14 when the shaft 15 is rotated 90 degrees each. FIG. 5 is a graph showing a relationship between the rotation angle of the shaft from the reference position and the volumetric capacity of the working chamber. FIG. 6 is a graph showing a relationship between the rotation angle of the shaft from the reference position and the pressure in the working chamber. FIG. 7 is a graph showing a relationship between the pressure in the working chamber and the volumetric capacity of the working chamber (between the pressure of the refrigerant and the volume of the refrigerant).

[0039] As shown in the upper left diagram and the upper right diagram in FIG. 4, in the first cylinder 11, the first suction space 16a is newly generated adjacent to the suction port 24 when the shaft 15 rotates from the position of 0 degrees to the position of 90 degrees. Thereby, the refrigerant cooled in the radiator 3 is drawn into the first suction space 16a through the suction port 24 (suction process). As the shaft 15 rotates, the volumetric capacity of the first suction space 16a increases. When the shaft 15 rotates 360 degrees, the volumetric capacity of the first suction space 16a reaches to its maximum capacity (= the volumetric capacity of the first space 16). Thereby, the suction process is completed.

[0040] In FIG. 5, the line AB indicates the change in the volumetric capacity of the first suction space 16a during the suction process. The suction process is completed at the point B. The volumetric capacity V1 at the point B corresponds to the volumetric capacity of the first space 16 of the first cylinder 11. In FIG. 6, the line AB indicates the suction process. The refrigerant drawn into the first suction space 16a during the suction process is the refrigerant that has been cooled in the radiator 3 while maintaining a high pressure, and the refrigerant has a suction pressure P1 (a first pressure).

[0041] Next, as shown in the upper left diagram and the upper right diagram in FIG. 4, the first suction space 16a changes into the first discharge space 16b when the shaft 15 rotates from the position of 360 degrees to the position of 450 degrees. In the second cylinder 12, the second suction space 17a is newly generated adjacent to the communication hole 25a. The first discharge space 16b is in communication with the second suction space 17a through the communication hole 25a. The first discharge space 16b, the communication hole 25a and the second suction space 17a form one working chamber that is in communication neither with the suction port 24 nor with the discharge port 27. As the shaft 15 rotates, the refrigerant is expanded to a discharge pressure P2 (a second pressure) in the working chamber formed of the first discharge space 16b, the communication hole 25a and the second suction space 17a (expansion process).

[0042] The amount of increase in the volumetric capacity of the second suction space 17a is significantly larger than the amount of decrease in the volumetric ca-

capacity of the first discharge space 16b, when the shaft 15 rotates only an unit angle. Thus, the refrigerant is expanded rapidly, and the pressure of the refrigerant falls below the discharge pressure P2 when the shaft 15 occupies the position of 450 degrees. As the shaft 15 rotates, the refrigerant is overexpanded to a pressure P3 (a third pressure) that is lower than the discharge pressure P2 (overexpansion process).

[0043] In the expansion process and the overexpansion process, the refrigerant releases pressure energy. The pressure energy released from the refrigerant is converted into a torque of the shaft 15 via the pistons 13 and 14. That is, the positive displacement fluid machine 4 recovers power from the refrigerant.

[0044] On the other hand, when the rotation angle of the shaft 15 exceeds 450 degrees, the refrigerant can be supplied to the second suction space 17a through the injection port 30. When the overexpansion of the refrigerant proceeds and the pressure in the second suction space 17a falls below the pressure in the injection suction pipe 29, that is, the evaporating pressure in the evaporator 7, the overexpansion of the refrigerant stops. At the same time, the refrigerant having the pressure P3 is supplied to the second suction space 17a through the injection port 30. In the second suction space 17a, the supplied refrigerant is mixed with the overexpanded refrigerant (injection process).

[0045] Thereafter, as shown in the lower right diagram and the lower left diagram in FIG. 4, the refrigerant having the pressure P3 continues being supplied to the second suction space 17a through the injection port 30 until the rotation angle of the shaft 15 reaches 720 degrees. As shown in the upper left diagram in FIG. 4, when the shaft 15 rotates to the position of 720 degrees, the volumetric capacity of the second suction space 17a reaches its maximum capacity (= the volumetric capacity of the second space 17). Thereby, the injection process is completed.

[0046] In FIG. 5, the dashed line BI indicates the change in the volumetric capacity of the first discharge space 16b during the expansion process, the overexpansion process and the injection process. The dashed line JE indicates the change in the volumetric capacity of the second suction space 17a. The line BE indicates the change in the volumetric capacity of the working chamber formed of the first discharge space 16b, the communication hole 25a and the second suction space 17a. The expansion process, the overexpansion process and the injection process are completed at the point E. The volumetric capacity V2 at the point E corresponds to the volumetric capacity of the second space 17 of the second cylinder 12.

[0047] In FIG. 6, the lines BC, CD and DE indicate the expansion process, the overexpansion process and the injection process, respectively. As the shaft 15 rotates, the pressure in the working chamber formed of the first discharge space 16b, the communication hole 25a and the second suction space 17a lowers from the pressure

P1 observed at the start of the expansion process. As mentioned above, the ratio ($V2/V1$) of the volumetric capacity V2 of the second space 17 to the volumetric capacity V1 of the first space 16 is very high. Thus, assuming that the injection port 30 is omitted, the pressure in the working chamber lowers along the dashed line DH on the extension of the line BCD even after lowering to the pressure P3 of the refrigerant in the evaporator 7. However, since the positive displacement fluid machine 4 used in the refrigeration cycle apparatus 100 of the present embodiment has the injection port 30, the refrigerant having the pressure P3 that has flowed out of the evaporator 7 is supplied to the second suction space 17a through the injection port 30 when the pressure in the working chamber lowers to the pressure P3. Thus, the pressure in the working chamber stops lowering, and the refrigerant having the pressure P3 continues being supplied to the working chamber until the volumetric capacity of the working chamber reaches the volumetric capacity V2 specified at the point E in FIG. 5. Thereby, the expansion process, the overexpansion process and the injection process are completed.

[0048] Next, as shown in the upper left diagram and the upper right diagram in FIG. 4, the second suction space 17a changes into the second discharge space 17b when the shaft 15 rotates from the position of 720 degrees to the position of 810 degrees. The discharge port 27 faces the second discharge space 17b. However, as described with reference to FIG. 2, the discharge port 27 is provided with the discharge valve 28. Thus, the refrigerant is compressed in the second discharge space 17b until the pressure in the second discharge space 17b exceeds the pressure in the discharge pipe 26, that is, the suction pressure in the compressor 2 (recompression process). The refrigerant to be compressed in the second discharge space 17b includes a fraction of the refrigerant drawn into the positive displacement fluid machine 4 through the suction port 24 and a fraction of the refrigerant drawn into the positive displacement fluid machine 4 through the injection port 30.

[0049] The power recovered from the refrigerant during the expansion process and the overexpansion process is used to compress the refrigerant during the recompression process. As can be understood from the upper left diagram and the upper right diagram in FIG. 4, when the recompression process is performed in the second discharge space 17b, the expansion process and the overexpansion process are performed in the newly generated second suction space 17a. The power recovered from the refrigerant during the expansion process and the overexpansion process is consumed as energy for compressing the refrigerant during the recompression process.

[0050] In the present embodiment, the expansion process and the overexpansion process continue from a point of time when the first discharge space 16b is brought into communication with the second suction space 17a through the communication hole 25a until a point of time

when the pressure in the second suction space 17a becomes equal to the pressure P3 (the third pressure) in the injection flow passage 10f. The recompression process continues from a point of time when the communication between the first discharge space 16b and the second suction space 17a through the communication hole 25a is interrupted until a point of time when the pressure in the second discharge space 17b becomes equal to the pressure P2 (the second pressure) in the flow passage 10c. In a period during which the shaft 15 makes one rotation, at least a part of a period during which the expansion process and the overexpansion process are performed is overlapped with a period during which the recompression process is performed. With such a configuration, unevenness in the torque of the shaft 15 is less likely to occur. This contributes to stable operation of the positive displacement fluid machine 4.

[0051] When the pressure in the second discharge space 17b exceeds the pressure in the discharge pipe 26, the discharge valve 28 is opened. Thereby, the refrigerant is discharged from the second discharge space 17b to the discharge pipe 26 through the discharge port 27 (discharge process). As the shaft 15 rotates, the volumetric capacity of the second discharge space 17b decreases, and the second discharge space 17b disappears when the shaft 15 rotates to the position of 1080 degrees. Thereby, the discharge process is completed.

[0052] In FIG. 5, the line EG indicates the change in the volumetric capacity of the second discharge space 17b during the recompression process and the discharge process. In FIG. 6, the line EF and line FG indicate the recompression process and the discharge process, respectively. Immediately after the completion of the expansion process and the overexpansion process, the pressure P3 of the refrigerant is lower than the pressure P2 in the discharge pipe 26. At this time, the discharge valve 28 is closed. As the volumetric capacity of the second discharge space 17b decreases, the refrigerant is recompressed to the pressure P2. Thereafter, the pressure in front of the discharge valve 28 is balanced with the pressure behind the discharge valve 28, so that the discharge valve 28 is opened and the refrigerant having the pressure P2 is discharged from the second discharge space 17b to the discharge pipe 26. The discharge process is completed at the point G.

[0053] FIG. 7 is a P-V diagram showing a relationship between the pressure in the working chamber and the volumetric capacity of the working chamber. The line AB indicates the suction process, the line BC indicates the expansion process, the line CD indicates the overexpansion process, the line DE indicates the injection process, the line EF indicates the recompression process, and the line FCG indicates the discharge process. The energy that the positive displacement fluid machine 4 recovers from the refrigerant corresponds to the area of the region surrounded by the points A, B, C, D, L and G. The work necessary to recompress the overexpanded refrigerant corresponds to the area of the region surrounded by the

points L, D, E, F, C and G. The recovered energy, the work necessary for the recompression, and various losses are balanced with each other. Thus, the positive displacement fluid machine 4 rotates autonomously without a motor or the like. Since the region surrounded by the points C, D, L and G is common between the recovered energy and the work necessary for the recompression, it can be cancelled. Eventually, the energy corresponding to the area of the region surrounded by the points A, B, C and G is recovered from the refrigerant, and the work corresponding to the area of the region surrounded by the points C, D, E and F is performed on the refrigerant by using the recovered energy.

[0054] As described above, in the present embodiment, the expansion process, the overexpansion process and the recompression process are performed as a sequence of steps between the suction process and the discharge process. Thus, in the present embodiment, unlike in the refrigeration cycle apparatus described in Patent Literature 1, the expander and the sub compressor do not need to be provided independently and it is possible to perform each step mentioned above by using the positive displacement fluid machine 4 having a simple structure. The parts count of the positive displacement fluid machine 4 is less than that in the case where the expander and the sub compressor are provided independently. Therefore, the production cost of the refrigeration cycle apparatus 100 can be suppressed.

[0055] Moreover, since the injection port 30 is provided with the check valve 31, it is possible to prevent backflow of the refrigerant from the second discharge space 17b to the injection port 30 during the recompression process and the discharge process. This contributes to the enhancement in the efficiency of the positive displacement fluid machine 4. In FIG. 4, the check valve 31 prevents the backflow of the refrigerant from the second discharge space 17b to the injection port 30 during the period in which the shaft 15 rotates from the position of 720 degrees to the position of 810 degrees.

[0056] Furthermore, since the discharge port 27 is provided with the discharge valve 28, the work for recompressing and discharging the refrigerant can be reduced. When the discharge valve 28 is not provided, backflow of the refrigerant may occur from the discharge pipe 26 (the flow passage 10c) to the second discharge space 17b at the moment when the rotation angle of the shaft 15 exceeds 720 degrees and the discharge port 27 faces the second discharge space 17b. In the case where the backflow of the refrigerant occurs, the recompression process and the discharge process are indicated by the line EKFG in FIG. 6 and by the line EKFCG in FIG. 7. That is, the work corresponding to the area of the region surrounded by the points E, K and F is needed as an extra work for recompressing and discharging the refrigerant. This drawback can be avoided by providing the discharge valve 28, and thereby the work for recompressing and discharging the refrigerant can be reduced and also the efficiency of the positive displacement fluid ma-

chine 4 is enhanced. In addition, explosive sound caused by connecting directly the suction pipe 26 filled with the refrigerant having the pressure P3 to the second discharge space 17b filled with the refrigerant having the pressure P2 can be prevented from occurring. Accordingly, noise and vibration of the positive displacement fluid machine 4 can be suppressed.

[0057] In the present embodiment, the positive displacement fluid machine 4 has a structure of a two-stage rotary fluid machine. The expansion process and the overexpansion process proceed in the working chamber formed of the first discharge space 16b, the communication hole 25a and the second suction space 17a, and the recompression process and the discharge process proceed in the second discharge space 17b. That is, the expansion process and the overexpansion process proceed at the same time with the recompression process and the discharge process in the positive displacement fluid machine 4. Thus, the energy recovery from the refrigerant can be performed at the same time with the compression work to the refrigerant. In the case where the energy recovery is performed at the same time with the compression work, the change in the rotating speed of the shaft 15 is less than in the case where they are performed alternately. Thereby, it is possible to operate stably the positive displacement fluid machine 4 and also to reduce the noise and vibration of the positive displacement fluid machine 4. Moreover, it is possible to prevent the shaft 15 from slowing down and stopping due to the change in the rotating speed of the shaft 15 when the circulation amount of the refrigerant in the refrigerant circuit 10 is small.

[0058] In addition, use of the two-stage rotary fluid machine can provide the following advantages. That is, it is easy to set the ratio (V_2/V_1) of the volumetric capacity V_2 of the second space 17 to the volumetric capacity V_1 of the first space 16 to be close to the ratio (V_{SEP}/V_{GC}) of the volumetric flow rate V_{SEP} of the refrigerant at the inlet of the gas-liquid separator 5 to the volumetric flow rate V_{GC} of the refrigerant at the outlet of the radiator 3.

[0059] In the present embodiment, the refrigerant to be supplied to the injection port 30 of the positive displacement fluid machine 4 through the injection flow passage 10f is a gas refrigerant. Specifically, the refrigerant that has received heat from a low temperature side heat source (air, for example) and evaporated from a liquid to a gas in the evaporator 7 is injected into the positive displacement fluid machine 4. Since the work to compress, in the positive displacement fluid machine 4, the refrigerant (liquid refrigerant) making no contribution to the thermal energy absorption from the low temperature side heat source is reduced, the COP of the refrigeration cycle apparatus 100 is enhanced. Therefore, it is preferable to regulate the opening of the expansion valve 6 (the expansion valve 45 in Embodiment 2) so that the refrigerant having a dryness of 1.0 or the overheated refrigerant (that is, only the gas refrigerant) is supplied to the injection port 30.

[0060] The refrigeration cycle apparatus 100 of the present embodiment can be used suitably in a hot water supply appliance and a hot water heater. For the purposes of the hot water supply and hot water heating, switching between cooling and heating, as in an air conditioner, is not necessary. That is, components, such as a four-way valve, can be omitted and further cost reduction can be expected.

[0061] Use of the refrigeration cycle apparatus 100 in a hot water supply appliance and a hot water heater provides the following advantages. Usually, the hot water supply appliance performs a rated operation in the case of reserving hot water in a tank by using night power. The hot water heater usually performs a continuous operation. When a certain period of time has elapsed since the starting of the hot water heater, the load on the hot water heater is stabilized because the temperature in a building becomes constant. Taking such an operation style into account, the ratio of the volumetric flow rate of the refrigerant at the inlet of the gas-liquid separator 5 to the volumetric flow rate of the refrigerant at the outlet of the radiator 3 is almost constant. Thus, it is easy to make the ratio (V_2/V_1) of the volumetric capacity V_2 of the second space 17 to the volumetric capacity V_1 of the first space 16 coincide with the volumetric flow rate ratio. Thereby, the effect of power recovery can be obtained more sufficiently.

[0062] The high pressure and the low pressure of a supercritical refrigerant typified by carbon dioxide is different largely in the refrigeration cycle. Specifically, there is a large difference between the suction pressure P1 and the discharge pressure P2 in the positive displacement fluid machine 4. Accordingly, the power that can be recovered by the positive displacement fluid machine 4 also is large. Thus, carbon dioxide is appropriate as the refrigerant for the refrigeration cycle apparatus 100. The type of the refrigerant is not particularly limited, of course, and a natural refrigerant other than carbon dioxide, a chlorofluorocarbon alternative such as R410A, and a low GWP (Global Warming Potential) refrigerant such as R1234yf can be used.

[0063] By using the positive displacement fluid machine 4 in the refrigeration cycle apparatus 100 as a means to recover power from the refrigerant, it is possible to utilize the recovered power as a part of the compression work. Since the difference between the suction pressure and the discharge pressure in the compressor 2 is reduced, the load on the compressor 2 is reduced and the COP of the refrigeration cycle apparatus 100 is improved. It should be noted, however, that the positive displacement fluid machine 4 described in the present embodiment may be usable also in apparatuses other than the refrigeration cycle apparatus.

(Embodiment 2)

[0064] FIG. 8 is a configuration diagram of a refrigeration cycle apparatus according to Embodiment 2 of the

present invention. The refrigeration cycle apparatus 200 includes the compressor 2, the radiator 3, a positive displacement fluid machine 44, an expansion valve 45 (a decompression valve), a first evaporator 46 and a second evaporator 47. These components are connected to each other by flow passages 50a to 50f so as to form a refrigerant circuit 50.

[0065] The compressor 2 and the radiator 3 are the same as in Embodiment 1, as can be understood from the fact that they are indicated by the same reference numerals as those in Embodiment 1, respectively. The positive displacement fluid machine 44 has the same function as that of the positive displacement fluid machine 4 described in Embodiment 1, although having structural differences. The expansion valve 45 is a valve with a variable opening, such as an electric expansion valve. The first evaporator 46 and the second evaporator 47 each are a device for providing heat to the refrigerant, and typically is composed of an air-refrigerant heat exchanger.

[0066] The flow passage 50a connects the compressor 2 to the radiator 3 so that the refrigerant compressed in the compressor 2 is supplied to the radiator 3. The flow passage 50b connects the radiator 3 to the positive displacement fluid machine 44 so that a part of the refrigerant that has flowed out of the radiator 3 is supplied to the positive displacement fluid machine 44. The flow passage 50c connects the positive displacement fluid machine 44 to the first evaporator 46 so that the refrigerant discharged from the positive displacement fluid machine 44 is supplied to the first evaporator 46. The flow passage 50d connects the first evaporator 46 to the compressor 2 so that the refrigerant that has flowed out of the first evaporator 46 is supplied to the compressor 2. The flow passage 50e connects the radiator 3 to the second evaporator 47 so that a part of the refrigerant that has flowed out of the radiator 3 is supplied to the second evaporator 47. Specifically, the flow passage 50e is a flow passage (branch flow passage) branched from the flow passage 50b, and has an upstream end connected to the flow passage 50b between the radiator 3 and the positive displacement fluid machine 44 and a downstream end connected to the second evaporator 47. The expansion valve 45 is disposed on the flow passage 50e. The refrigerant is decompressed by the expansion valve 45 and then flows into the second evaporator 47. The flow passage 50f connects the second evaporator 47 to the positive displacement fluid machine 44 so that the gas refrigerant that has flowed out of the second evaporator 47 is supplied (injected) to the positive displacement fluid machine 44.

[0067] The first evaporator 46 and the second evaporator 47 are disposed on a flow passage for a heat medium (air, for example) so that the heat medium cooled in the first evaporator 46 is cooled further in the second evaporator 47. The direction indicated by the arrows in FIG. 8 is the flowing direction of the heat medium. The temperature of the refrigerant in the first evaporator 46

is higher than that of the refrigerant in the second evaporator 47. Thus, as shown in Fig. 8, in the case where the first evaporator 46 and the second evaporator 47 are disposed respectively on an upstream and a downstream of the flow passage for the heat medium, it is almost like the heat medium (air) and the refrigerant form mutually opposed flows. Thereby, the efficiency of the heat exchange between the refrigerant and the heat medium in the evaporators 46 and 47 is enhanced. Moreover, since the pressure of the refrigerant that has flowed out of the second evaporator 47 is increased in the positive displacement fluid machine 44, the COP of the refrigeration cycle apparatus 200 is enhanced as in Embodiment 1.

[0068] The compressor 2 draws the refrigerant and compresses the drawn refrigerant. The compressed refrigerant is cooled in the radiator 3 while remaining at a high pressure. The cooled refrigerant flows into the two flow passages 50b and 50e. Apart of the cooled refrigerant is drawn into the positive displacement fluid machine 44 through the flow passage 50b. The refrigerant drawn into the positive displacement fluid machine 44 is decompressed to an intermediate pressure in the positive displacement fluid machine 44 to be turned into a gas-liquid two phase. The refrigerant discharged from the positive displacement fluid machine 44 flows into the first evaporator 46 through the flow passage 50c. The refrigerant that has flowed into the first evaporator 46 is heated in the first evaporator 46, and then drawn into the compressor 2 through the flow passage 50d. On the other hand, the remainder of the refrigerant cooled in the radiator 3 is decompressed by the expansion valve 45 to be turned into a gas-liquid two phase, and then supplied to the second evaporator 47 through the flow passage 50e. The refrigerant that has flowed into the second evaporator 47 is heated in the second evaporator 47, and then supplied (injected) to the positive displacement fluid machine 44 through the injection flow passage 50f.

[0069] FIG. 9 is a vertical cross-sectional view of the positive displacement fluid machine 44 shown in FIG. 8. FIG. 10 is a transverse cross-sectional view of the positive displacement fluid machine, taken along the line Z-Z. The positive displacement fluid machine 44 has a closed casing 59, a shaft 53, an upper bearing 55, a cylinder 51, a piston 52, a vane 57 and a lower bearing 56. The positive displacement fluid machine 44 is constituted as a single-stage rotary fluid machine.

[0070] As shown in Fig. 9, the shaft 53 has an eccentric portion 53a protruding radially outward. The shaft 53 extends through the cylinder 51 and is supported rotatably by the upper bearing 55 and the lower bearing 56. The rotation axis of the shaft 53 coincides with the center of the cylinder 51. The cylinder 51 is closed by the upper bearing 55 and the lower bearing 56.

[0071] As shown in FIG. 10, the piston 52 has a ring shape in plan view, and is disposed inside the cylinder 51 so as to form a crescent-shaped space 54 between itself and the cylinder 51. Inside the cylinder 51, the piston 52 is fitted around the eccentric portion 53a of the shaft

53. A vane groove 68 is formed in the cylinder 51. The vane 57 is placed slidably in the vane groove 68. The vane 57 partitions the space 54 along the circumferential direction of the piston 52. Thereby, a suction space 54a and a discharge space 54b are formed inside the cylinder 51. A spring 69 is disposed behind the vane 57. The spring 69 presses the vane 57 toward the center of the shaft 53. A lubricating oil held in the closed casing 59 is supplied to the vane groove 68. The piston 52 and the vane 57 may be formed of a single component, a so-called swing piston. The vane 57 may be engaged with the piston 52.

[0072] As shown in Fig. 9, the positive displacement fluid machine 44 further has a suction pipe 58, a suction port 60, a discharge pipe 62, a discharge port 63, an injection port 67 and an injection suction pipe 65. The refrigerant can be supplied to the space 54 (specifically the suction space 54a) through the suction port 60. The refrigerant can be discharged from the space 54 (specifically the discharge space 54b) through the discharge port 63. The suction pipe 58 and the discharge pipe 62 are connected to the suction port 60 and the discharge port 63, respectively. The suction pipe 58 constitutes a part of the flow passage 50b in the refrigerant circuit 50 (FIG. 8). The discharge pipe 62 constitutes a part of the flow passage 50c in the refrigerant circuit 50. The injection port 63 is provided with a discharge valve 64 (a check valve) for preventing backflow of the refrigerant from the flow passage 50c to the discharge space 54b. Typically, the discharge valve 64 is a reed valve made of a metal thin plate. When the pressure in the discharge space 54b exceeds the pressure in the discharge pipe 62 (the pressure in the flow passage 50c), the discharge valve 64 is opened. When the pressure in the discharge space 54b is equal to or lower than the pressure in the discharge pipe 62, the discharge valve 64 is closed.

[0073] The suction port 60 and the discharge port 63 are formed in the upper bearing 55 and the lower bearing 56, respectively. However, the suction port 60 and the discharge port 63 each may be formed in the cylinder 51.

[0074] The positive displacement fluid machine 44 further has a suction mechanism 61 for controlling the timing at which the refrigerant flows into the space 54 of the cylinder 51 through the suction port 60. In the present embodiment, the suction mechanism 61 is composed of a solenoid valve including a suction valve 61a and a solenoid 61b. It is possible to control the open/close operation of the suction valve 61a by switching on and off the voltage applied to the solenoid 61b.

[0075] The injection port 67 is formed in the cylinder 51 so that the refrigerant can be supplied to the suction space 54a. The injection port 67 is provided with a check valve 66 for preventing backflow of the refrigerant from the suction space 54a or the discharge space 54b to the injection flow passage 50f. The detailed structures of the injection port 67 and the check valve 66 are as described in Embodiment 1.

[0076] In the present embodiment, the position where

the vane 57 is disposed (the position of the vane groove 68), with respect to the rotational direction of the shaft 53, is defined as a "reference position" having an angle of 0 degrees. The injection port 67 is provided at a position in the range of, for example, 90 to 180 degrees with respect to the rotational direction of the shaft 53. The suction port 60 and the discharge port 63 are provided at positions adjacent to the vane 57.

[0077] In the positive displacement fluid machine 44, the suction space 54a functions as a working chamber into which the refrigerant is drawn and in which the refrigerant is expanded and overexpanded. The discharge space 54b functions as a working chamber in which the refrigerant is recompressed and from which refrigerant is discharged.

[0078] Next, the operation of the positive displacement fluid machine is described in detail with reference to FIG. 6 and FIG. 11. FIG. 11 is a diagram illustrating the operation principle of the positive displacement fluid machine. The upper left diagram, upper right diagram, lower right diagram and lower left diagram in FIG. 11 each show the position of the piston 52 when the shaft 53 is rotated 90 degrees each. In the present embodiment, the suction valve 61a is opened when the rotation angle of the shaft 53 is in the range of 0 to 90 degrees, and thereafter repeats being opened and closed in a cycle of 360 degrees.

[0079] As shown in the upper left diagram in FIG. 11, the suction space 54a is newly generated adjacent to the suction port 60 when the shaft 53 rotates from the position of 0 degrees to the position of 90 degrees. The refrigerant is drawn into the suction space 54a through the suction port 60 (suction process). When the shaft 53 rotates from the position of 0 degrees to the position of about 90 degrees, the suction valve 61a is closed. Thereby, the suction process is completed. In FIG. 6, the line AB indicates the suction process.

[0080] When the suction valve 61a is closed, the refrigerant is expanded to the discharge pressure P2 in the suction space 54a (expansion process). As the shaft 53 rotates, the refrigerant is overexpanded to the pressure P3 lower than the discharge pressure P2 (overexpansion process). The positive displacement fluid machine 44 recovers power from the refrigerant during the expansion process and the overexpansion process. In FIG. 6, the line BCD indicates the expansion process and the overexpansion process.

[0081] When the rotation angle of the shaft 53 exceeds about 120 degrees, the refrigerant can be supplied to the suction space 54a through the injection port 67. When the overexpansion of the refrigerant proceeds and the pressure in the suction space 54a falls below the pressure in the injection suction pipe 65, that is, the evaporating pressure in the second evaporator 47, the overexpansion of the refrigerant stops. At the same time, the refrigerant having the pressure P3 is supplied to the suction space 54a through the injection port 67. In the suction space 54a, the supplied refrigerant is mixed with the overexpanded refrigerant (injection process).

[0082] Thereafter, the refrigerant having the pressure P3 continues being supplied to the suction space 54a through the injection port until the rotation angle of the shaft 53 reaches 360 degrees. As shown in the upper left diagram in FIG. 11, when the shaft 53 rotates to the position of 360 degrees, the volumetric capacity of the suction space 54a reaches its maximum capacity (= the volumetric capacity of the space 54). Thereby, the injection process is completed. In FIG. 6, the line DE indicates the injection process.

[0083] The volumetric capacity V1 of the working chamber (the suction space 54a) when the suction process is completed is specified by the rotation angle of the shaft 53 at the moment when the suction valve 61a is closed. In the present embodiment, the ratio ($V2/V1$) of the volumetric capacity V2 when the injection process is completed to the volumetric capacity V1 when the suction process is completed is almost equal to the ratio ($V_{EVA}N_{GC}$) of a volumetric flow rate V_{EVA} of the refrigerant at an inlet of the first evaporator 46 to the volumetric flow rate V_{GC} of the refrigerant at the outlet of the radiator 3. Also, the volumetric capacity ratio ($V2/V1$) is set to be sufficiently higher than the ratio of the specific volume of the refrigerant that can be calculated from the ratio of the pressure P3 in the working chamber (the space 54) when the injection process is completed to the pressure P1 in the working chamber (the space 54) when the suction process is completed.

[0084] Next, as shown in the upper left diagram and the upper right diagram in FIG. 11, the suction space 54a changes into the discharge space 54b when the shaft 53 rotates from the position of 360 degrees to the position of 450 degrees. The discharge port 63 faces the discharge space 54b. However, as described with reference to FIG. 9, the discharge port 63 is provided with the discharge valve 64. Thus, the refrigerant is compressed in the discharge space 54b until the pressure in the discharge space 54b exceeds the pressure in the discharge pipe 62, that is, the suction pressure in the compressor 2 (recompression process).

[0085] When the pressure in the discharge space 54b exceeds the pressure in the discharge pipe 62, the discharge valve 64 is opened. Thereby, the refrigerant is discharged from the discharge space 54b to the discharge pipe 62 through the discharge port 63 (discharge process). As the shaft 53 rotates, the volumetric capacity of the discharge space 54b decreases, and the discharge space 54b disappears when the shaft 53 rotates to the position of 720 degrees. Thereby, the discharge process is completed. In FIG. 6, the line EF and the line FG indicate the recompression process and the discharge process, respectively.

[0086] With the configuration and processes described above, the same effects can be obtained also in the present embodiment as those in Embodiment 1. In the present embodiment, the positive displacement fluid machine 44 has a structure of a single-stage rotary fluid machine including a single cylinder and a single piston.

Thus, in the present embodiment, it is possible to reduce the parts count of the positive displacement fluid machine 44, downsize the positive displacement fluid machine 44, and lower the cost of the refrigeration cycle apparatus 200.

[0087] Instead of the positive displacement fluid machine 44, the positive displacement fluid machine 4 described in Embodiment 1 may be used in the refrigeration cycle apparatus 200. Likewise, the positive displacement fluid machine 44 may be used in the refrigeration cycle apparatus 100 in Embodiment 1. Moreover, other types of fluid machines, such as a scroll type fluid machine, may be used as these positive displacement fluid machines.

INDUSTRIAL APPLICABILITY

[0088] The refrigeration cycle apparatus of the present invention can be used in a hot water supply appliance, a hot water heater, an air conditioner and the like.

Claims

1. A refrigeration cycle apparatus comprising:

a compressor for compressing a refrigerant;
a radiator for cooling the refrigerant compressed in the compressor;
a positive displacement fluid machine having a working chamber and an injection port, and configured to perform (i) a step of drawing, at a first pressure, the refrigerant cooled in the radiator into the working chamber, (ii) a step of, in the working chamber, expanding the drawn refrigerant to a second pressure lower than the first pressure and overexpanding further the refrigerant to a third pressure lower than the second pressure, (iii) a step of supplying, through the injection port, the refrigerant having the third pressure to the working chamber so as to mix the supplied refrigerant with the overexpanded refrigerant, (iv) a step of recompressing, in the working chamber, the mixed refrigerant to the second pressure by using power recovered from the refrigerant in the step (ii), and (v) a step of discharging the recompressed refrigerant from the working chamber;
an evaporator for heating the refrigerant discharged from the positive displacement fluid machine; and
an injection flow passage through which the refrigerant having the third pressure is supplied to the injection port of the positive displacement fluid machine.

2. The refrigeration cycle apparatus according to claim 1, wherein

the positive displacement fluid machine has:

a first cylinder;
 a first piston disposed inside the first cylinder so as to form a first space between itself and the first cylinder;
 a first vane partitioning the first space into a first suction space and a first discharge space;
 a second cylinder disposed concentrically with respect to the first cylinder;
 a second piston disposed inside the second cylinder so as to form, between itself and the second cylinder, a second space having a larger volumetric capacity than that of the first space;
 a second vane partitioning the second space into a second suction space and a second discharge space;
 an intermediate plate disposed between the first cylinder and the second cylinder;
 a communication flow passage provided in the intermediate plate so as to bring the first discharge space into communication with the second suction space;
 a suction port through which the refrigerant is drawn into the first suction space; and
 a discharge port through which the refrigerant is discharged from the second discharge space, and
 the working chamber is formed of the first space, the second space and the communication flow passage, and
 the injection port is provided at a position that allows the refrigerant to be supplied to the second suction space through the injection port.

3. The refrigeration cycle apparatus according to claim 2, wherein
 the step (ii) continues from a point of time when the first discharge space is brought into communication with the second suction space through the communication flow passage until a point of time when a pressure in the second suction space becomes equal to the third pressure,
 the step (iv) continues from a point of time when the communication between the first discharge space and the second suction space through the communication flow passage is interrupted until a point of time when the pressure in the second discharge space becomes equal to the second pressure, and
 in a period during which the shaft makes one rotation, at least a part of a period during which the step (ii) is performed is overlapped with a period during which the step (iv) is performed.
4. The refrigeration cycle apparatus according any one of Claims 1 to 3, wherein the injection flow passage connects the evaporator to the positive displacement fluid machine so that the refrigerant that has flowed

out of the evaporator is supplied to the positive displacement fluid machine as the refrigerant having the third pressure.

5. The refrigeration cycle apparatus according to claim 4, further comprising:

a gas-liquid separator for separating the refrigerant discharged from the positive displacement fluid machine into a gas refrigerant and a liquid refrigerant;
 a flow passage connecting the gas-liquid separator to the compressor so that the gas refrigerant separated out in the gas-liquid separator is supplied to the compressor; and
 a flow passage connecting the gas-liquid separator to the evaporator so that the liquid refrigerant separated out in the gas-liquid separator is supplied to the evaporator.

6. The refrigeration cycle apparatus according to claim 5, further comprising a decompression valve provided on the flow passage connecting the gas-liquid separator to the evaporator.

7. The refrigeration cycle apparatus according to any one of Claims 1 to 3, further comprising:

a flow passage connecting the radiator to the positive displacement fluid machine so that the refrigerant that has flowed out of the radiator is supplied to the positive displacement fluid machine;
 a branch flow passage having an upstream end connected to the flow passage between the radiator and the positive displacement fluid machine;
 a decompression valve provided on the branch flow passage; and
 a second evaporator to which a downstream end of the branch flow passage is connected, wherein the injection flow passage connects the second evaporator to the positive displacement fluid machine so that the refrigerant that has flowed out of the second evaporator is supplied to the positive displacement fluid machine as the refrigerant having the third pressure.

8. The refrigeration cycle apparatus according to claim 7, wherein
 assuming that the evaporator for heating the refrigerant discharged from the positive displacement fluid machine is a first evaporator,
 the refrigeration cycle apparatus further comprises a flow passage, the flow passage connecting the first evaporator to the compressor so that the refrigerant heated in the first evaporator is supplied to the compressor, and

the first evaporator and the second evaporator are disposed respectively on an upstream and a downstream of a flow passage for a heat medium so that the heat medium that has heated the refrigerant in the first evaporator flows into the second evaporator. 5

9. The refrigeration cycle apparatus according to any one of Claims 1 to 8, wherein the refrigerant to be supplied to the positive displacement fluid machine through the injection flow passage is a gas refrigerant. 10
10. The refrigeration cycle apparatus according to any one of Claims 1 to 9, wherein the refrigerant is carbon dioxide. 15
11. A hot water supply appliance comprising the refrigeration cycle apparatus according to any one of Claims 1 to 10. 20
12. A hot water heater comprising the refrigeration cycle apparatus according to any one of Claims 1 to 10. 25

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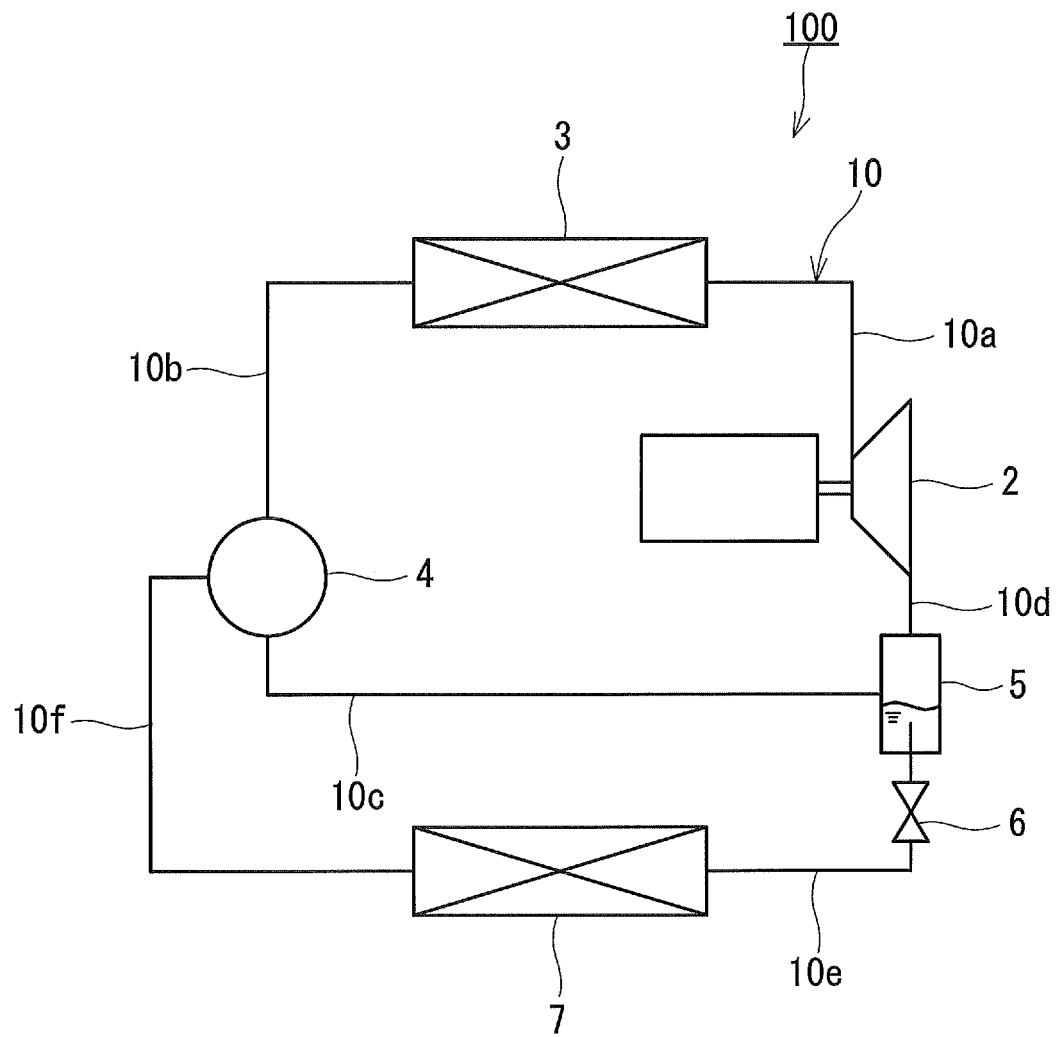


FIG.1

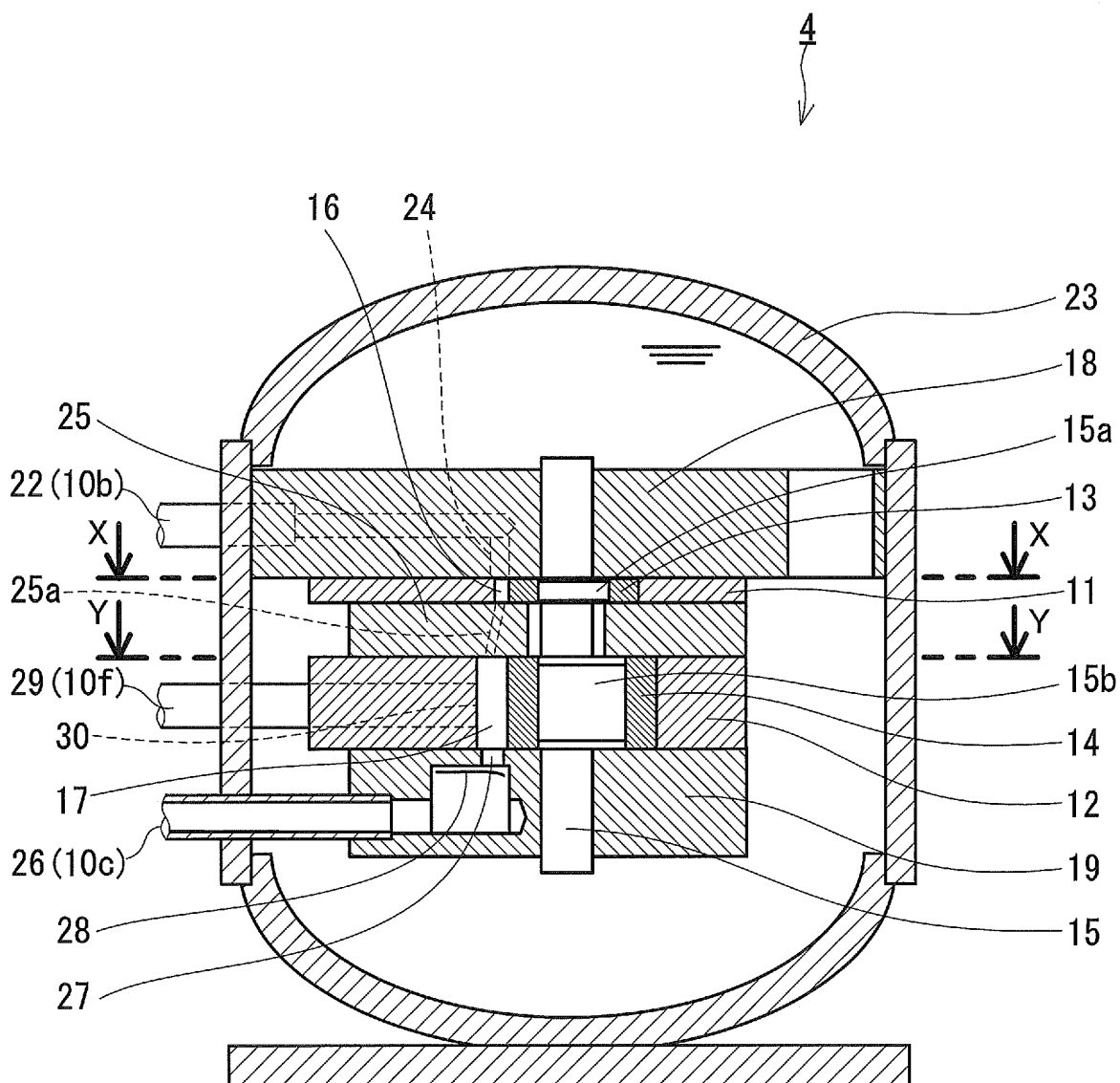


FIG.2

FIG.3A

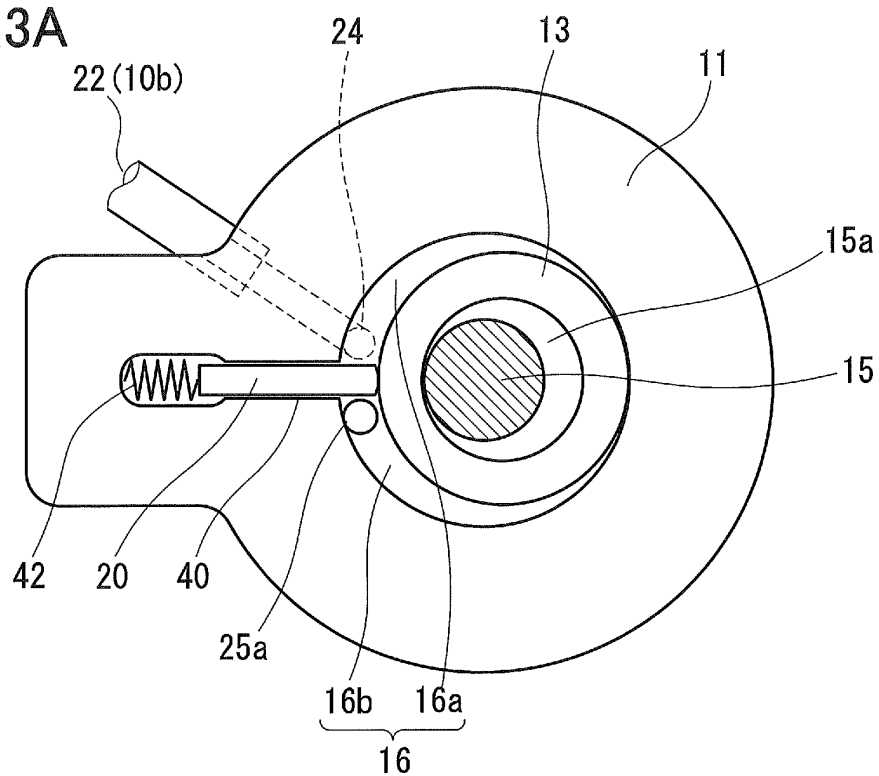
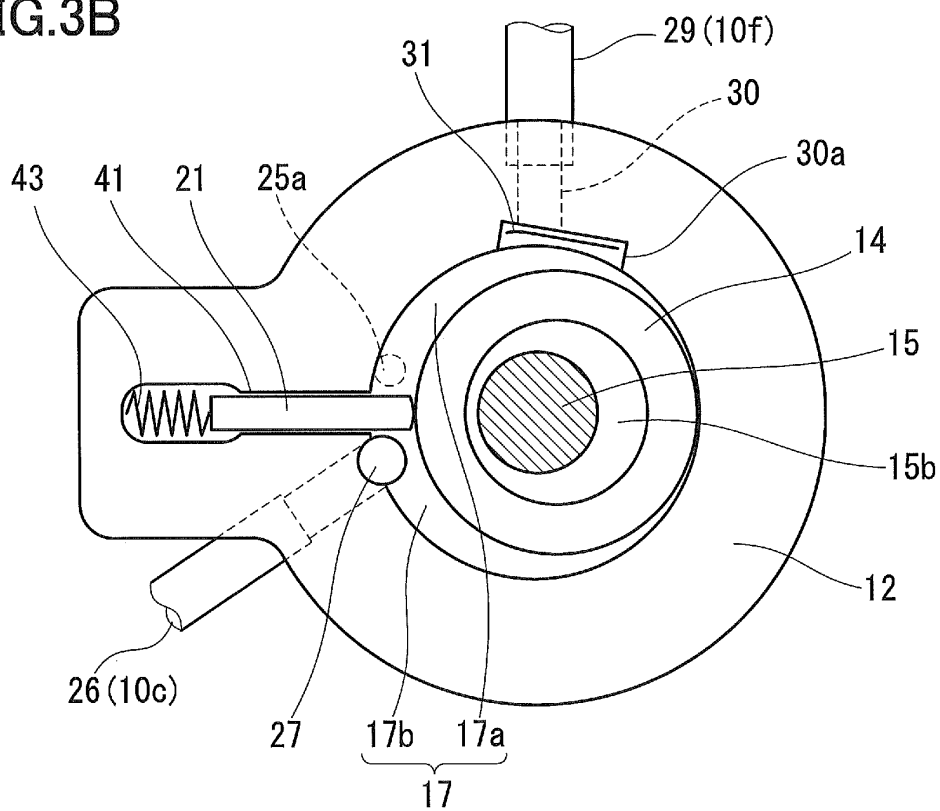
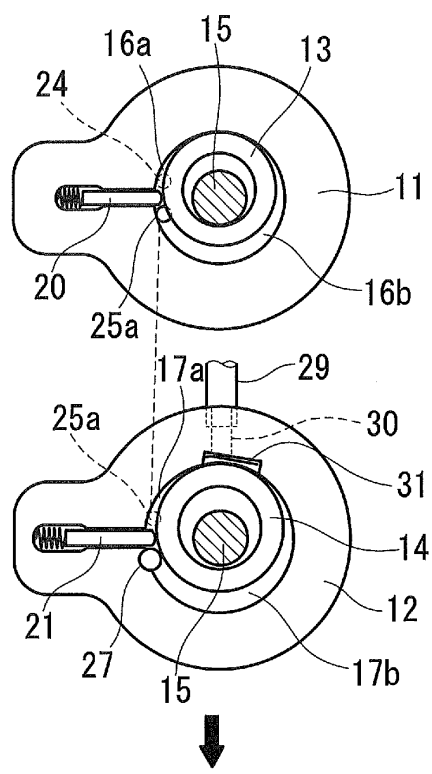
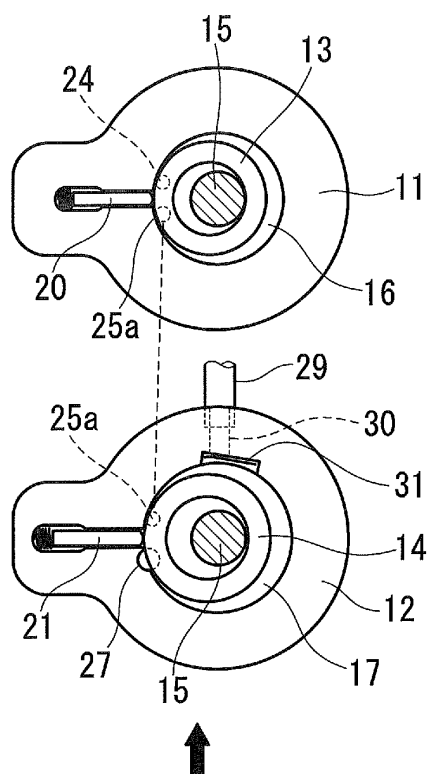


FIG.3B



0deg, 360deg, 720deg, 1080deg

90deg, 450deg, 810deg



270deg, 630deg, 990deg

180deg, 540deg, 900deg

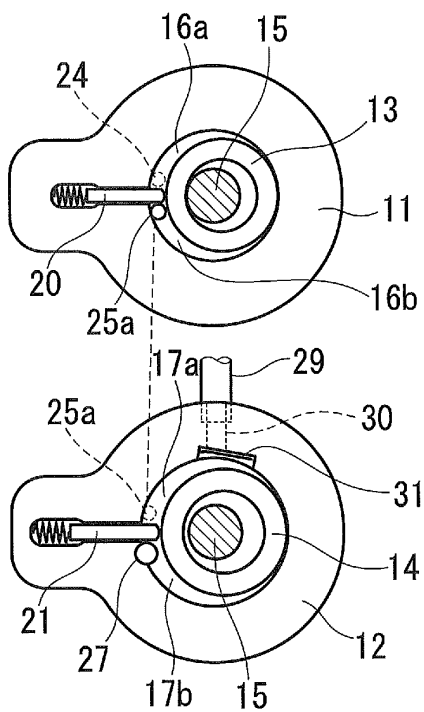
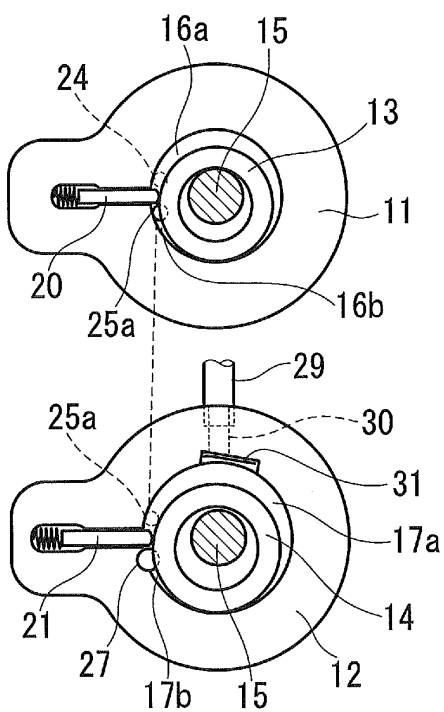


FIG.4

FIG.5

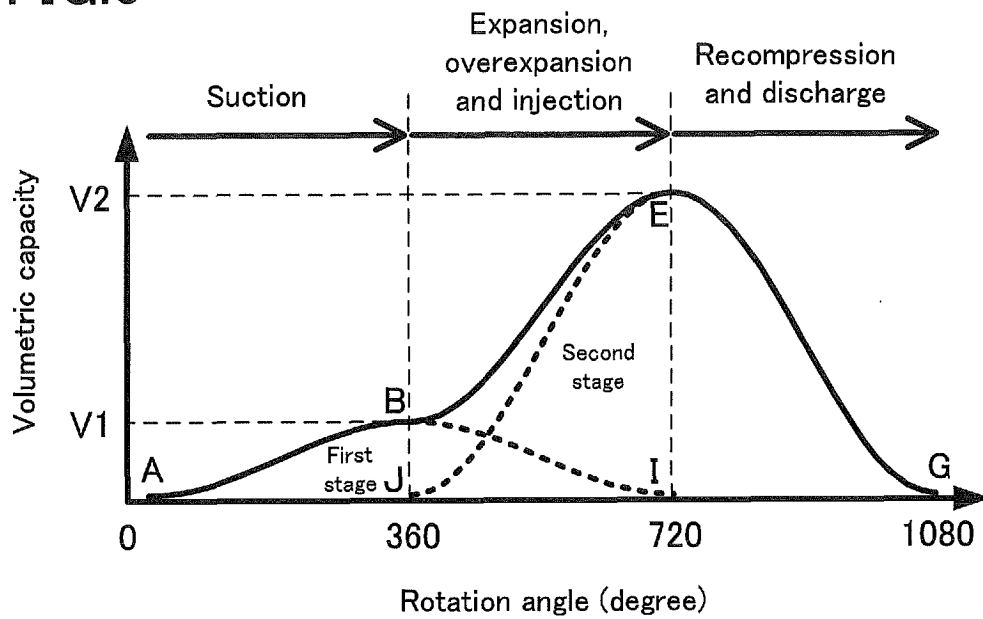
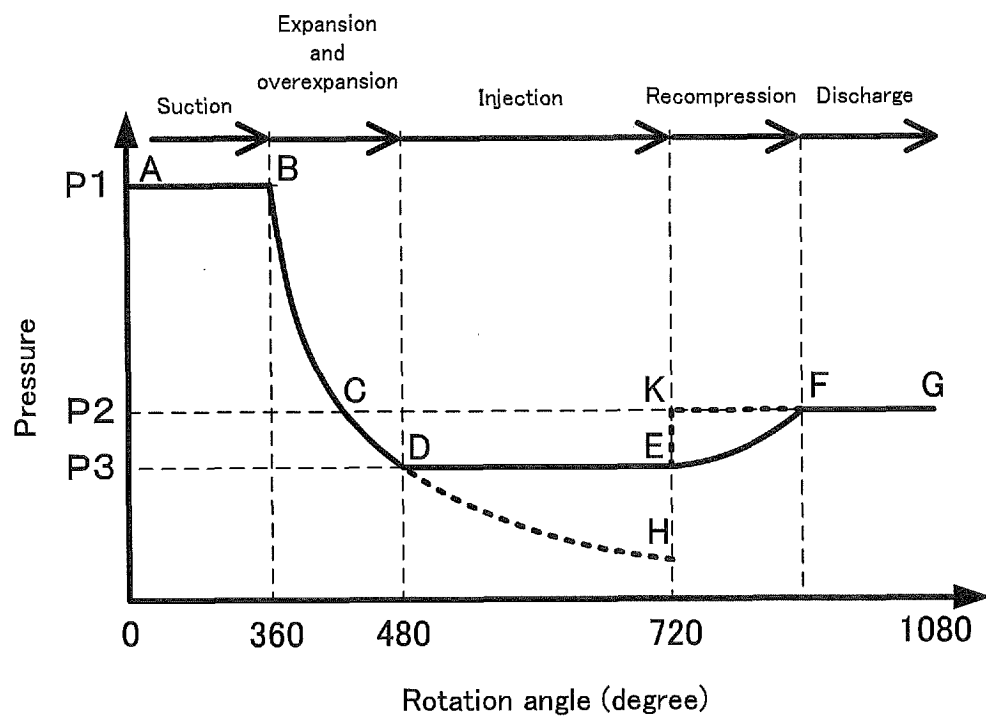


FIG.6



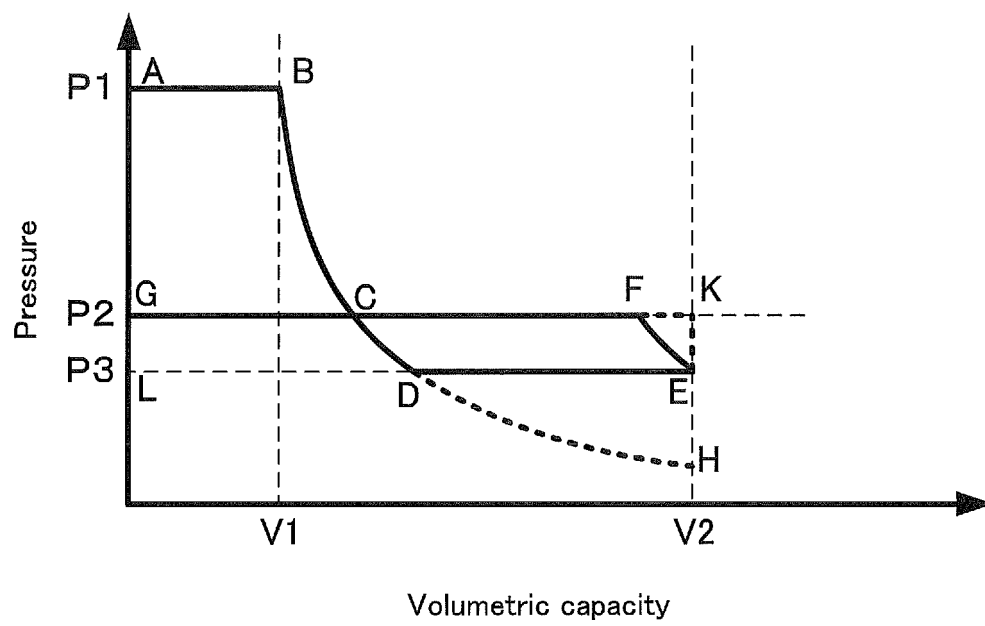


FIG.7

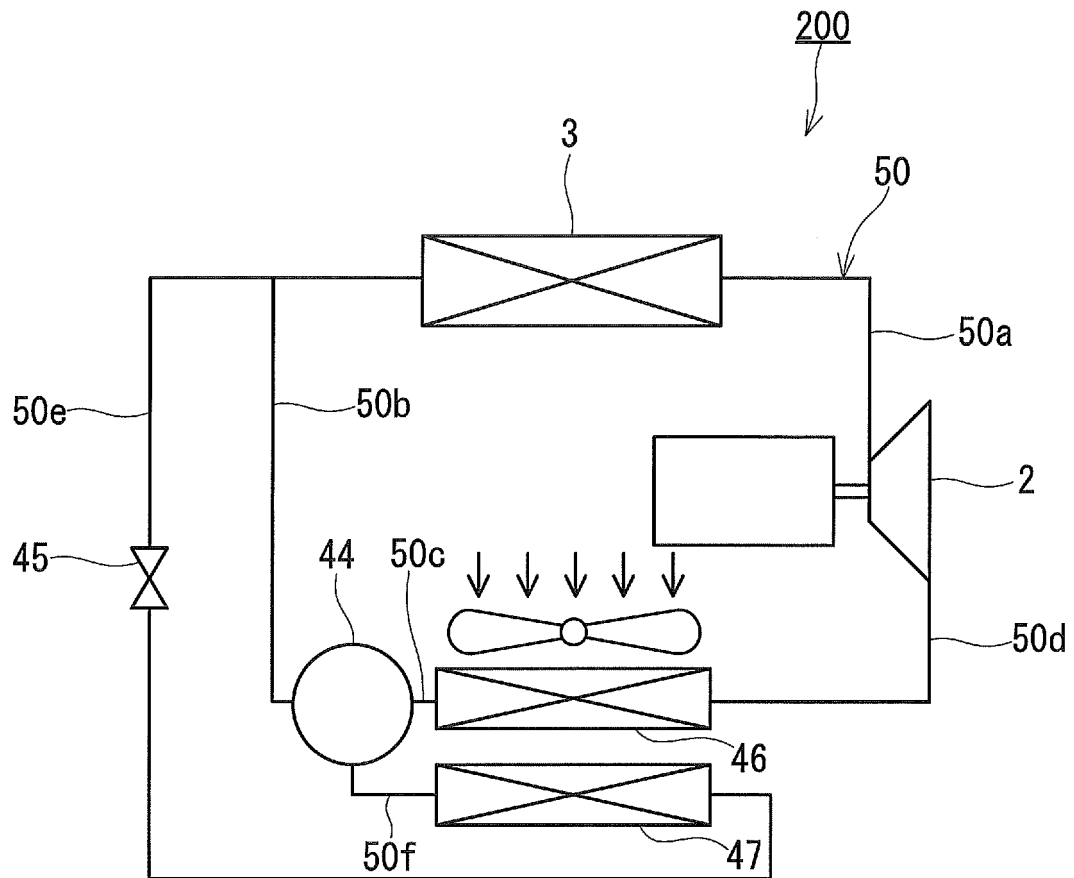


FIG.8

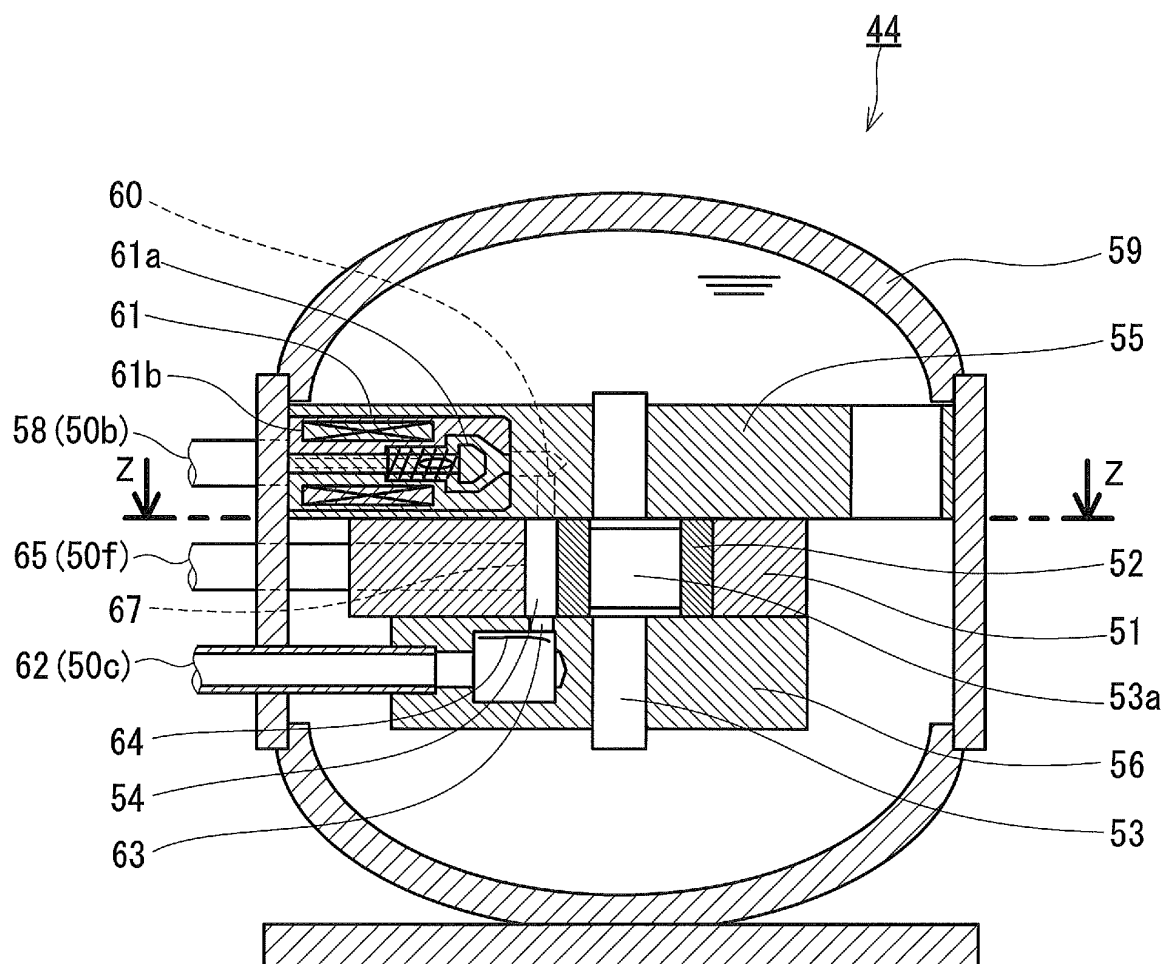


FIG.9

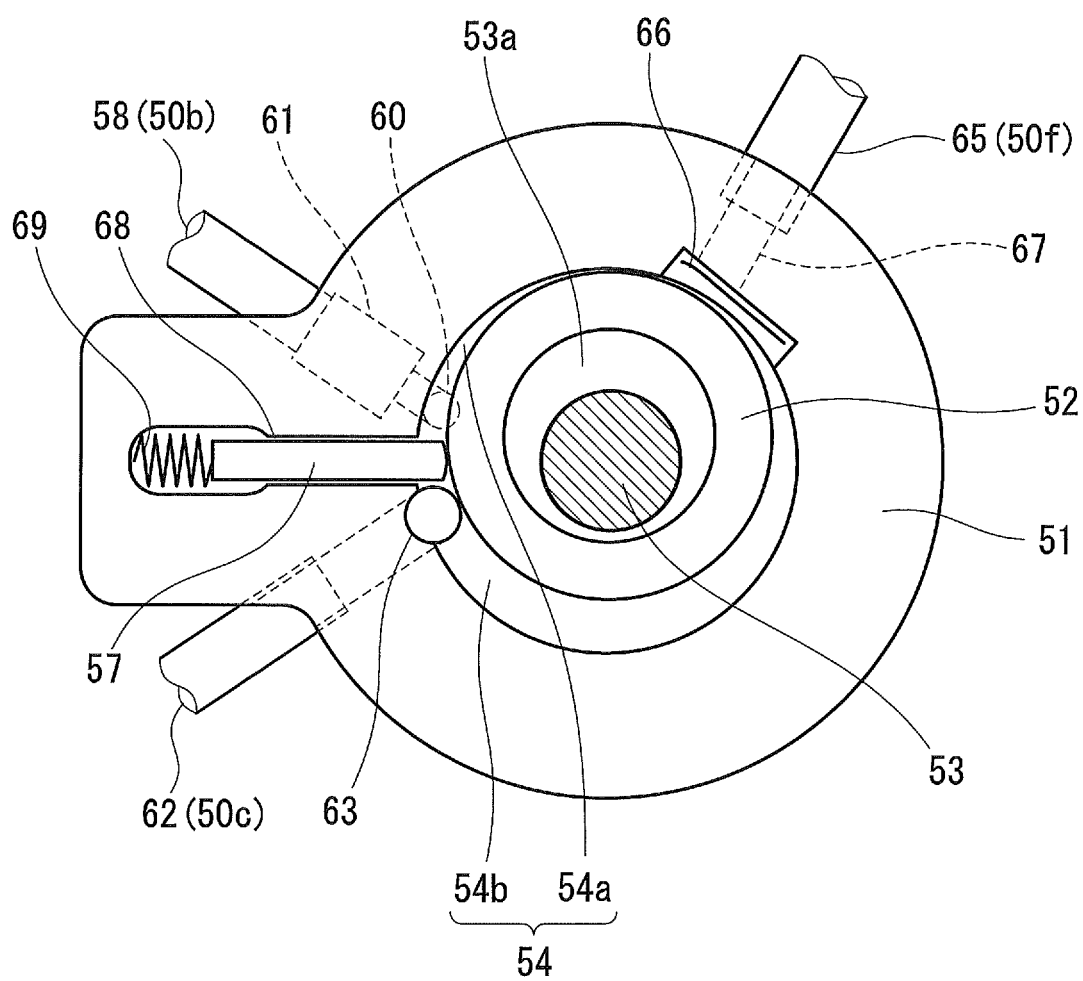


FIG. 10

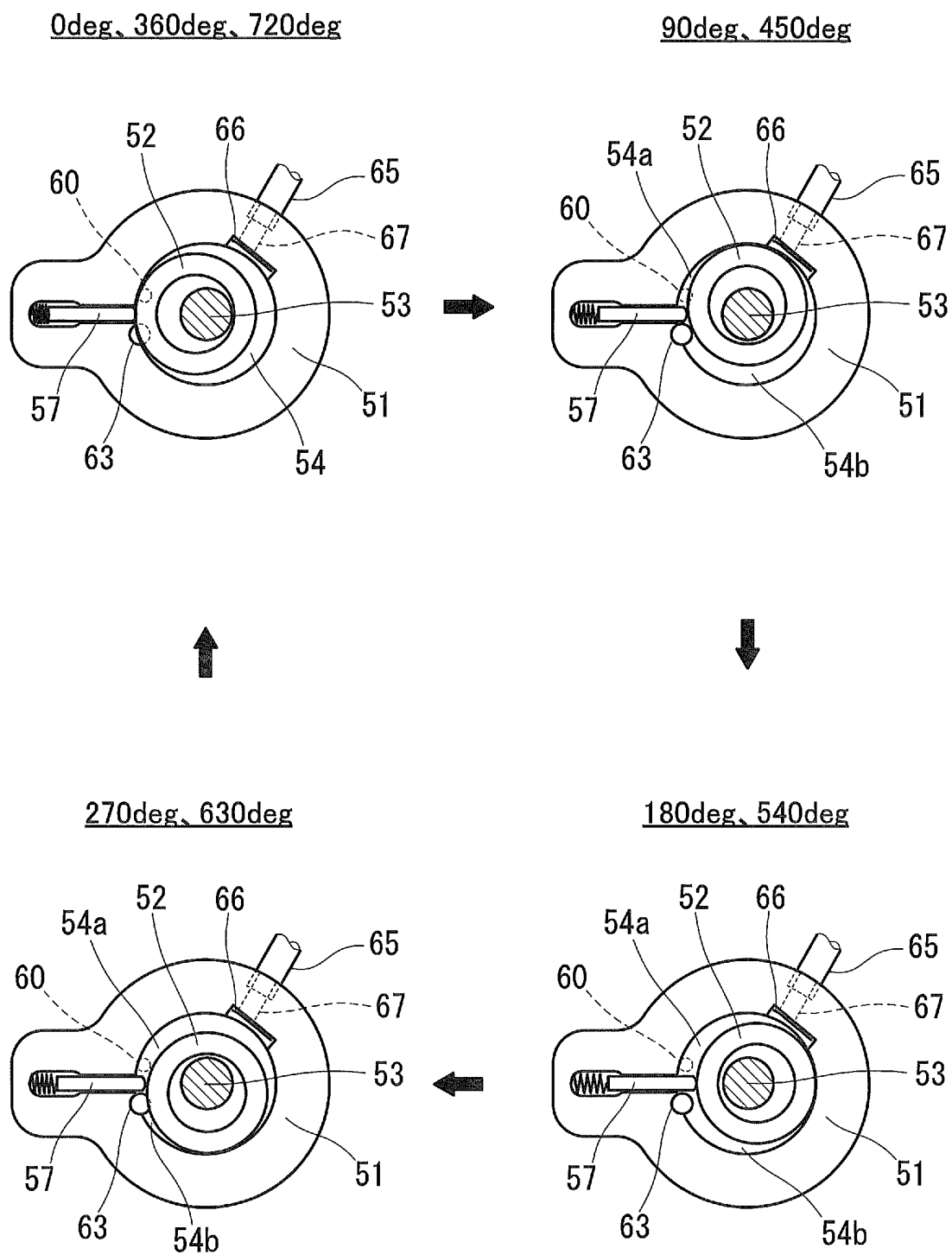


FIG.11

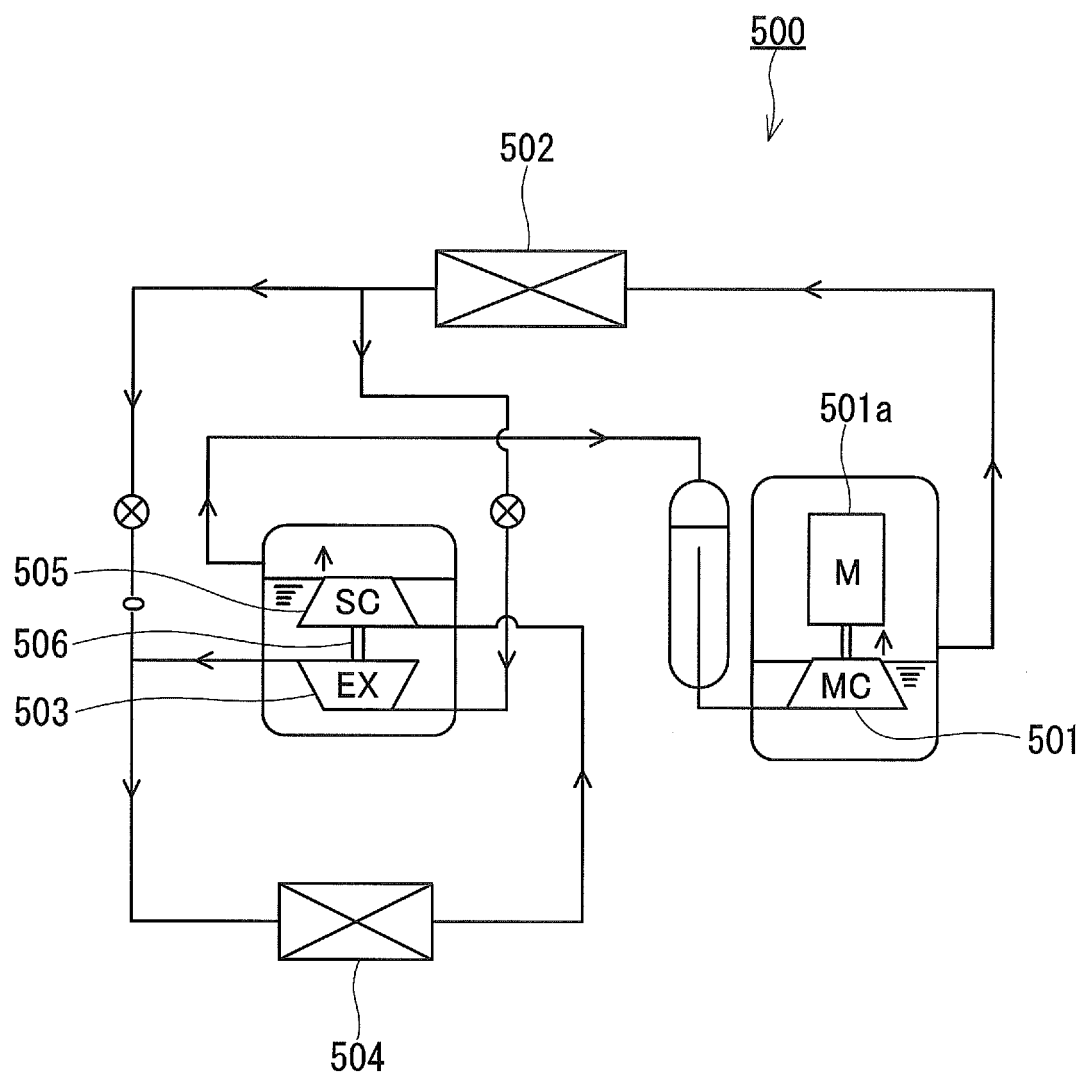


FIG.12

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2011/003536

A. CLASSIFICATION OF SUBJECT MATTER

F25B1/00(2006.01)i, F01C1/356(2006.01)i, F01C13/04(2006.01)i, F25B5/04(2006.01)i, F25B11/02(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)

F25B1/00, F01C1/356, F01C13/04, F25B5/04, F25B11/02

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	1996-2011
Kokai Jitsuyo Shinan Koho	1971-2011	Toroku Jitsuyo Shinan Koho	1994-2011

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2004-251558 A (Matsushita Electric Industrial Co., Ltd.), 09 September 2004 (09.09.2004), paragraphs [0019] to [0037]; fig. 1 (Family: none)	1-12
A	JP 2005-300031 A (Matsushita Electric Industrial Co., Ltd.), 27 October 2005 (27.10.2005), paragraphs [0040] to [0059]; fig. 1 to 3 (Family: none)	1-12
A	JP 2006-308166 A (Mitsubishi Electric Corp.), 09 November 2006 (09.11.2006), paragraphs [0060] to [0077]; fig. 14 to 15 (Family: none)	1-12

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

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Date of the actual completion of the international search
15 September, 2011 (15.09.11)

Date of mailing of the international search report
27 September, 2011 (27.09.11)

Name and mailing address of the ISA/
Japanese Patent Office

Authorized officer

Facsimile No.

Telephone No.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2011/003536

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2010-116927 A (Denso Corp.), 27 May 2010 (27.05.2010), paragraphs [0124] to [0137]; fig. 20 to 22 & US 2009/0232665 A1 & DE 102009012158 A & CN 101532513 A & SG 155861 A	7, 8

Form PCT/ISA/210 (continuation of second sheet) (July 2009)

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2004325019 A [0006]
- JP 2006046257 A [0006]