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(54) FLUID MACHINE AND REFRIGERATION CYCLE DEVICE

(57) A fluid machine 110 includes a power recovery mechanism 105 for recovering power from a working fluid, a sub-compressor 102 driven by the recovered power, a shaft 12 coupling the power recovery mechanism 105 and the sub-compressor 102 to each other so that the recovered power is transmitted from the power recovery mechanism 105 to the sub-compressor 102. The power recovery mechanism 105 is provided with a first suction port 26 and a second suction port 27 that open and close, as the first piston 21 rotates, so that the refrigerant flows into the high pressure-side working chamber 23a. The second the suction port 27 is provided at a position facing the first suction port 26 in the axis direction of the shaft 12.

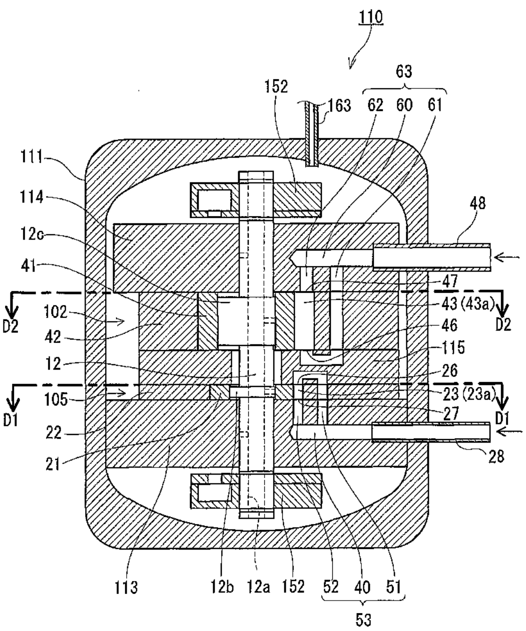

FIG.2A

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Description

TECHNICAL FIELD

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

BACKGROUND ART

[0002] Generally, a refrigerant circuit for a refrigeration cycle apparatus has a configuration in which a compressor, a heat radiator, an expansion valve and an evaporator are connected in this order. The refrigerant undergoes a pressure change from high pressure to low pressure at the expansion valve while being expanded, and releases its internal energy at that time. The internal energy to be released increases as the pressure difference between the low-pressure side (evaporator side) and the high-pressure side (heat radiator side) in the refrigerant circuit increases, thus decreasing the energy efficiency of the refrigeration cycle. In view of such a problem, various techniques for recovering the internal energy of the refrigerant have been proposed.

[0003] Fig. 8 is a configuration diagram showing a conventional refrigeration cycle apparatus 501 disclosed in JP 2004-324595 A and WO 2008/050654 A. The refrigeration cycle apparatus 501 includes a refrigerant circuit formed by connecting a heat radiator 502, a power recovery means 503 (expander), an evaporator 504, a positive displacement blower 505 (sub-compressor) and a main compressor 506 in this order. A fluid machine 507 includes the power recovery means 503, the positive displacement blower 505, a shaft 508 and a closed casing 509 that accommodates these. The power recovery means 503 and the positive displacement blower 505 are coupled to each other by the shaft 508 so that the power recovered by the power recovery means 503 is transmitted to the positive displacement blower 505. Part of the internal energy released from the refrigerant at the power recovery means 503 is converted into a torque on the shaft 508 and transmitted to the positive displacement blower 505 to be used as power for driving the positive displacement blower 505. The positive displacement blower 505 preliminarily increases the pressure of the refrigerant before being drawn into the main compressor 506.

[0004] JP 2004-324595 A describes the startup (self-starting) of the fluid machine 507 as follows. After the main compressor 506 is started, a negative pressure is first generated in a discharge pipe of the positive displacement blower 505. Then, a torque for rotating the shaft 508 is generated. Next, a positive pressure is generated in a suction pipe of the power recovery means 503. Thus, the power recovery means 503 is rotated.

[0005] However, different from the main compressor 506 that receives its driving force for startup from a motor, the fluid machine 507 receives its driving force for startup only from the negative pressure in the discharge pipe of the positive displacement blower 505 or the positive pressure in the suction pipe of the power recovery means 503. Therefore, there is a possibility of failing to ensure sufficient driving force for startup.

[0006] A specific example of the fluid machine 507 is disclosed in WO 2008/050654 A. Fig. 9 is a sectional view showing a power recovery means of the fluid machine disclosed in WO 2008/050654 A. The power recovery means 503 includes a cylinder 510, a piston 513 and a vane 511. The refrigerant flows into a working chamber 515 through a suction pipe 514, and flows out to the outside of the power recovery means 503 through a discharge pipe 516, as the shaft 508 rotates. According to the power recovery means 503, in the case where the piston 513 is stopped while blocking the suction port 517, the piston 513 is to be pushed toward an end plate (which is a member closing the cylinder 510) by the positive pressure generated in the suction pipe 514 at the next startup. That is, the friction between the piston 513 and the end plate at the time of startup is relatively large. Therefore, extra torque for rotating the piston 513 is required. This is not preferable for starting the fluid machine 507 smoothly.

CITATION LIST

Patent Literature

[0007]

Patent Literature 1: JP 2004-324595 A
Patent Literature 2: WO 2008/050654 A

SUMMARY OF INVENTION

Technical Problem

[0008] The present invention has been devised in view of the problems described above, and an object thereof is to provide a fluid machine that can be started smoothly. Furthermore, the present invention provides a refrigeration cycle apparatus using the fluid machine.

Solution to Problem

[0009] That is, the present invention provides a fluid machine that includes: a power recovery mechanism for recovering power from a working fluid; a sub-compressor that is driven by the recovered power; and a shaft coupling the power recovery mechanism and the sub-compressor to each other so that the recovered power is transmitted from the power recovery mechanism to the sub-compressor. The power recovery mechanism includes: (a1) a first closing member; (b1) a second closing member facing the first closing member; (c1) a cylinder surrounding a part of the shaft in the circumferential direction and having both ends closed by the first closing member and the second closing member; (d1) a piston that is mounted on the shaft inside the cylinder and that forms a working chamber between its outer circumferential surface and the inner circumferential surface of the cylinder; (e1) a partition member partitioning the working chamber into the high pressure-side working chamber and the low pressure-side working chamber; (f1) a first suction port provided in the first closing member so as to open and close, as the piston rotates, so that the working fluid flows into the high pressure-side working chamber; and (g1) a second suction port provided in the second closing member at a position facing the first suction port in the axis direction of the shaft so as to open and close, as the piston rotates, so that the working fluid flows into the high pressure-side working chamber.

Advantageous Effects of Invention

[0010] According to the above-mentioned present invention, the power recovery mechanism includes the first suction port, and the second suction port provided at a position facing the first suction port. Therefore, the positive pressure generated in the suction pipe acts on both of the upper surface and lower surface of the piston through the first and second suction ports. That is, the forces pressing the piston toward the closing members are counteracted. Accordingly, the present invention can provide a fluid machine that can be started smoothly. Depending on the case, the need for an auxiliary driving device such as a motor even can be eliminated.

BRIEF DESCRIPTION OF DRAWINGS

[0011]

Fig. 1 is a configuration diagram showing a refrigeration cycle apparatus according to one embodiment of the present invention.

Fig. 2A is a vertical sectional view of a fluid machine shown in Fig. 1.

Fig. 2B is a vertical sectional view of the fluid machine cut at a different angle from that of Fig. 2A.

Fig. 3 is an enlarged sectional view showing a suction path provided in a power recovery mechanism.

Fig. 4 is a horizontal sectional view taken along the line D1-D1 in the fluid machine shown in Fig. 2.

Fig. 5 is a view illustrating the principle of operation of the power recovery mechanism.

Fig. 6 is a horizontal sectional view taken along the line D2-D2 in the fluid machine shown in Fig. 2.

Fig. 7 is a view illustrating the principle of operation of a sub-compressor.

Fig. 8 is a configuration diagram showing a conventional refrigeration cycle apparatus.

Fig. 9 is a horizontal sectional view showing a conventional expander.

DESCRIPTION OF EMBODIMENTS

[0012] Hereinafter, the embodiments of the present invention are described with reference to the drawings. However, the present invention is not limited to the following embodiments.

[0013] In this embodiment, a fluid pressure motor that is generally used only for an incompressible working fluid in view of the characteristics of the fluid pressure motor is used as the power recovery mechanism and the sub-compressor of a refrigeration cycle apparatus that uses a compressible refrigerant as a working fluid. This allows the operational energy efficiency of the refrigeration cycle apparatus to be enhanced.

[0014] In this description, a "fluid pressure motor" means a motor that is rotated by the pressure difference between the pressure of the working fluid (typically, a refrigerant) on the suction side and the pressure of the working fluid on the discharge side, and that starts a discharge process without allowing the volume change of the drawn working fluid. The pressure of the working fluid on the suction side means the pressure of the working fluid to be drawn in the fluid pressure motor. The pressure of the working fluid on the discharge side means the pressure of the working fluid discharged from the fluid pressure motor. More specifically, the fluid pressure motor is a motor that does not allow the volume change of the working fluid until the discharge process is started. After the discharge process is started, in other words, after the inside of the fluid pressure motor is brought into communication with a discharge path, the pressure inside the fluid pressure motor is reduced or raised, so that the working fluid is expanded or compressed.

[0015] The technique disclosed in this description is effective particularly for a refrigeration cycle apparatus using a refrigerant that reaches a supercritical state on the high-pressure side, such as carbon dioxide. In the case of using such a refrigerant that reaches a supercritical state on the high-pressure side, the refrigerant exhibits an extremely small expansion coefficient, which is represented by the ratio of the density of the refrigerant at the outlet of a radiator to the density of the refrigerant at the inlet of an evaporator. The energy to be released when the refrigerant of this type is expanded is composed mostly of the internal energy released due to the pressure drop. The internal energy released due to the increase of the specific volume is small, and it can be smaller than the overexpansion loss in some cases. Accordingly, it can be more advantageous, in terms of energy recovery efficiency, to employ a configuration that can prevent the occurrence of overexpansion loss while intentionally abandoning the recovery of the internal energy released due to the increase of the specific volume than to employ a configuration that tries to recover the full amount of the internal energy to be released.

[0016] Further, the fluid pressure motor used as a power recovery mechanism and sub-compressor performs a suction process for drawing the refrigerant and a discharge process for discharging the drawn refrigerant substantially continuously, in this embodiment. Specifically, there is substantially no period during which a suction port and a discharge port are closed simultaneously. In other words, at least one of the suction port and the discharge port is opened substantially over the entire period.

[0017] For this reason, the occurrence of pressure pulsation can be suppressed. Accordingly, problems are unlikely to emerge, such as damage to components of the refrigeration cycle apparatus (e.g., a suction pipe constituting the suction path), rotational instability of the fluid pressure motor due to torque variation, and generation of vibration and noise. A phrase "there is substantially no period during which a suction port and a discharge port are closed simultaneously" means a concept that includes a situation where the suction port and the discharge port are closed simultaneously but momentarily within a range that does not cause any torque variation in the fluid pressure motor.

[0018] Furthermore, the refrigerant circuit is configured so that at least part of the refrigerant discharged from the power recovery mechanism is in the vapor phase as follows. When part of the refrigerant is in the vapor phase, the refrigerant is allowed to be compressible. This compressibility reduces the water hammer pressure that results from variation in discharge flow rate due to intermittent discharge of the refrigerant. This enables the power recovery mechanism to be started smoothly and reduces vibration and noise as well.

[0019] Hereinafter, the refrigeration cycle apparatus according to this embodiment is described in detail with reference to Figs. 1 to 7.

[0020] As shown in Fig. 1, a refrigeration cycle apparatus 101 includes a refrigerant circuit 109 having a main compressor 103, a heat radiator 104, a power recovery mechanism 105, an evaporator 106, and a sub-compressor 102. The refrigerant circuit 109 is filled with a refrigerant such as carbon dioxide and hydrofluorocarbon to serve as a working fluid. In the case of using a refrigerant that reaches a supercritical state on the high-pressure side of the refrigeration cycle such as carbon dioxide, the present invention exhibits particularly excellent effects.

[0021] The main compressor 103 includes a compression mechanism 103a (compressor main body), a motor 108 connected to the compression mechanism 103a, and a closed casing 160 that accommodates the compression mechanism 103a and motor 108. The compression mechanism 103a is driven by the motor 108. The compression mechanism 103a compresses the refrigerant circulating in the refrigerant circuit 109 to high temperature and high pressure. For the main compressor 103, a positive displacement compressor such as a scroll compressor and a rotary compressor can be used.

[0022] The heat radiator 104 is connected to the main compressor 103. The heat radiator 104 causes the refrigerant that has been compressed by the main compressor 103 to release the heat. In other words, the heat radiator 104 cools the refrigerant. The refrigerant is cooled by the heat radiator 104 to intermediate temperature and high pressure.

[0023] The power recovery mechanism 105 is connected to the heat radiator 104. The power recovery mechanism 105 is composed of a fluid pressure motor. Specifically, the power recovery mechanism 105 performs a process of drawing the refrigerant flowing from the heat radiator 104 and a process of discharging the drawn refrigerant, substantially continuously. That is, the power recovery mechanism 105 draws the refrigerant that has changed to intermediate temperature and high pressure by the heat radiator 104, and discharges it to the evaporator 106 side substantially without allowing the volume change of the refrigerant. The main compressor 103 keeps the pressure on the heat radiator 104 side relatively high and the pressure on the evaporator 106 side relatively low with the power recovery mechanism 105 interposed therebetween. Accordingly, the refrigerant drawn into the power recovery mechanism 105 is expanded when being discharged from the power recovery mechanism 105, and the pressure thereof is lowered.

[0024] The evaporator 106 is connected to the power recovery mechanism 105. The refrigerant flowing from the power recovery mechanism 105 is heated and evaporated in the evaporator 106.

[0025] The sub-compressor 102 is arranged between the evaporator 106 and the main compressor 103 in the refrigerant circuit 109. The sub-compressor 102 is coupled to the power recovery mechanism 105 by a shaft 12. The sub-compressor 102 is driven by the power recovered by the power recovery mechanism 105. The sub-compressor 102 is composed of a fluid pressure motor in the same manner as the power recovery mechanism 105. The sub-compressor 102 performs a process of drawing the refrigerant flowing from the evaporator 106 and a process of discharging the drawn refrigerant to the main compressor 103 side, substantially continuously. The sub-compressor 102 draws the refrigerant flowing from the evaporator 106, and discharges it to the main compressor 103 side substantially without allowing the volume change of the refrigerant. The refrigerant flowing from the evaporator 106 is preliminarily compressed by being discharged from the sub-compressor 102. The preliminarily compressed refrigerant is further compressed to high temperature and high pressure again by the main compressor 103.

[0026] The refrigeration cycle apparatus 101 further includes a bypass circuit 107a. The bypass circuit 107a bypasses the sub-compressor 102 and connects the outlet of the evaporator 106 to the inlet of the main compressor 103. The bypass circuit 107a is provided with a bypass valve 107b. In normal operation, the bypass valve 107b is closed so that the supercharge effect (pre-compression effect) by the sub-compressor 102 can be obtained. At the time of starting the refrigeration cycle apparatus 101, the bypass valve 107b is opened. It is possible to cause a relatively large pressure difference between the inlet and outlet of the power recovery mechanism 105 by opening the bypass valve 107b. It makes it easy to start the refrigeration cycle apparatus 101 smoothly.

[0027] As shown in Fig. 2A, the power recovery mechanism 105 (first fluid mechanism) and the sub-compressor 102 (second fluid mechanism) constitute a single fluid machine 110. The fluid machine 110 has a closed casing 111 filled with a refrigeration oil. The power recovery mechanism 105 and the sub-compressor 102 are arranged in this closed casing 111. This allows a reduction in size of the refrigeration cycle apparatus 101.

[0028] The fluid machine 110 is provided with balance weights 152. Specifically, the balance weights 152 each are mounted on both ends of the shaft 12. The balance weight 152 has a function of reducing the unevenness in weight around the central axis of the shaft 12. One end of an oil equalizing pipe 163 is connected to the closed casing 111. The other end of the oil equalizing pipe 163 is connected to the closed casing 160 of the main compressor 103. In this embodiment, the fluid machine 110 does not have a motor.

<Configuration of power recovery mechanism 105>

[0029] The power recovery mechanism 105 is arranged at the lower part of the closed casing 111. The present embodiment describes an example in which the power recovery mechanism 105 is composed of a rotary fluid pressure motor. However, the power recovery mechanism 105 is not limited to the rotary fluid pressure motor. The power recovery mechanism 105 may be composed of an expander having a specific volume ratio, such as a rotary expander and scroll expander.

[0030] The power recovery mechanism 105 includes a first closing member 115 and a second closing member 113. The first closing member 115 and the second closing member 113 face each other. A first cylinder 22 is arranged between the first closing member 115 and the second closing member 113. The first cylinder 22 has an internal space of substantially cylindrical shape. The internal space of the first cylinder 22 is closed by the first closing member 115 and the second closing member 113. The first closing member 115 and the second closing member 113 are positioned respectively above and below the first cylinder 22.

[0031] The shaft 12 extends through the first cylinder 22 in the axis direction of the first cylinder 22. The first cylinder 22 surrounds a part of the shaft 12 in the circumferential direction. The shaft 12 is arranged on the central axis of the first cylinder 22. The shaft 12 is supported by the second closing member 113 and a third closing member 114 to be described later. The shaft 12 is formed with an oil supply hole 12a extending through the shaft 12 in the axis direction. The refrigeration oil in the closed casing 111 is supplied to bearings, gaps, etc. in the sub-compressor 102 and the power recovery mechanism 105 through the oil supply hole 12a. The shaft 12 may be composed of a single component, or may be composed of a plurality of components.

[0032] A first piston 21 is arranged in the internal space of substantially cylindrical shape that is defined by the inner circumferential surface of the first cylinder 22, the first closing member 115 and the second closing member 113. The first piston 21 is mounted on the shaft 12 eccentrically with respect to the central axis of the shaft 12. Specifically, the shaft 12 is provided with an eccentric portion 12b having a central axis different from that of the shaft 12. The first piston 21 having a tubular shape is fitted around the eccentric portion 12b. Therefore, the first piston 21 is eccentric with respect to the central axis of the first cylinder 22. Accordingly, the first piston 21 eccentrically rotates as the shaft 12 rotates.

[0033] A first working chamber 23 is defined by the outer circumferential surface of the first piston 21, the inner circumferential surface of the first cylinder 22, the first closing member 115, and the second closing member 113, in the first cylinder 22 (see also Fig. 4). The volume of the first working chamber 23 remains substantially unchanged even if the first piston 21 rotates with the shaft 12.

[0034] As shown in Fig. 4, the first cylinder 22 is formed with a linear groove 22a opening into the first working chamber 23. A first partition member 24 having a plate shape is slidably inserted into the linear groove 22a. A biasing means 25 is arranged between the first partition member 24 and the bottom of the linear groove 22a. The first partition member 24 is pressed into contact with the outer circumferential surface of the first piston 21 by the biasing means 25. Thus, the first working chamber 23 is partitioned into two spaces. Specifically, the first working chamber 23 is partitioned into a suction working chamber 23a on the high-pressure side and a discharge working chamber 23b on the low-pressure side.

[0035] The biasing means 25 can be composed, for example, of a spring. Specifically, the biasing means 25 may be a compression coil spring.

[0036] Further, the biasing means 25 may be a so-called gas spring, or the like. In other words, when the first partition member 24 slides in the direction that reduces the volume of the back space of the first partition member 24, the pressure in the back space may be set higher than the pressure in the first working chamber 23, thereby causing the first partition member 24 to be pressed toward the first piston 21 due to the pressure difference. For example, the back space of the first partition member 24 may be formed as a closed space so that a reaction force is applied to the first partition member 24 when the volume of the back space is reduced as the first partition member 24 moves backward. The biasing means 25 may be composed of a plurality of types of springs, such as a compression coil spring and a gas spring, of course. It should be noted that the pressure in the first working chamber 23 means an average pressure between the pressure in the suction working chamber 23a and the pressure in the discharge working chamber 23b. The back space means a space formed between the rear edge of the first partition member 24 and the bottom of the linear groove 22a.

[0037] As shown in Fig. 2A, the first closing member 115 is provided with a first suction port 26 that opens and closes, as the first piston 21 rotates, so that the refrigerant flows into the suction working chamber 23a. Similarly, the second closing member 113 is provided with a second suction port 27 that opens and closes, as the first piston 21 rotates, so that the refrigerant flows into the suction working chamber 23a. The second suction port 27 is provided at a position facing the first suction port 26 in the axis direction of the shaft 12. That is, the power recovery mechanism 105 is provided with the two suction ports 26 and 27. Even if the first piston 21 is stopped while blocking the suction ports 26 and 27, a positive pressure acts on both of the upper surface and lower surface of the first piston 21 at the next startup. This can prevent the first piston 21 from being pressed strongly toward the closing member 115 or 113, thus enabling the refrigeration cycle apparatus 101 to be started smoothly. Furthermore, the pressure of the refrigerant acts on both of the upper surface and lower surface of the first piston 21 in normal operation as well. Therefore, the friction loss between the first piston 21 and the closing member 115 or 113 can be reduced, which improves the efficiency of the power recovery mechanism 105.

[0038] Specifically, the power recovery mechanism 105 includes a suction path 53 for supplying the refrigerant from the outside of the power recovery mechanism 105 (heat radiator 104) to the suction working chamber 23a through each of the first suction port 26 and second suction port 27. This suction path 53 is composed of a common suction path 40, a first suction path 51 and a second suction path 52. The first suction port 26 is located at the terminal end of the first suction path 51, and the second suction port 27 is located at the terminal end of the second suction path 52. Further, the power recovery mechanism 105 includes a suction pipe 28 for introducing the refrigerant from the outside of the closed casing 111 to the suction path 53.

[0039] The common suction path 40 is formed in the second closing member 113, and is a large path extending from the outer circumferential surface of the second closing member 113 toward the center of the shaft 12. The suction pipe 28 is connected directly to the common suction path 40. The first suction path 51 branches from the common suction path 40 and extends through the first cylinder 22 in the axis direction to reach the first suction port 26 so as to allow the refrigerant to be supplied from the common suction path 40 to the suction working chamber 23a through the first suction port 26. The second suction path 52 branches from the common suction path 40 at a more internal position than the first suction path 51 in the radial direction of the shaft 12 and extends in the axis direction to reach the second suction port 27 so as to allow the refrigerant to be supplied from the common suction path 40 to the suction working chamber 23a through the second suction port 27. According to such a structure, it is possible to provide the two suction ports 26 and 27 without increasing the number of the suction pipe 28.

[0040] More specifically, the first suction path 51 includes a portion formed in the second closing member 113, a portion formed in the first cylinder 22, and a portion formed in the first closing member 115. In the axis direction, the first suction path 51 extends around from below to above the working chamber 23. That is, the first suction path 51 has a hook-shaped cross-sectional profile.

[0041] A configuration in which the common suction path 40 is provided in the first cylinder 22 so that the length of the first suction path 51 should be equal to the length of the second suction path 52 also is conceivable. However, when the volume of the working chamber 23 is small, the thickness of the first cylinder 22 is small as well, and therefore it is impossible to provide the common suction path 40 in the first cylinder 22. In such a case, the configuration of this embodiment is effective. This is also applicable to the below-mentioned discharge path.

[0042] Next, as shown in Fig. 2B, the first closing member 115 is provided with a first discharge port 29 (first flow outlet) that opens and closes, as the first piston 21 rotates, so that the refrigerant flows out from the discharge working chamber 23b. Similarly, the second closing member 113 is provided with a second discharge port 30 (second flow outlet) that opens and closes, as the first piston 21 rotates, so that the refrigerant flows out from the discharge working chamber 23b. The second discharge port 30 is provided at a position facing the first discharge port 29 in the axis direction. That is, the power recovery mechanism 105 includes the two discharge ports 29 and 30. Even if the first piston 21 is stopped while blocking the discharge ports 29 and 30, a negative pressure acts on both of the upper surface and lower surface of the first piston 21 at the next startup. This can prevent the first piston 21 from being pulled strongly toward the closing member 115 or 113, thus making it easy to start the refrigeration cycle apparatus 101 smoothly. Furthermore, the pressure of the refrigerant acts on both of the upper surface and lower surface of the first piston 21 in normal operation as well. Therefore, the friction loss between the first piston 21 and the closing member 115 or 113 can be reduced, which improves the efficiency of the power recovery mechanism 105.

[0043] Specifically, the power recovery mechanism 105 includes a discharge path 58 for introducing the refrigerant from the discharge working chamber 23b to the outside of the power recovery mechanism 105 (to the evaporator 106) through each of the first discharge port 29 and the second discharge port 30. This discharge path 58 is composed of a common discharge path 55, a first discharge path 56 and a second discharge path 57. The first discharge port 29 is located at the starting end of the first discharge path 56, and the second discharge port 30 is located at the starting end of the second discharge path 57. Further, the power recovery mechanism 105 includes a discharge pipe 31 for introducing the refrigerant from the discharge path 58 to the outside of the closed casing 111. When the refrigeration cycle apparatus 101 is being started, a negative pressure is generated in the discharge path 58 by opening the bypass valve 107b and activating the main compressor 103.

[0044] The common discharge path 55 is formed in the second closing member 113, and is a large path extending from the outer circumferential surface of the second closing member 113 toward the center of the shaft 12. The discharge pipe 31 is connected directly to the common discharge path 55. The first discharge path 56 extends from the first discharge port 29 outwardly through the first cylinder 22 in the axis direction to merge with the common discharge path 55 so as to allow the refrigerant to be introduced from the discharge working chamber 23b to the common discharge path 55 through the first discharge port 29. The second discharge path 57 extends from the second discharge port 30 in the axis direction and merges with the common discharge path 55 at a more internal position than the first discharge path 56 in the radial direction of the shaft 12 so as to allow the refrigerant to be introduced from the discharge working chamber 23b to the common discharge path 55 through the second discharge port 30. According to such a structure, it is possible to provide the two discharge ports 29 and 30 without increasing the number of the discharge pipe 31.

[0045] More specifically, the first discharge path 56 includes a portion formed in the first closing member 115, a portion formed in the first cylinder 22, and a portion formed in the second closing member 113 and extends around from above to below the working chamber 23. That is, the first discharge path 56 has a hook-shaped cross-sectional profile.

[0046] As shown in Fig. 4, the suction path 53 opens into the suction working chamber 23a in the area adjacent to the first partition member 24. More specifically, the first suction path 51 and the second suction path 52 that have been described with reference to Fig. 2A each open into the suction working chamber 23a.

[0047] The second suction port 27 is formed in a substantially fan shape that extends in an arc shape from the portion of the suction working chamber 23a adjacent to the first partition member 24 in the direction in which the suction working chamber 23a is enlarged. The second suction port 27 is closed completely by the first piston 21 only when the first piston 21 is located at its top dead center. At least a part of the second suction port 27 is exposed to the suction working chamber 23a over the entire period except for the moment when the first piston 21 is located at its top dead center. Specifically, the second suction port 27 has an outer edge side 27a that is formed in an arc shape along the outer circumferential surface of the first piston 21 located at its top dead center, in plan view. In other words, the outer edge side 27a is formed in an arc shape having substantially the same radius as the outer circumferential surface of the first piston 21. It should be noted that the "outer edge side" herein means an edge side located outward of the shaft 5 in the radial direction. The "top dead center" means a location of the piston at which the vane is pushed into the deepest point of the vane groove.

[0048] Though not shown in Fig. 4, the first suction port 26 has the same opening shape as the second suction port 27. Furthermore, the first suction port 26 has an opening area equal to the opening area of the second suction port 27. With such a configuration, the force acting on the lower surface of the first piston 21 can be counteracted effectively by the force acting on the upper surface thereof.

[0049] The pressure of the refrigerant flowing into the suction working chamber 23a through the first suction port 26 is substantially equal to the pressure of the refrigerant flowing into the suction working chamber 23a through the second suction port 27. When the first suction port 26 and the second suction port 27 completely overlap each other in the axis direction, the overlapping area of the first piston 21 and the first suction port 26 is equal to the overlapping area of the first piston 21 and the second suction port 27. Accordingly, the force acting on the upper surface of the first piston 21 is equal to the force acting on the lower surface thereof (force = pressure × area). That is, the effect to counteract the forces acting on the first piston 21 in the thickness direction (axis direction) can be enhanced most.

[0050] It should be noted that since the first suction path 51 is longer than the second suction path 52, when the cross-sectional area of the first suction path 51 is equal to that of the second suction path 52, the pressure loss in the first suction path 51 exceeds the pressure loss in the second suction path 52. Therefore, even if the first suction port 26 and the second suction port 27 completely overlap each other in the axis direction, the force acting on the upper surface of the first piston 21 is not strictly equal to the force acting on the lower surface thereof due to the influence of the difference in pressure loss.

[0051] As shown in Fig. 3, the first suction path 51 has a larger cross-sectional area than the second suction path 52 in this embodiment. This configuration can reduce the pressure loss in the first suction path 51, and therefore is more effective to make the force acting on the upper surface of the first piston 21 equal to the force acting on the lower surface thereof. As a result, the effect to counteract the forces acting on the first piston 21 in the thickness direction can be more enhanced.

[0052] The cross-sectional shape of each suction path is not specifically limited. However, each suction path typically has a circular cross-sectional shape. The first suction port 26 and the second suction port 27 each having a shape shown in Fig. 4 are formed by shallow counterbores provided on the ends of the first suction path 51 and the second suction path 52. Such a configuration also can be applied to the sub-compressor 102 in addition to the discharge paths and discharge ports.

[0053] As shown in Fig. 4, the discharge path 58 opens into the discharge working chamber 23b in the area adjacent to the first partition member 24. More specifically, the first discharge path 56 and the second discharge path 57 that have been described with reference to Fig. 2B each open into the discharge working chamber 23b.

[0054] The second discharge port 30 is formed in a substantially fan shape that extends in an arc shape from the portion of the suction working chamber 23b adjacent to the first partition member 24 in the direction in which the discharge working chamber 23b is enlarged. The second discharge port 30 is closed completely by the first piston 21 only when the first piston 21 is located at its top dead center. At least a part of the second discharge port 30 is exposed to the discharge working chamber 23b over the entire period except for the moment when the first piston 21 is located at its top dead center. Specifically, the second discharge port 30 has an outer edge side 30a that is formed in an arc shape along the outer circumferential surface of the first piston 21 located at its top dead center, in plan view. In other words, the outer edge side 30a is formed in an arc shape having substantially the same radius as the outer circumferential surface of the first piston 21.

[0055] Though not shown in Fig. 4, the first discharge port 29 has the same opening shape as the second discharge port 30. Furthermore, the first discharge port 29 has an opening area equal to the opening area of the second discharge port 30. With such a configuration, the force acting on the lower surface of the first piston 21 (suction force) can be counteracted effectively by the force acting on the upper surface thereof (suction force).

[0056] The pressure of the refrigerant discharged to the discharge path 58 through the first discharge port 29 is substantially equal to the pressure of the refrigerant discharged to the discharge path 58 through the second discharge port 30. When the first discharge port 29 and the second discharge port 30 completely overlap each other in the axis direction, the overlapping area of the first piston 21 and the first discharge port 29 is equal to the overlapping area of the first piston 21 and the second discharge port 30. Accordingly, the force acting on the upper surface of the first piston 21 is equal to the force acting on the lower surface thereof (force = pressure × area). That is, the effect to counteract the forces acting on the first piston 21 in the thickness direction (axis direction) can be enhanced most.

[0057] Similarly to the first suction path 51 and the second suction path 52 that has been described with reference to Fig. 3, the first discharge path 56 may have a larger cross-sectional area than the second discharge path 57. This configuration can reduce the pressure loss in the first discharge path 56, and therefore is more effective to make the force acting on the upper surface of the first piston 21 equal to the force acting on the lower surface thereof.

[0058] Meanwhile, the effect to counteract the forces acting on the first piston 21 can be obtained independently from the configuration in which a plurality of the suction ports 26 and 27 are provided, and from the configuration in which a plurality of the discharge ports 29 and 30 are provided. However, the pressure of the refrigerant in the suction path 53 is far higher than the pressure of the refrigerant in the discharge path 58. For example, in the case of using carbon dioxide as a refrigerant, the difference between the pressure in the suction path 53 and the pressure in the discharge path 58 reaches as high as several MPa. Taking this into consideration, the effect to be obtained by combining the suction ports 26 and 27 is higher than the effect to be obtained by combining the discharge ports 29 and 30.

[0059] Fig. 5 is a view illustrating the principle of operation of the power recovery mechanism 105, and illustrates four states ST1 to ST4 of the power recovery mechanism 105.

[0060] As shown in Fig. 5 (ST2 to ST4), when the suction ports 26 and 27 are opened as the first piston 21 rotates, the volume of the suction working chamber 23a gradually increases due to the refrigerant at high pressure flowing in through the suction ports 26 and 27. The rotational torque applied to the first piston 21 as the volume of the suction working chamber 23a increases is incorporated as part of the rotational driving force for the shaft 12. In the case where the first suction port 26 overlaps the second suction port 27 in the axis direction, the timings of the opening and closing of the two suction ports 26 and 27 match each other. Similarly, in the case where the first discharge port 29 overlaps the second discharge port 30 in the axis direction, the timings of the opening and closing of the two discharge ports 29 and 30 also match each other.

[0061] As viewed from the power recovery mechanism 105, the pressure on the evaporator 106 side is lower than that on the heat radiator 104 side. The refrigerant at low temperature and high pressure in the discharge working chamber 23b is drawn to the evaporator 106 side, and discharged from the discharge working chamber 23b to the discharge path 58. When the discharge working chamber 23b is brought into communication with the discharge path 58 so as to start the discharge process, the specific volume of the refrigerant rapidly increases. The rotational torque applied to the first piston 21 due to this discharge process of the refrigerant also is incorporated as part of the rotational driving force for the shaft 12. That is, the shaft 12 rotates by the inflow of the refrigerant at high pressure to the suction working chamber 23a and the suction of the refrigerant in the discharge process. Then, the rotational torque of the shaft 12 is used as power for the sub-compressor 102 as described later in detail.

[0062] The suction working chamber 23a constantly communicates with the suction path 53. Further, the discharge working chamber 23b constantly communicates with the discharge path 58. In other words, the process for drawing the refrigerant and the process for discharging the drawn refrigerant are performed substantially continuously in the power recovery mechanism 105. For this reason, the drawn refrigerant passes through the power recovery mechanism 105 substantially without changing its volume.

[0063] As shown in the upper left view (ST1) of Fig. 5, both of the suction port 27 and the discharge port 30 are closed completely only at the moment when the first piston 21 is located at its top dead center. That is, both of the suction port 27 and the discharge port 30 are closed completely at the moment when the first working chamber 23 is allowed to be one without being partitioned. More specifically, the suction working chamber 23a communicates with the suction path 53 until the moment when the suction working chamber 23a communicates with the discharge path 58. After the moment when the suction working chamber 23a communicates with the discharge path 58 so that the suction working chamber 23a comes to serve as the discharge working chamber 23b, the discharge working chamber 23b is separated from the suction path 53 by the first piston 21. This can inhibit the direct flow of the refrigerant from the suction path 53 to the discharge path 58. Accordingly, high-efficiency power recovery can be achieved.

[0064] In order to completely restrict the direct flow of the refrigerant from the suction path 53 to the discharge path 58, it is preferable that both of the suction port 27 and the discharge port 30 be closed at the moment when the first piston 21 is located at its top dead center. However, even if only one of the suction port 27 and the discharge port 30 is closed at the moment when the first piston 21 is located at its top dead center, the direct flow between the suction path 53 and the discharge path 58 substantially does not occur as long as the difference between the timing of the closing of the suction port 27 and the timing of the closing of the discharge port 30 is less than about 10° in terms of the rotation angle of the shaft 12. That is, the direct flow of the refrigerant from the suction path 53 to the discharge path 58 can be inhibited by setting the difference between the timing of the closing of the suction port 27 and the timing of the closing of the discharge port 30 to less than about 10° in terms of the rotation angle of the shaft 12.

[0065] For preventing the direct flow of the refrigerant, it is preferable that the timings of the opening and closing of the suction ports 26 and 27 match each other, and the timings of the opening and closing of the discharge ports 29 and 30 also match each other.

<Configuration of sub-compressor 102>

[0066] As shown in Fig. 2A, the sub-compressor 102 is arranged above the power recovery mechanism 105 in the closed casing 111. In this way, it is possible to inhibit the heat exchange between the sub-compressor 102 and the power recovery mechanism 105 by arranging the sub-compressor 102 at a relatively high temperature above the power recovery mechanism 105 at a relatively low temperature. However, the sub-compressor 102 may be arranged below the power recovery mechanism 105.

[0067] The sub-compressor 102 is coupled to the power recovery mechanism 105 by the shaft 12. This embodiment describes an example in which the sub-compressor 102 is composed of a rotary fluid pressure motor. However, the sub-compressor 102 is not limited to a rotary fluid pressure motor. The sub-compressor 102 may be composed of a compressor having a specific volume ratio, such as a rotary compressor and scroll compressor.

[0068] The sub-compressor 102 has a basic configuration substantially the same as that of the power recovery mechanism 105. Specifically, the sub-compressor 102 includes the first closing member 115 that serves as a lower closing member and a third closing member 114 that serves as an upper closing member, as shown in Fig. 2A. The power recovery mechanism 105 and the sub-compressor 102 are arranged adjacent to each other in the axis direction in the closed casing 111 so that the first closing member 115 of the power recovery mechanism 105 can be used commonly as the lower closing member of the sub-compressor 102. Such a configuration allows the number of components to be reduced and is advantageous in reducing the size of the fluid machine 110.

[0069] The first closing member 115 and the third closing member 114 face each other. Specifically, the third closing member 114 faces one surface of the first closing member 115 opposite to the other surface thereof that faces the second closing member 113. A second cylinder 42 is arranged between the first closing member 115 and the third closing member 114. The second cylinder 42 has an internal space of substantially cylindrical shape. The internal space of the second cylinder 42 is closed by the first closing member 115 and the third closing member 114. The third closing member 114 and the first closing member 115 are arranged respectively above and below the second cylinder 42.

[0070] The shaft 12 extends through the second cylinder 42 in the axis direction of the second cylinder 42. The second cylinder 42 surrounds a part of the shaft 12 in the circumferential direction. The shaft 12 is arranged on the central axis of the second cylinder 42. A second piston 41 is arranged in the internal space of substantially cylindrical shape that is defined by the inner circumferential surface of the second cylinder 42, the first closing member 115 and the third closing member 114. The second piston 41 is mounted on the shaft 12 eccentrically with respect to the central axis of the shaft 12. Specifically, the shaft 12 is provided with an eccentric portion 12c having a central axis different from that of the shaft 12. The second piston 41 having a tubular shape is fitted around the eccentric portion 12c. Therefore, the second piston 41 is eccentric with respect to the central axis of the second cylinder 42. Accordingly, the second piston 41 eccentrically rotates as the shaft 12 rotates.

[0071] The eccentric portion 12c is eccentric substantially in the same direction as the eccentric portion 12b. For this reason, the eccentric direction of the first piston 21 with respect to the central axis of the first cylinder 22 and the eccentric direction of the second piston 41 with respect to the central axis of the second cylinder 42 are substantially the same as each other in this embodiment. Here, the phrase "substantially the same" is intended to include not only the case of these directions being completely the same, but also the case of them having an error of about ± 2 to 3°.

[0072] A second working chamber 43 is defined by the outer circumferential surface of the second piston 41, the inner circumferential surface of the second cylinder 42, the first closing member 115, and the third closing member 114 in the second cylinder 42 (see also Fig. 6). The volume of the second working chamber 43 remains substantially unchanged even if the second piston 41 rotates as the shaft 12 rotates.

[0073] As shown in Fig. 6, the second cylinder 42 is formed with a linear groove 42a opening into the second working chamber 43. A second partition member 44 having a plate shape is slidably inserted into the linear groove 42a. A biasing means 45 is arranged between the second partition member 44 and the bottom of the linear groove 42a. The second partition member 44 is pressed into contact with the outer circumferential surface of the second piston 41 by the biasing means 45. Thus, the second working chamber 43 is partitioned into two spaces. Specifically, the second working chamber 43 is partitioned into a suction working chamber 43a on the low-pressure side and a discharge working chamber 43b on the high-pressure side.

[0074] The biasing means 45 can be composed, for example, of a spring. Specifically, the biasing means 45 may be a compression coil spring, or a so-called gas spring, similarly to the aforementioned biasing means 25.

[0075] As shown in Fig. 2B, the first closing member 115 is provided with a first discharge port 49 (lower discharge port) that opens and closes, as the second piston 41 rotates, so that the refrigerant flows out from the discharge working chamber 43b. Similarly, the third closing member 114 is provided with a second discharge port 50 (upper discharge port) that opens and closes, as the second piston 41 rotates, so that the refrigerant flows out from the discharge working chamber 43b. The second discharge port 50 is provided at a position facing the first discharge port 49 in the axis direction. That is, the sub-compressor 102 includes the two discharge ports 49 and 50. Even if the second piston 41 is stopped while blocking the discharge ports 49 and 50, a negative pressure acts on both of the upper surface and lower surface of the second piston 41 at the next startup. This can prevent the second piston 41 from being pulled strongly toward the closing member 115 or 114, thus making it easy to start the refrigeration cycle apparatus 101 smoothly. Furthermore, the pressure of the refrigerant acts on both of the upper surface and lower surface of the second piston 41 in normal operation as well. Therefore, the friction loss between the second piston 41 and the closing member 115 or 114 can be reduced, which improves the efficiency of the sub-compressor 102.

[0076] Specifically, the sub-compressor 102 includes a discharge path 68 for introducing the refrigerant from the discharge working chamber 43b to the outside of the sub-compressor 102 (to the main compressor 103) through each of the first discharge port 49 and the second discharge port 50. This discharge path 68 is composed of a common discharge path 65, a first discharge path 66 and a second discharge path 67. The first discharge port 49 is located at the starting end of the first discharge path 66, and the second discharge port 50 is located at the starting end of the second discharge path 67. Further, the sub-compressor 102 includes a discharge pipe 151 for introducing the refrigerant from the discharge path 68 to the outside of the closed casing 111. When the refrigeration cycle apparatus 101 is being started, a negative pressure is generated in the discharge path 68 by opening the bypass valve 107b and activating the main compressor 103.

[0077] The common discharge path 65 is formed in the third closing member 114, and is a large path extending from the outer circumferential surface of the third closing member 114 toward the center of the shaft 12. The discharge pipe 151 is connected directly to the common discharge path 65. The first discharge path 66 extends from the first discharge port 49 outwardly through the second cylinder 42 in the axis direction to merge with the common discharge path 65 so as to allow the refrigerant to be introduced from the discharge working chamber 43b to the common discharge path 65 through the first discharge port 49. The second discharge path 67 extends from the second discharge port 50 in the axis direction and merges with the common discharge path 65 at a more internal position than the first discharge path 66 in the radial direction of the shaft 12 so as to allow the refrigerant to be introduced from the discharge working chamber 43b to the common discharge path 65 through the second discharge port 50. According to such a structure, it is possible to provide the two discharge ports 49 and 50 without increasing the number of the discharge pipe 151.

[0078] More specifically, the first discharge path 66 includes a portion formed in the first closing member 115, a portion formed in the second cylinder 42, and a portion formed in the third closing member 114, and extends around from below to above the working chamber 43. That is, the first discharge path 66 has a hook-shaped cross-sectional profile.

[0079] As shown in Fig. 2A, the first closing member 115 is provided with a first suction port 46 (lower suction port) that opens and closes, as the second piston 41 rotates, so that the refrigerant flows into the suction working chamber 43a. Similarly, the third closing member 114 is provided with a second suction port 47 (upper suction port) that opens and closes, as the second piston 41 rotates, so that the refrigerant flows into the suction working chamber 43a. The second suction port 47 is provided at a position facing the first suction port 46 in the axis direction of the shaft 12. That is, the sub-compressor 102 includes the two suction ports 46 and 47. Even if the second piston 41 is stopped while blocking the suction ports 46 and 47, a negative pressure acts on both of the upper surface and lower surface of the second piston 41 at the next startup. This can prevent the second piston 41 from being pulled strongly toward the closing member 115 or 114, thus making it easy to start the refrigeration cycle apparatus 101 smoothly. Furthermore, the pressure of the refrigerant acts on both of the upper surface and lower surface of the second piston 41 in normal operation as well. Therefore, the friction loss between the second piston 41 and the closing member 115 or 114 can be reduced, which improves the efficiency of the sub-compressor 102.

[0080] Specifically, the sub-compressor 102 includes a suction path 63 for supplying the refrigerant from the outside of the sub-compressor 102 (from the evaporator 106) to the suction working chamber 43a through each of the first suction port 46 and the second suction port 47. This suction path 63 is composed of a common suction path 60, a first suction path 61 and a second suction path 62. The first suction port 46 is located at the terminal end of the first suction path 61, and the second suction port 47 is located at the terminal end of the second suction path 62. Further, the sub-compressor 102 includes a suction pipe 48 for introducing the refrigerant from the outside of the closed casing 111 to the suction path 63. When the refrigeration cycle apparatus 101 is being started, a negative pressure is generated also in the suction path 63 by opening the bypass valve 107b and activating the main compressor 103. That is, the pressure in the suction path 63 is equal to the pressure in the discharge path 68 in the state where the bypass valve 107b is opened.

[0081] The common suction path 60 is formed in the third closing member 114, and is a large path extending from the outer circumferential surface of the third closing member 114 toward the center of the shaft 12. The suction pipe 48 is connected directly to the common suction path 60. The first suction path 61 branches from the common suction path 60 and extends through the second cylinder 42 in the axis direction to reach the first suction port 46 so as to allow the refrigerant to be supplied from the common suction path 60 to the suction working chamber 43a through the first suction port 46. The second suction path 62 branches from the common suction path 60 at a more internal position than the first suction path 61 in the radial direction of the shaft 12 and extends in the axis direction to reach the second suction port 47 so as to allow the refrigerant to be supplied from the common suction path 60 to the suction working chamber 43a through the second suction port 47. According to such a structure, it is possible to provide the two suction ports 46 and 47 without increasing the number of the suction pipe 48.

[0082] More specifically, the first suction path 61 includes a portion formed in the third closing member 114, a portion formed in the second cylinder 42, and a portion formed in the first closing member 115. In the axis direction, the first suction path 61 extends around from above to below the working chamber 43. That is, the first suction path 61 has a hook-shaped cross-sectional profile.

[0083] As shown in Fig. 6, the suction path 63 opens into the suction working chamber 43a in the area adjacent to the second partition member 44. More specifically, the first suction path 61 and the second suction path 62 that have been described with reference to Fig. 2A each open into the suction working chamber 43a.

[0084] The first suction port 46 is formed in a substantially fan shape that extends in an arc shape from the portion of the suction working chamber 43a adjacent to the second partition member 44 in the direction in which the suction working chamber 43a is enlarged. The first suction port 46 is closed completely by the second piston 41 only when the second piston 41 is located at its top dead center. At least a part of the first suction port 46 is exposed to the suction working chamber 43a over the entire period except for the moment when the second piston 41 is located at its top dead center. Specifically, the first suction port 46 has an outer edge side 46a that is formed in an arc shape along the outer circumferential surface of the second piston 41 located at its top dead center, in plan view. In other words, the outer edge side 46a is formed in an arc shape having substantially the same radius as the outer circumferential surface of the second piston 41.

[0085] Though not shown in Fig. 6, the second suction port 47 has the same opening shape as the first suction port 46. Furthermore, the first suction port 46 has an opening area equal to the opening area of the second suction port 47. With such a configuration, the force acting on the lower surface of the second piston 41 can be counteracted effectively by the force acting on the upper surface thereof.

[0086] The pressure of the refrigerant flowing into the suction working chamber 43a through the first suction port 46 is substantially equal to the pressure of the refrigerant flowing into the suction working chamber 43a through the second suction port 47. When the first suction port 46 and the second suction port 47 completely overlap each other in the axis direction, the overlapping area of the second piston 41 and the first suction port 46 is equal to the overlapping area of the second piston 41 and the second suction port 47. Accordingly, the force acting on the upper surface of the second piston 41 is equal to the force acting on the lower surface thereof (force = pressure $\times$ area). That is, the effect to counteract the forces acting on the second piston 41 in the thickness direction (axis direction) can be enhanced most.

[0087] As shown in Fig. 6, the discharge path 68 opens into the discharge working chamber 43b in the area adjacent to the second partition member 44. More specifically, the first discharge path 66 and the second discharge path 67 that have been described with reference to Fig. 2B each open into the discharge working chamber 43b.

[0088] The first discharge port 49 is formed in a substantially fan shape that extends in an arc shape from the portion of the suction working chamber 43b adjacent to the second partition member 44 in the direction in which the discharge working chamber 43b is enlarged. The first discharge port 49 is closed completely by the second piston 41 only when the second piston 41 is located at its top dead center. At least a part of the first discharge port 49 is exposed to the discharge working chamber 43b over the entire period except for the moment when the second piston 41 is located at its top dead center. Specifically, the first discharge port 49 has an outer edge side 49a that is formed in an arc shape along the outer circumferential surface of the second piston 41 located at its top dead center, in plan view. In other words, the outer edge side 49a is formed in an arc shape having substantially the same radius as the outer circumferential surface of the second piston 41.

[0089] Though not shown in Fig. 6, the second discharge port 50 has the same opening shape as the first discharge port 49. That is, the first discharge port 49 has an opening area equal to the opening area of the second discharge port 50. With such a configuration, the force acting on the lower surface of the second piston 41 can be counteracted effectively by the force acting on the upper surface thereof.

[0090] The pressure of the refrigerant discharged to the discharge path 68 through the first discharge port 49 is substantially equal to the pressure of the refrigerant discharged to the discharge path 68 through the second discharge port 50. When the first discharge port 49 and the second discharge port 50 completely overlap each other in the axis direction, the overlapping area of the second piston 41 and the first discharge port 49 is equal to the overlapping area of the second piston 41 and the second discharge port 50. Accordingly, the force acting on the upper surface of the second piston 41 is equal to the force acting on the lower surface thereof (force = pressure × area). That is, the effect to counteract the forces acting on the second piston 41 in the thickness direction (axis direction) can be enhanced most.

[0091] As shown in Fig. 6, the discharge path 68 is connected to a back space 155 via a communication path 156. Specifically, the communication path 156 communicates with the back space 155 when the second partition member 44 approaches the central axis of the shaft 12 most closely, in this embodiment. The communication path 156 is configured to be closed by the second partition member 44 when the second partition member 44 shifts away from the central axis of the shaft 12 to some extent. That is, while the second partition member 44 slides from the forward position, which is closest to the central axis of the shaft 12, to the backward position, which is most distant from the central axis of the shaft 12, the communication path 156 changes its state from open to closed, and the back space 155 changes from an open space that communicates with the communication path 156 to a closed space that is isolated from the communication path 156. This causes the communication path 156 to be closed by the second partition member 44. Upon the back space 155 having changed into a closed space, the back space 155 that serves as a gas spring presses the second partition member 44 toward the second piston 41.

[0092] The configuration of the suction paths 51 and 52 of the power recovery mechanism 105 that has been described with reference to Fig. 3 can be adopted to the sub-compressor 102. That is, the first suction path 61 may have a larger cross-sectional area than the second suction path 62 in the sub-compressor 102. Furthermore, the first discharge path 66 may have a larger cross-sectional area than the second discharge path 67. This configuration can reduce the pressure loss in the first suction path 61 and the first discharge path 66, and therefore is more effective to make the force acting on the upper surface of the second piston 41 equal to the force acting on the lower surface thereof.

[0093] The effect to counteract the force acting on the second piston 41 can be obtained independently from the configuration in which a plurality of the suction ports 46 and 47 are provided, and from the configuration in which a plurality of the discharge ports 49 and 50 are provided. However, the effect to be obtained by combining the discharge ports 49 and 50 is higher than the effect to be obtained by combining the suction ports 46 and 47. The reasons for this are as follows. First, when the refrigeration cycle apparatus 101 is being started, the suction path 63 and the discharge path 68 have the same pressure temporarily. This is because the bypass valve 107b is opened at the time of startup (see Fig. 1). On the other hand, after the refrigeration cycle apparatus 101 is started, the bypass valve 107b is closed, which causes the pressure in the discharge path 68 to be higher than the pressure in the suction path 63. Accordingly, the combination of the discharge ports 49 and 50 can reduce the friction loss of the refrigeration cycle apparatus 101 in normal operation more effectively.

[0094] Next, the principle of operation of the sub-compressor 102 is described in detail with reference to Fig. 7. Fig. 7 illustrates four states T1 to T4 of the sub-compressor 102. The sub-compressor 102 has almost the same principle of operation as the power recovery mechanism 105.

[0095] The shaft 12 is rotated by power recovered by the power recovery mechanism 105. The second piston 41 rotates as the shaft 12 rotates, so that the sub-compressor 102 is driven. In the case where the first suction port 46 overlaps the second suction port 47 in the axis direction, the timings of the opening and closing of the two suction ports 46 and 47 match each other. Similarly, in the case where the first discharge port 49 overlaps the second discharge port 50 in the axis direction, the timings of the opening and closing of the two discharge ports 49 and 50 also match each other.

[0096] The volume of the second working chamber 43 remains substantially unchanged. The suction working chamber 43a constantly communicates with the suction path 63. The discharge working chamber 43b constantly communicates with the discharge path 68. Therefore, the refrigerant is neither compressed nor expanded in the second working chamber 43 of the sub-compressor 102. When the shaft 12 is rotated by the power recovery mechanism 105 and the sub-compressor 102 is driven, the pressure on the downstream side of the second working chamber 43 is rendered higher than the pressure on the upstream side of the second working chamber 43. In other words, the sub-compressor 102 that is driven by the power recovered by the power recovery mechanism 105 causes the pressure on the main compressor 103 side from the discharge ports 49 and 50 to be higher than that on the evaporator 106 side from the suction ports 46 and 47. That is, the sub-compressor 102 causes an increase in pressure.

[0097] The suction working chamber 43a constantly communicates with the suction path 63. Further, the discharge working chamber 43b constantly communicates with the discharge path 68. In other words, the process for drawing the refrigerant and the process for discharging the drawn refrigerant are performed substantially continuously in the sub-compressor 102. For this reason, the drawn refrigerant passes through the sub-compressor 102 substantially without changing its volume.

[0098] It should be noted that the timing at which the first piston 21 is located at its top dead center substantially match the timing at which the second piston 41 is located at its top dead center, in this embodiment.

[0099] As shown in the upper left view (T1) of Fig. 7, both of the suction port 46 and the discharge port 49 are closed completely only at the moment when the second piston 41 is located at its top dead center. That is, both of the suction port 46 and the discharge port 49 are closed completely at the moment when the second working chamber 43 is allowed to be one without being partitioned. More specifically, the suction working chamber 43a communicates with the suction path 63 until the moment when the suction working chamber 43a communicates with the discharge path 49. After the moment when the suction working chamber 43a communicates with the discharge path 68 so that the suction working chamber 43a comes to serve as the discharge working chamber 43b, the discharge working chamber 43b is separated from the suction path 63 by the second piston 41. This can inhibit the back flow of the refrigerant from the discharge path 68 at relatively high pressure to the suction path 63 at relatively low pressure. Accordingly, high-efficiency supercharge can be achieved. As a result, the efficiency of using recovered power is enhanced.

[0100] In order to restrict the back flow of the refrigerant from the discharge path 68 to the suction path 63 completely, it is preferable that both of the suction path 63 and the discharge path 68 be closed at the moment when the second piston 41 is located at its top dead center. However, even if only one of the suction port 46 and the discharge port 49 is closed at the moment when the second piston 41 is located at its top dead center, the back flow of the refrigerant from the discharge path 68 to the suction path 63 substantially does not occur as long as the difference between the timing of closing of the suction port 46 and the timing of closing of the discharge port 49 is less than about 10° in terms of the rotation angle of the shaft 12. That is, it is possible to inhibit the back flow of the refrigerant from the discharge path 68 to the suction path 63 by setting the difference between the timing of closing of the suction port 46 and the timing of closing of the discharge port 49 to less than about 10° in terms of the rotation angle of the shaft 12.

[0101] For preventing the back flow of the refrigerant, it is preferable that the timings of the opening and closing of the suction ports 46 and 47 match each other, and the timings of the opening and closing of the discharge ports 49 and 50 also match each other.

INDUSTRIAL APPLICABILITY

[0102] The present invention is useful for a refrigeration cycle apparatus such as a water heater and an air conditioner.

Claims

1. A fluid machine comprising:

a power recovery mechanism for recovering power from a working fluid;
a sub-compressor that is driven by the recovered power; and
a shaft coupling the power recovery mechanism and the sub-compressor to each other so that the recovered power is transmitted from the power recovery mechanism to the sub-compressor, wherein
the power recovery mechanism includes:

(a1) a first closing member;
(b1) a second closing member facing the first closing member;
(c1) a cylinder surrounding a part of the shaft in the circumferential direction, the cylinder having both ends closed by the first closing member and the second closing member;
(d1) a piston mounted on the shaft in the cylinder, the piston forming a working chamber between its outer circumferential surface and the inner circumferential surface of the cylinder;
(e1) a partition member partitioning the working chamber into a high pressure-side working chamber and a low pressure-side working chamber;
(f1) a first suction port provided in the first closing member so as to open and close,

as the piston rotates, so that the working fluid flows into the high pressure-side working chamber; and
(g1) a second suction port provided in the second closing member at a position facing the first suction port in the axis direction of the shaft so as to open and close, as the piston rotates, so that the working fluid flows into the high pressure-side working chamber.

2. The fluid machine according to claim 1, wherein the power recovery mechanism further includes:

(h1) a first discharge port provided in the first closing member so as to open and close, as the piston rotates, so that the working fluid flows out from the low pressure-side working chamber; and
(i1) a second discharge port provided in the second closing member at a position facing the first discharge port in the axis direction so as to open and close, as the piston rotates, so that the working fluid flows out from the low pressure-side working chamber.

3. The fluid machine according to claim 2, wherein the first discharge port has the same opening shape as the second discharge port.

4. The fluid machine according to claim 2 or 3, wherein the first discharge port has an opening area equal to an opening area of the second discharge port.

5. The fluid machine according to any one of claims 1 to 4, wherein
the first suction port has the same opening shape as the second suction port.

6. The fluid machine according to any one of claims 1 to 5, wherein
the first suction port has an opening area equal to an opening area of the second suction port.

7. The fluid machine according to any one of claims 1 to 6, wherein
the power recovery mechanism further includes a suction path for supplying the working fluid from the outside of the power recovery mechanism to the high pressure-side working chamber through each of the first suction port and the second suction port, and the suction path includes:

(i) a common suction path extending from the outer circumferential surface of the second closing member toward the center of the shaft;
(ii) a first suction path branching from the common suction path and extending through the cylinder in the axis direction to reach the first suction port so as to allow the working fluid to be supplied from the common suction path to the high pressure-side working chamber through the first suction port; and
(iii) a second suction path branching from the common suction path at a more internal position than the first suction path in the radial direction of the shaft and extending in the axis direction to reach the second suction port so as to allow the working fluid to be supplied from the common suction path to the high pressure-side working chamber through the second suction port.

8. The fluid machine according to claim 7, wherein the first suction path has a larger cross-sectional area than the second suction path.

9. The fluid machine according to any one of claims 1 to 8, wherein
the sub-compressor includes:

(a2) a lower closing member;
(b2) an upper closing member facing the lower closing member;
(c2) a second cylinder surrounding a part of the shaft in the circumferential direction, the second cylinder having both ends closed by the lower closing member and the upper closing member;
(d2) a second piston mounted on the shaft in the second cylinder, the second piston forming a working chamber between its outer circumferential surface and the inner circumferential surface of the second cylinder;
(e2) a second partition member partitioning the working chamber into a low pressure-side working chamber and a high pressure-side working chamber;
(f2) a first suction port provided in the lower closing member so as to open and close, as the second piston rotates, so that the working fluid flows into the low pressure-side working chamber; and
(g2) a second suction port provided in the upper closing member at a position facing the first suction port in the axis direction of the shaft so as to open and close, as the second piston rotates, so that the working fluid flows into the low pressure-side working chamber.

10. The fluid machine according to claim 9, wherein the sub-compressor further includes:

(h2) a first discharge port provided in the lower closing member so as to open and close, as the second piston rotates, so that the working fluid flows out from the high pressure-side working chamber; and (i2) a second discharge port provided in the upper closing member at a position facing the first discharge port in the axis direction so as to open and close, as the second piston rotates, so that the working fluid flows out from the high pressure-side working chamber.

11. The fluid machine according to claim 9 or 10, further comprising:

a closed casing accommodating the power recovery mechanism, the sub-compressor and the shaft, wherein
the power recovery mechanism and the sub-compressor are arranged adjacent to each other in the axis direction in the closed casing so that the first closing member of the power recovery mechanism is used commonly as the lower closing member of the sub-compressor.

12. A refrigeration cycle apparatus provided with a refrigerant circuit in which a refrigerant circulates, the refrigerant circuit comprising:

the fluid machine according to any one of claims 1 to 11;
a main compressor for compressing the refrigerant that has been pre-compressed by the sub-compressor in the fluid machine;
a heat radiator for cooling the refrigerant that has been compressed by the main compressor; and
an evaporator for evaporating the refrigerant discharged from the power recovery mechanism in the fluid machine.

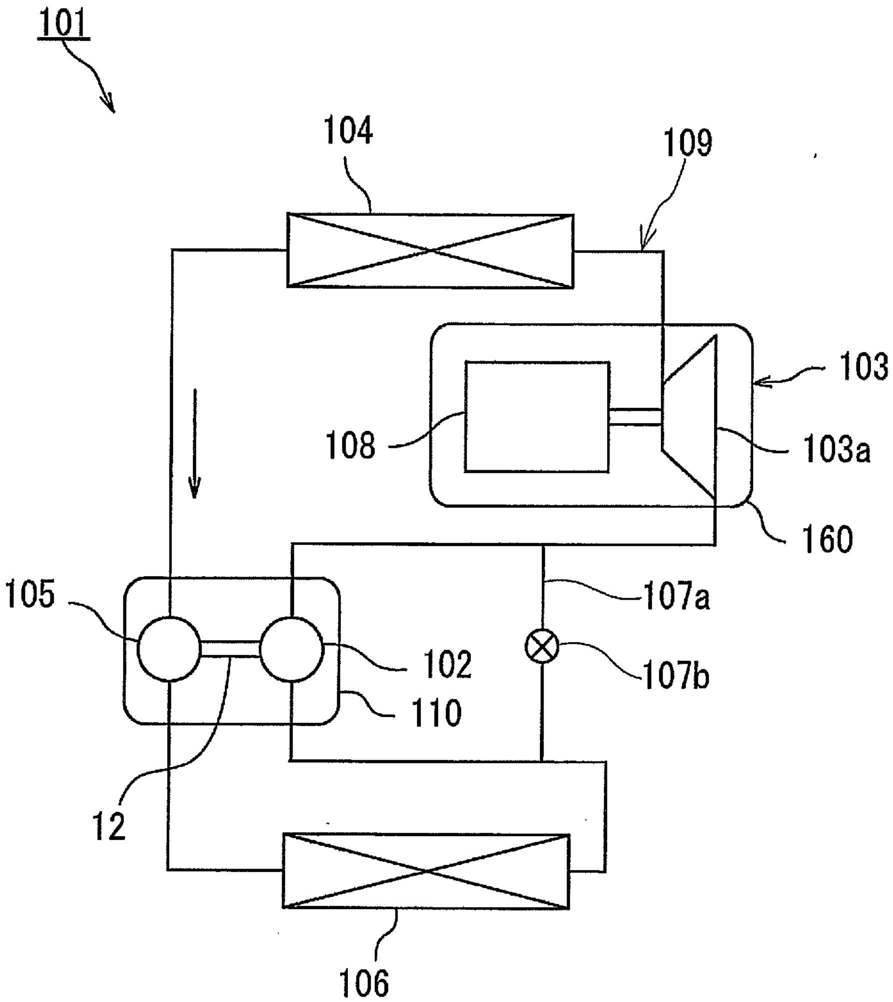
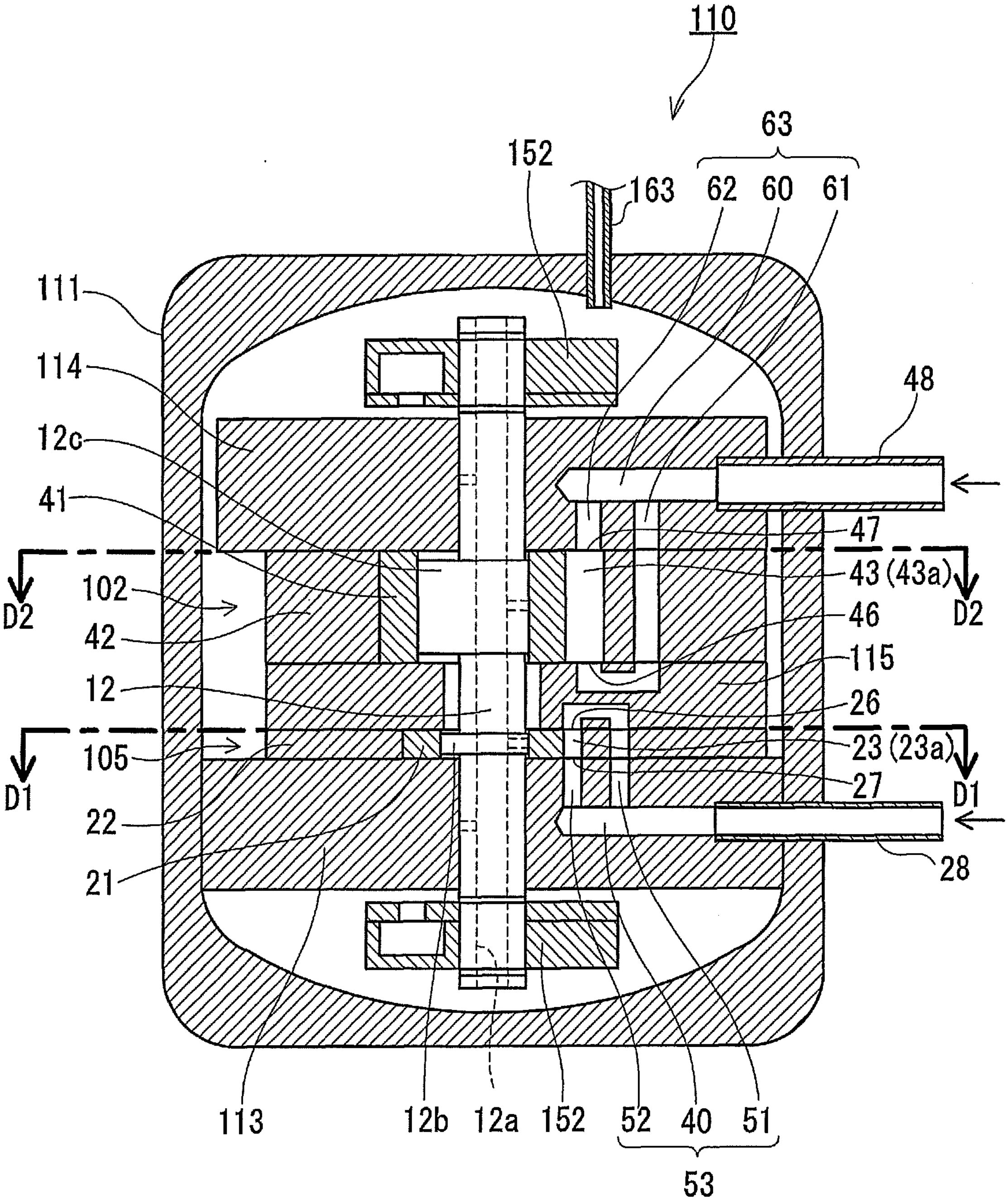


FIG.1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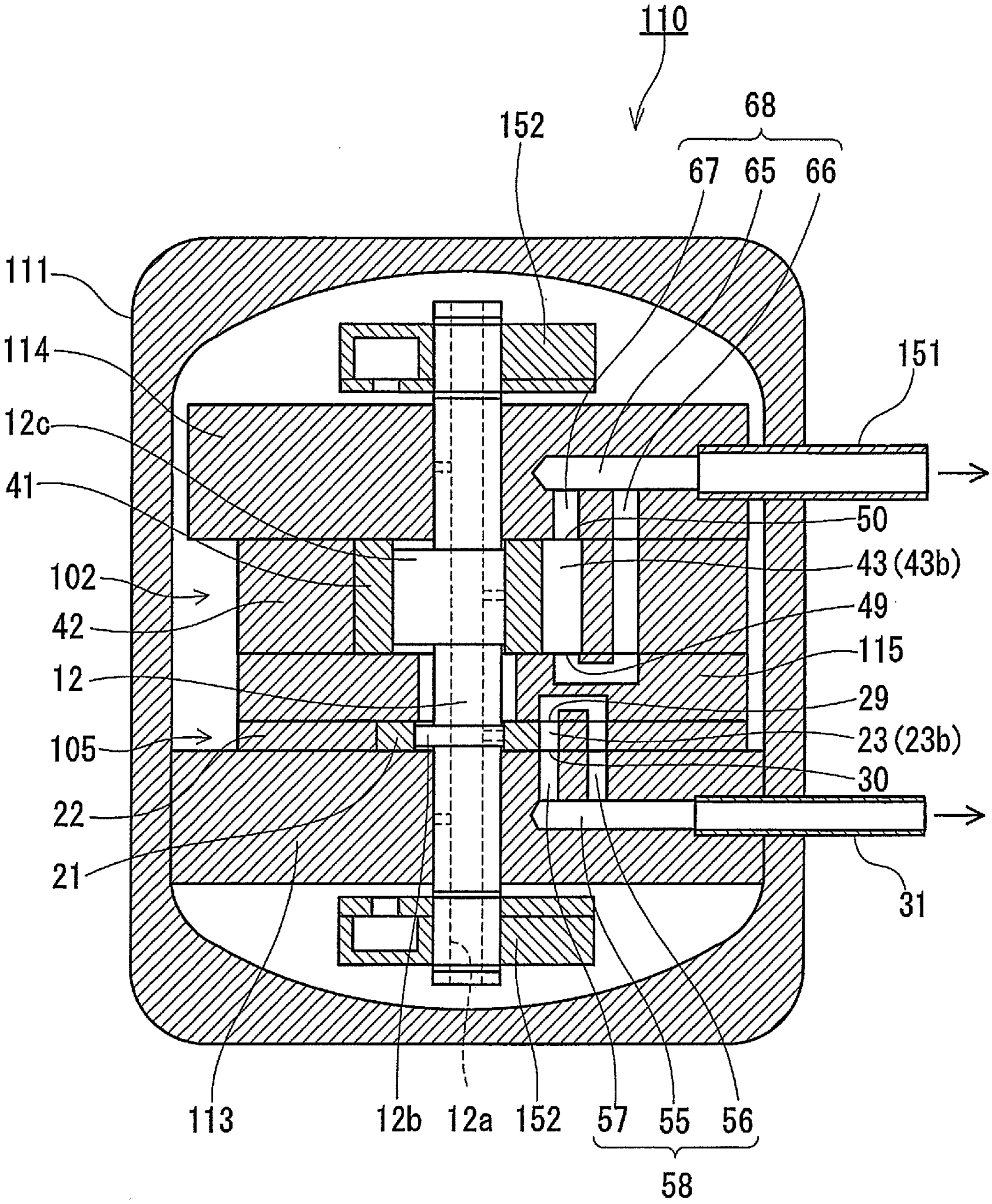
41
43 (43a)
102
D2
D2
42
46
115
12
26
105
23 (23a)
D1
D1
27
22
21
28
113
12b
12a
152
52
40
51
53

FIG.2A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43 (43b)
102
49
42
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105
23 (23b)
30
22
21
31
113
12b
12a
152
57
55
56
58

FIG.2B

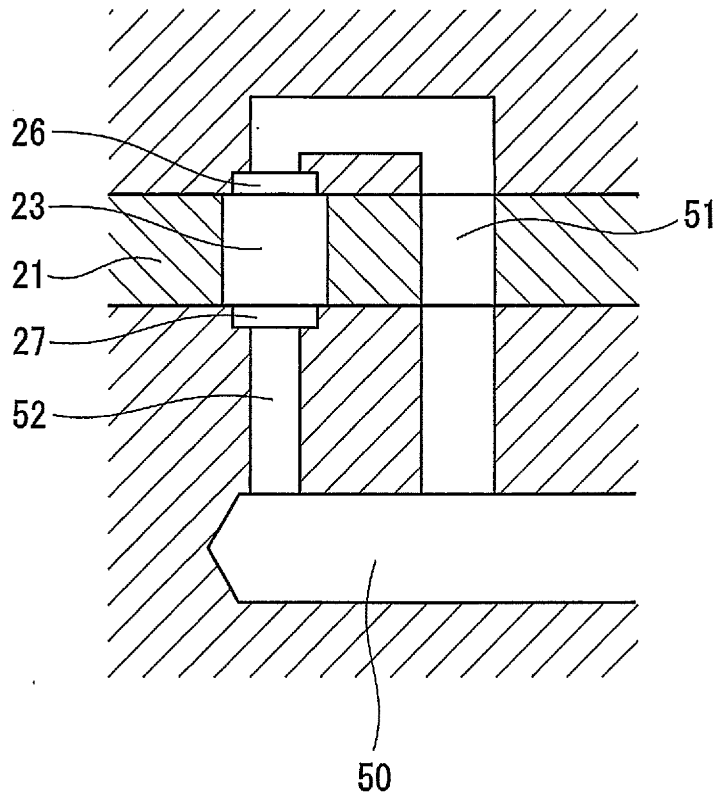


FIG.3

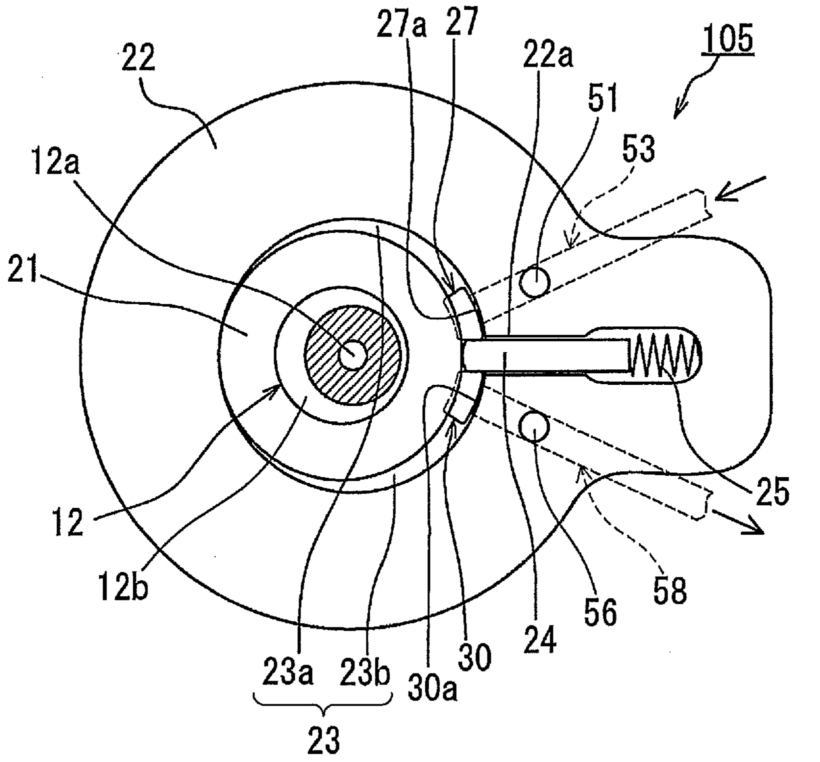
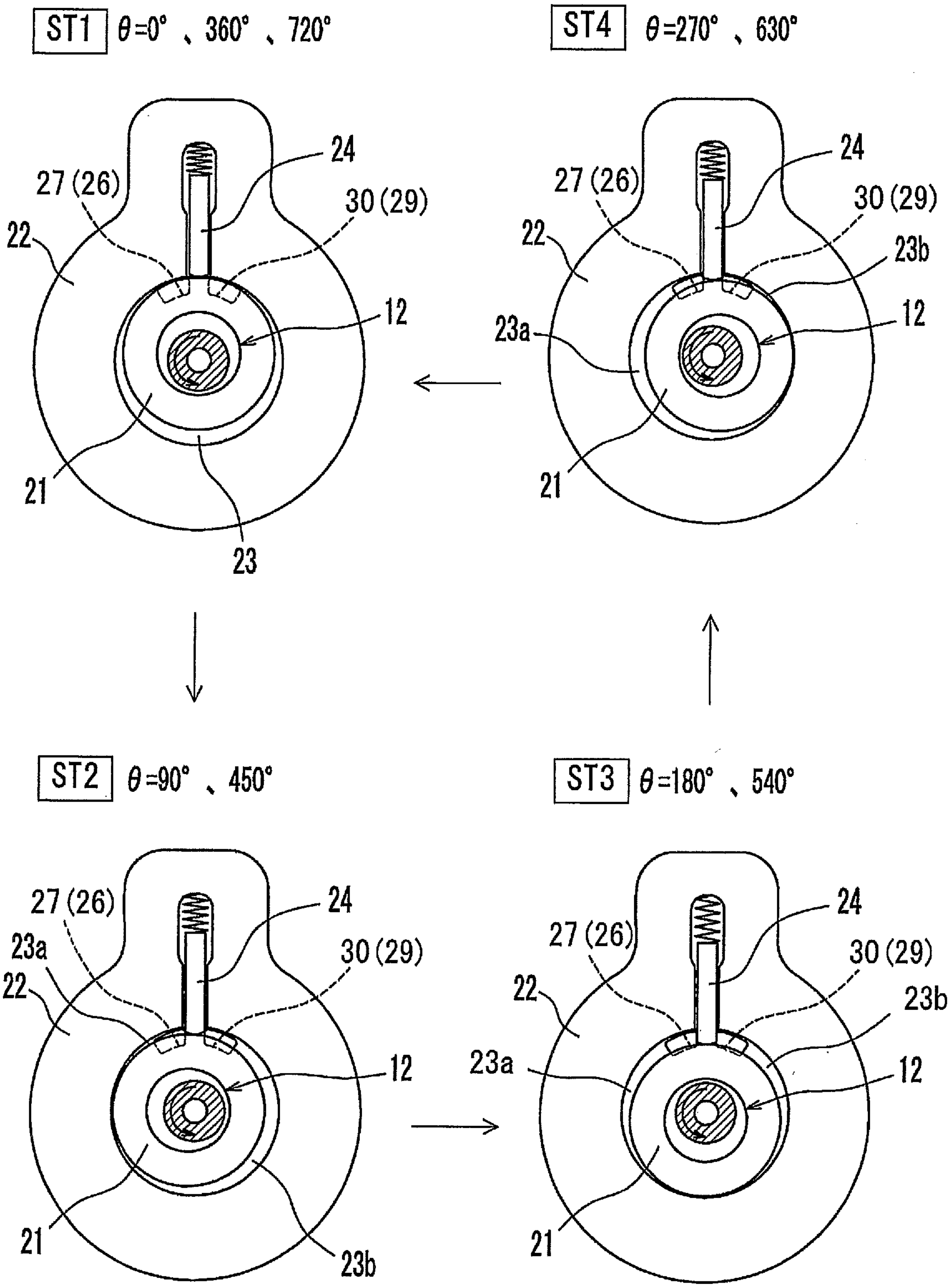


FIG.4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ST4 θ=270°、630°
ST2 θ=90°、450°
ST3 θ=180°、540°
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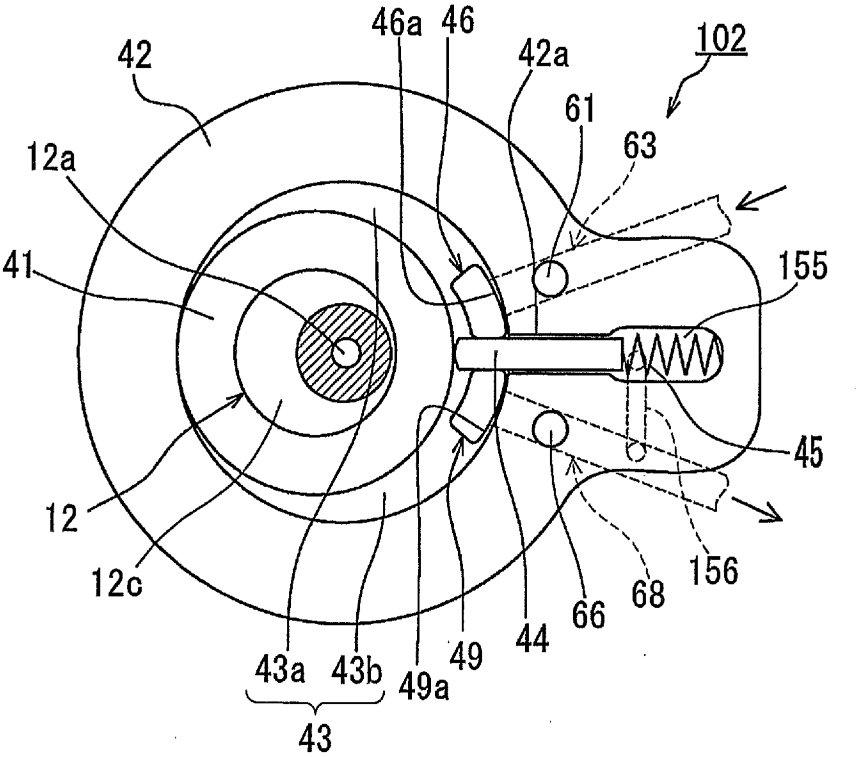
27 (26)
30 (29)
22
12
21
23
23a
23b

FIG.5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46a
46
42a
102
61
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12a
41
155
45
12
12c
43a
43b
49a
49
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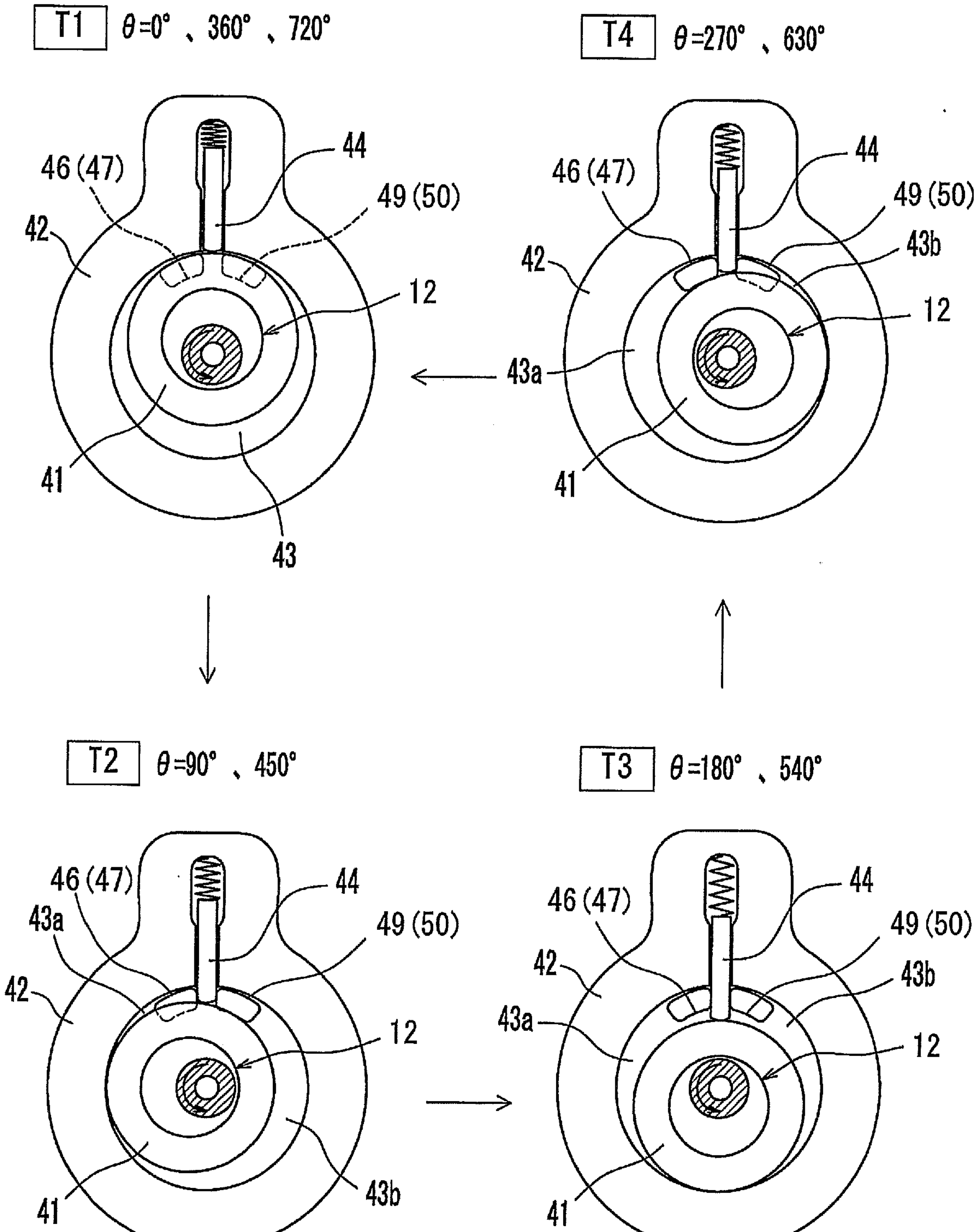
66
68
156
43

FIG.6


T1 θ=0°、360°、720°
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44
49 (50)
42
12
41
43
T4 θ=270°、630°
46 (47)
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43b
42
12
43a
41
T2 θ=90°、450°
46 (47)
44
43a
49 (50)
42
12
41
43b
T3 θ=180°、540°
46 (47)
44
49 (50)
42
43b
43a
12
41

FIG.7

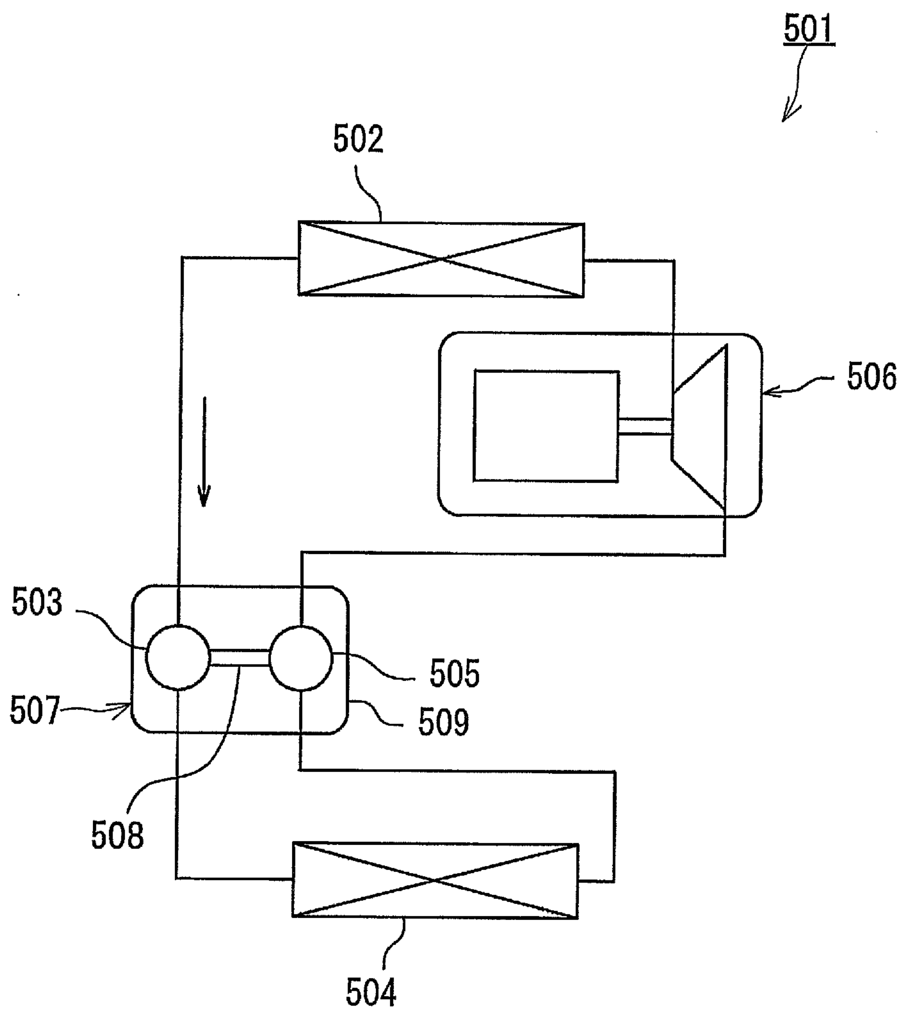

FIG.8

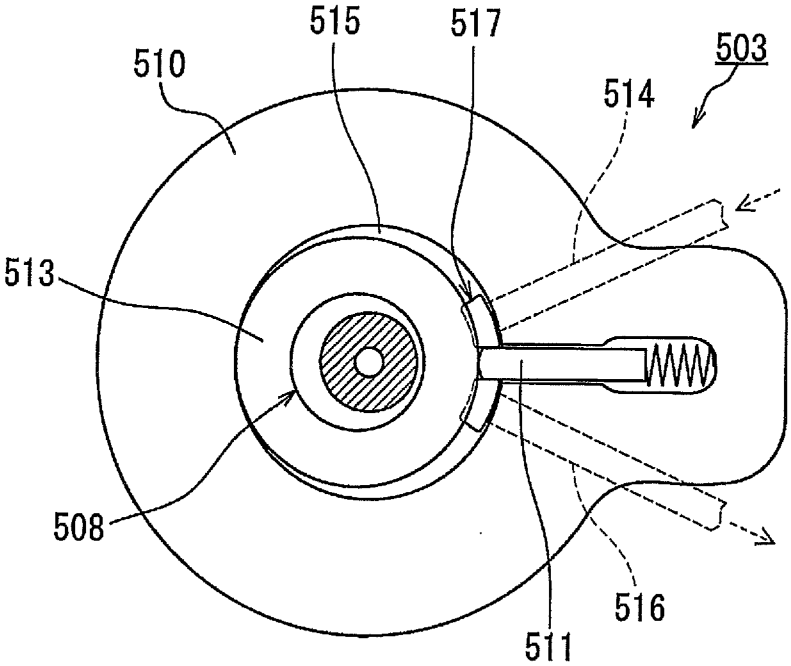

FIG.9

INTERNATIONAL SEARCH REPORT

International application No. PCT/JP2009/002231

A. CLASSIFICATION OF SUBJECT MATTER
F01C20/10(2006.01)i, *F01C1/356*(2006.01)i, *F01C13/04*(2006.01)i, *F25B1/04*(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)
F01C20/10, F01C1/356, F01C13/04, F25B1/04

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	1996-2009
Kokai Jitsuyo Shinan Koho	1971-2009	Toroku Jitsuyo Shinan Koho	1994-2009

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	WO 2008/050654 A1 (Matsushita Electric Industrial Co., Ltd.), 02 May, 2008 (02.05.08), Par. Nos. [0121] to [0170]; Figs. 14 to 19 & JP 4261620 B & JP 2009-92378 A & EP 2077426 A	1-12
Y	JP 2001-12201 A (Sankyo Seiki Mfg. Co., Ltd.), 16 January, 2001 (16.01.01), Par. Nos. [0009], [0058], [0060]; Fig. 2 & US 6692237 B1 & EP 1197634 A1 & WO 2000/079101 A1 & DE 60038381 D & AU 5427400 A & CN 1355868 A & AT 389783 T	1-12

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

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"O" document referring to an oral disclosure, use, exhibition or other means
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"&" document member of the same patent family

Date of the actual completion of the international search 04 August, 2009 (04.08.09)	Date of mailing of the international search report 18 August, 2009 (18.08.09)
Name and mailing address of the ISA/ Japanese Patent Office Facsimile No.	Authorized officer Telephone No.

Form PCT/ISA/210 (second sheet) (April 2007)

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Patent documents cited in the description

- JP 2004324595 A **[0003] [0004] [0007]**
- WO 2008050654 A **[0003] [0006] [0007]**