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(54) **REFRIGERATION CYCLE DEVICE**

KÄLTEKREISLAUFVORRICHTUNG

DISPOSITIF À CYCLE DE RÉFRIGÉRATION

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Description

Summary of Invention

Technical Field

Technical Problem

[0001] The present invention relates to a refrigeration cycle apparatus recovering power by using an expander.

Background Art

[0002] In conventional refrigeration cycle apparatuses used for refrigeration, air-conditioning, and the like, for example, an expansion process is carried out in a positive displacement expander, and an expansion power recovered by this process is used in the compression process carried out in a positive displacement compressor.

[0003] However, since an expander and a compressor that is driven by power recovered by an expander are rotary machines, a "negative power" is generated therein by frictional resistance, mechanical loss, and the like. Accordingly, in order to start up an expander and a compressor that is driven by power recovered by an expander, power that can overcome this "negative power" is required. Hence, there has been proposed a refrigeration cycle apparatus that is designed to reduce the "negative power" that hinders the start up (rotation) of the expander and the compressor that is driven by power recovered by the expander, and a refrigeration cycle apparatus that is designed to increase the "positive power" (power that rotates the expander) at the start up of the expander.

[0004] A refrigeration cycle apparatus as above is proposed, for example, that "has a structure in which a drive shaft of the other compressor is connected to an output shaft of an expansion mechanism. A structure in which a bypass pipe is provided that connects a gas suction port and a gas discharge port and that bypasses the other compressor, the bypass pipe provided with a check valve that regulates the communication of a refrigerant from the gas discharge port to the gas suction port" (refer to Patent Literature 1, for example).

[0005] Further, a refrigeration cycle apparatus as above is proposed that increases the power that can be recovered by the expander by increasing the pressure difference between the inlet side and the outlet side of the expander (refer to Patent Literature 2, for example).

Citation List

Patent Literature

[0006]

Patent Literature 1: Japanese Unexamined Patent Application Publication No. 11-94379 (paragraphs [0009] and [0013], Fig. 1)

Patent Literature 2: Japanese Unexamined Patent Application Publication No. 2006-132818 (paragraphs [0014] to [0021])

[0007] For example, in the refrigeration cycle apparatus described in Patent Literature 1, a bypass pipe equalizes pressure between the discharge side pressure and the suction side pressure of the compressor. This facilitates the start up of the expander (expansion mechanism) and the compressor that is connected to this expander with a shaft.

[0008] However, the compressor that is connected to the expander with a shaft is a positive displacement compressor, and, thus the pressure inside increases. Fig. 11 is an explanatory diagram of Patent Literature 1 illustrating a pressure change in the compression chamber of the compressor connected to the expander with a shaft. The pressure in the compression chamber of the compressor changes during the process depicted by arrows in Fig. 11. As mentioned above, the compressor is a positive displacement compressor, and, thus, the pressure increases in the inside. Therefore, in order to start up the compressor, a compression power amounting to the area C illustrated in Fig. 1 is needed. That is to say, even when the suction side and the discharge side of the compressor is bypassed, as illustrated in Patent Literature 1, a "negative power" will exist. Thus, in some cases, the "negative power" becomes larger than the "positive power" obtained in the expander, and a possibility of the expander not starting up arises.

[0009] Further, the start up of expanders and compressors are influenced by the static friction acting on thrust bearings, radial bearings, and the like of the expanders and compressors. This static friction is larger than the kinetic friction acting on the thrust bearings, radial bearings, and the like while the expanders and compressors are driven. Therefore, in order to start up expanders and compressors, a "positive power" overcoming the static friction acting on the thrust bearings, radial bearings, and the like of the expanders and compressors will also be required, and the start up of the expanders and the compressors become even more unstable.

[0010] For example, in a scroll compressor, in order to reduce the load applied to the thrust bearing (the friction acting on the thrust bearing), refrigerant in a compression process is typically introduced into the back side of the oscillating scroll. For example, in a scroll expander, in order to reduce the load applied to the thrust bearing (the friction acting on the thrust bearing), refrigerant in the expansion process is typically introduced into the back side of the oscillating scroll. However, these methods of reducing the load applied to the thrust bearing (the friction acting on the thrust bearing) are under the assumption that the thrust bearing is rotating. That is, the methods are for reducing kinetic friction acting on the thrust bearing. Accordingly, it will be not possible to expect the static friction acting on the thrust bearing to be reduced while in a state in which the oscillating scroll is suspended (a

state in which the pressure to reduce the thrust load is not acting on the back side of the oscillating scroll). If pressure to reduce the thrust load is acting on the back side while the oscillating scroll is suspended, it is the pressure due to the leakage of the refrigerant from the expansion chamber or compression chamber. In these expanders and compressors, the performance improvement effect during a steady state in which the oscillating scroll is oscillating will be remarkably diminished, and the primary objective (expansion and compression of the refrigerant) will not be accomplished.

[0011] Further, if the expander or the compressor should fail to start up once, and is mechanically stuck (jammed), a driving source such as a motor will be needed to be rotated with a torque surpassing the jamming. Alternatively, to cancel the jamming, the driving source needs to be rotated slightly backwards. In any event, they are not reliable start up methods.

[0012] Furthermore, in the refrigeration cycle apparatus of the above-mentioned Patent Literature 2, start up of the expander is facilitated by increasing the pressure difference between the suction side and the discharge side of the expander. However, an expander is typically designed based on the steady state. That is, an expander is not designed under the assumption that the start up of the expander will be carried out in a state in which the pressure difference of the inlet side and the outlet side of the expander is small.

[0013] Accordingly, when a refrigerant with high density (with isopycnic lines of low density) flows into the expander, as shown in Fig. 12, the pressure difference in the expansion chamber becomes large, and, thus, the refrigerant becomes over-expanded. Specifically, the power recovered by the expander disadvantageously becomes a power (negative power) corresponding to "area F - area G", and a problem that the expander is unable to continue driving occurs.

[0014] An expander designed with focus on its start up can be considered, but then, the expansion becomes insufficient during steady operation and adequate performance improvement effect cannot be obtained, and the primary objective cannot be achieved.

[0015] EP-A-1 411 309 discloses a refrigeration cycle apparatus according to the preamble of claim 1.

[0016] The present invention has been made to solve at least one of the above problems and an object of the invention is, in a refrigeration cycle apparatus recovering power with an expander, to obtain a refrigeration cycle apparatus that is capable of reliably starting up an expander compared to conventional refrigeration cycle apparatuses.

Solution to Problem

[0017] An refrigeration cycle apparatus according to the invention includes a refrigerant circuit having the features of claim 1.
a discharge side of the expander to be lower than a pres-

sure on a suction side of the expander and that controls a density of the refrigerant flowing into the

Advantageous Effects of Invention

[0018] A refrigeration cycle apparatus according to the invention is provided with a pressure regulating device that maintains the pressure on the discharge side of a second compressor lower than the pressure on the suction side of the second compressor at least until the second compressor is started up. Hence, the compression power is reduced compared to conventional refrigeration cycle apparatuses, and the expander can be reliably started up compared to conventional refrigeration cycle apparatuses.

[0019] Further, the refrigeration cycle apparatus according to the invention is provided with an expander startup facilitating device that controls the density of the refrigerant flowing into the expander such that the pressure on the discharge side of the expander is lower than the pressure on the inlet side of the expander at least until the expander is started up. Accordingly, even when the expander is started up in a state in which a pressure difference is small between the inlet side and the outlet side of the expander, high-density refrigerant flowing into the expander can be prevented. Hence, the expander can be reliably started up compared to conventional refrigeration cycle apparatuses.

Brief Description of Drawings

[0020]

[Fig. 1] Fig. 1 is a refrigerant circuit diagram of a refrigeration cycle apparatus of Embodiment 1.

[Fig. 2] Fig. 2 is a refrigerant circuit diagram showing a refrigerant flow during a steady state of the refrigeration cycle apparatus of Embodiment 1.

[Fig. 3] Fig. 3 is a refrigerant circuit diagram showing a refrigerant flow during a start up of the refrigeration cycle apparatus of Embodiment 1.

[Fig. 4] Fig. 4 is an explanatory diagram illustrating a pressure change in an expansion chamber of an expander during the start up of the expander of Embodiment 1.

[Fig. 5] Fig. 5 is an explanatory diagram illustrating a pressure change in a compression chamber of a second compressor during the start up of the second compressor of Embodiment 1.

[Fig. 6] Fig. 6 is another refrigerant circuit diagram of the refrigeration cycle apparatus of Embodiment 1 of the invention.

[Fig. 7] Fig. 6 is still another refrigerant circuit diagram of the refrigeration cycle apparatus of Embodiment 1 of the invention.

[Fig. 8] Fig. 8 is a refrigerant circuit diagram of a refrigeration cycle apparatus of Embodiment 2.

[Fig. 9] Fig. 9 is a refrigerant circuit diagram showing

a refrigerant flow during a steady state of the refrigeration cycle apparatus of Embodiment 2.

[Fig. 10] Fig. 10 is a refrigerant circuit diagram showing a refrigerant flow during a start up of the refrigeration cycle apparatus of Embodiment 2.

[Fig. 11] Fig. 11 is an explanatory diagram illustrating a pressure change in a compression chamber of a compressor connected to an expander with a shaft shown in Patent Literature 1.

[Fig. 12] Fig. 12 is an explanatory diagram illustrating a pressure change in an expansion chamber when a high-density refrigerant flows into an expander during start up of the expander shown in Patent Literature 2.

Description of Embodiment

Embodiment 1

[0021] Embodiment of the invention will be described below with reference to the drawings.

[0022] Fig. 1 is a refrigerant circuit diagram of a refrigeration cycle apparatus of Embodiment 1 of the invention.

[0023] A refrigeration cycle apparatus 1 uses carbon dioxide as a refrigerant and includes a first compressor 2, a second compressor 3, a radiator 4, an expander 5, and an evaporator 6 connected in order with a refrigerant piping. Further, a drive shaft of the second compressor 3 and a drive shaft of the expander 5 are connected with a shaft 7. Note that the radiator 4 and the evaporator 6 may be disposed in plural numbers.

[0024] The first compressor 2 is equipped with, for example, a motor that is driven with supply of electrical power, and is capable of driving independently. The second compressor 3 is a positive displacement compressor and is driven by power recovered by the expander 5. The expander 5 is a positive displacement expander and supplies the power recovered during the expansion of the refrigerant to the second compressor 3. Additionally, in the vicinity of the radiator 4, a fan 4a is provided that sends air (heat medium), which exchanges heat with the refrigerant flowing in the radiator 4, to the radiator 4. In the vicinity of the evaporator 6, a fan 6a is provided that sends air (heat medium), which exchanges heat with the refrigerant flowing in the evaporator 6, to the evaporator 6.

[0025] Note that the radiator 4 corresponds to a first heat exchanger in the invention. In addition the evaporator 6 corresponds to a second heat exchanger in the invention. Fan 4a corresponds to a heat medium sending device.

[0026] In the refrigeration cycle apparatus 1, a check valve 10 and a bypass is also provided. The check valve 10 is disposed between the radiator 5 and the expander 5, and regulates the refrigerant from flowing from the expander 5 to the radiator 4. One end of the bypass 8 is connected between the first compressor 2 and the second compressor 3, and the other end is connected be-

tween the check valve 10 and the expander 5. This bypass 8 is provided with an on-off valve 9 that closes and opens the bypass 8.

[0027] Additionally, the refrigeration cycle apparatus 1 is disposed with a temperature sensor 21 on the discharge side of the second compressor 3, the temperature sensor 21 serving as a refrigerant temperature measuring device.

[0028] A controller 100 controls the rotation speed of the motor equipped in the first compressor 2, rotation speed of the fan 4a, rotation speed of the fan 6a, and the closing and opening of the on-off valve 9. This controller 100 also receives the detection value of the temperature sensor 21.

<Description of Operation>

[0029] Description of the operation of the refrigeration cycle apparatus 1 configured as above will be made. First, the operation of the refrigeration cycle apparatus 1 during steady operation will be described. Then, the operation of the refrigeration cycle apparatus 1 during a start up will be described.

(Operation During Steady Operation)

[0030] The operation of the refrigeration cycle apparatus 1 during the steady operation will be described.

[0031] Fig. 2 is a refrigerant circuit diagram showing the refrigerant flow during the steady state of the refrigeration cycle apparatus according to Embodiment 1 of the invention. During the steady state, the on-off valve 9 is in a closed state. That is, in the steady state, the refrigerant is not allowed to flow in the bypass 8. Note that in Fig. 2, piping in which the refrigerant flows is depicted with thick lines.

[0032] The refrigerant that has been compressed into a high-temperature middle-pressure refrigerant in the first compressor 2 is discharged from the first compressor 2. This high-temperature middle-pressure refrigerant is compressed in the second compressor 3 into a high-temperature high-pressure state (supercritical state), and flows into the radiator 4. The refrigerant that has flowed into the radiator 4 transfers heat to the air sent by the fan 4a and turns into a low-temperature high-pressure refrigerant. This low-temperature high-pressure refrigerant passes through the first check valve 10 and flows into the expander 5. The refrigerant that has flowed into the expander 5 is decompressed into a low-pressure refrigerant with low dryness. During this decompression process, the expander 5 recovers power. Then, the recovered power is supplied to the second compressor 3 through the shaft 7. The low-pressure refrigerant with low dryness that has flowed out from the expander 5 flows into the evaporator 6. The refrigerant that has flowed into the evaporator 6 receives heat from the air sent from the fan 6a and turns into a low-pressure refrigerant with high dryness or a low-pressure super-heated gas refrigerant.

The refrigerant that has flowed out of the evaporator 6 is sucked into the first compressor 2.

[0033] Since the power recovered by the expander 5 is used as compression power in the second compressor 3, the power required in the first compressor is reduced by the amount of power recovered. Hence, the refrigeration cycle apparatus 1 achieves energy saving.

(Operation During Start Up)

[0034] Next, the operation of the refrigeration cycle apparatus 1 during start up will be described.

[0035] Fig. 3 is a refrigerant circuit diagram showing the refrigerant flow during the start up of the refrigeration cycle apparatus of Embodiment 1 of the invention. During the start up, the on-off valve 9 is in an opened state. That is, in the start up, the refrigerant is allowed to flow in the bypass 8. Note that in Fig. 3, piping in which the refrigerant flows is depicted with thick lines.

[0036] During the start up, since the second compressor 3 is still suspended, the refrigerant that has been compressed into a high-temperature middle-pressure refrigerant in the first compressor 2 flows through the bypass 8 and reaches the expander 5. At this time, the check valve 10 prevents the refrigerant flowing out of the bypass 8 to flow to the radiator 4 and the discharge side of the second compressor 3. Specifically, during the state in which the second compressor 3 is suspended, the pressure on the suction side of the second compressor 3 is the pressure of the refrigerant that has been discharged from the first compressor 2, which is higher than the pressure on the discharge side of the second compressor 3.

[0037] Note that during the state in which the second compressor 3 is suspended, even if the check valve 10 is not provided, the pressure on the suction side of the second compressor 3 is higher than the pressure on the discharge side of the second compressor 3. The time for the second compressor 3 to start up after the first compressor 2 has started up is a few seconds (with the refrigeration cycle apparatus 1 of Embodiment 1, about two to three seconds, for example). Accordingly, the refrigerant flowing in the discharge side of the second compressor 3 is stored in the radiator 4 (the radiator 4 serving as a buffer), and therefore the pressure rise on the discharge side of the second compressor 3 becomes slack.

[0038] That is, the bypass 8 and the on-off valve 9 are the pressure regulating device of the invention. In Embodiment 1, the check valve 10 is provided in order to reliably obtain the pressure difference between the suction side of the second compressor 3 and the pressure of the discharge side thereof.

[0039] Further, with the start up of the first compressor 2, the refrigerant on the outlet side of the expander 5 is sucked into the first compressor 2 via the evaporator 6. Specifically, when the expander 5 is in a suspended state, the pressure on the discharge side of the expander 5 becomes smaller than the inlet side of the expander 5.

Further, since the refrigerant flowing into the inlet side of the expander 5 is a refrigerant that has not passed through the radiator 4, the refrigerant is low in density. That is, the bypass 8 and the on-off valve 9 are the expander startup facilitating device of the invention. Note that during the state in which the second compressor 3 is suspended, even if the check valve 10 is not provided, the refrigerant flowing into the inlet side of the expander 5 is a low-density refrigerant that has not passed through the radiator 4. Accordingly, the check valve 10 does not have to be a constitution of the expander startup facilitating device.

[0040] When the pressure difference between the pressure on the inlet side of the expander 5 and the pressure on the outlet side of the expander 5 (hereinafter referred to as "pressure difference of the expander 5") becomes large, the expander 5 is started up (the driving starts).

[0041] At this time, the pressure in the expansion chamber of the expander 5 is as shown in Fig. 4.

[0042] Fig. 4 is an explanatory diagram illustrating a pressure change in an expansion chamber of the expander during the start up of the expander according to Embodiment 1 of the invention. The pressure in the expansion chamber of the expander 5 changes during the process depicted by arrows in Fig. 4. Further, for reference purpose, the pressure change in the expansion chamber during start up of the expander according to Patent Literature 2 will be depicted with a broken line.

[0043] Since the pressure difference of the expander 5 during the start up is smaller than the pressure difference of the expander 5 during the steady state, the refrigerant is slightly over-expanded, but power (positive power) corresponding to "area D - area E" can be obtained. Thus, the driving of the expander 5 can be continued.

[0044] Meanwhile, the pressure of the compression chamber of the second compressor 3 that is connected to the expander 5 via the shaft 7 changes as shown in Fig. 5.

[0045] Fig. 5 is an explanatory diagram illustrating a pressure change in the compression chamber of the second compressor during the start up of the second compressor according to Embodiment 1 of the invention. The pressure in the compression chamber of the second compressor 3 changes during the process depicted by arrows in Fig. 5.

[0046] Since the pressure on the suction side of the second compressor 3 is larger than the pressure on the discharge side thereof (the pressure is inverse), it is supercompressed. The compression power at this time is the power corresponding to the "area A - area B", and is smaller than that of the conventional refrigeration cycle apparatus that equalizes the pressure on the discharge side and the suction side of the compressor (Patent Literature 1, for example). Accordingly, it is easier to start up the second compressor 3 than the conventional refrigeration cycle apparatus. Further, depending on the

extent of the inverse pressure, a power recovery corresponding to area B - area A can be obtained. The power in proportion to this will contribute to the stable start up of the second compressor 3.

[0047] Once the expander 5 and the second compressor 3 is started up, it is possible to continue the driving of the expander 5 and the second compressor 3 even when the on-off valve 9 is closed. However, in Embodiment 1, in order to reliably continue the driving of the expander 5 and the second compressor 3, the on-off valve 9 is in an opened state until the refrigeration cycle apparatus 1 is capable of operating in the steady state.

[0048] More specifically, the controller 100 controls the on-off valve 9 as below. When the second compressor 3 is driven continuously, the refrigerant temperature discharged from the second compressor 3 rises. Additionally, the pressure on the discharge side of the second compressor 3 becomes larger or equal to the pressure on the suction side. That is, it is possible to operate the refrigeration cycle apparatus 1 in the steady state.

[0049] In the refrigeration cycle apparatus 1, the temperature of the refrigerant discharged from the second compressor 3 is detected with the temperature sensor 21. In addition, the controller 100 determines that the refrigeration cycle apparatus 1 is capable of operating in the steady state when the detection temperature of the temperature sensor 21 is above or equal to a certain threshold value, and closes the on-off valve 9.

[0050] Note that even if a delay occurs in determining that the refrigeration cycle apparatus 1 is capable of operating in the steady state, because the check valve 10 is provided, the refrigerant flows to the expander 5 without the discharge pressure of the second compressor 3 rising suddenly. Accordingly, it is possible to reliably start up the refrigeration cycle apparatus 1 without the operation of a protective device for high pressure and high temperature.

[0051] As described above, in the above-configured refrigeration cycle apparatus 1, the pressure on the suction side of the second compressor 3 is made to be larger than the pressure on the discharge side thereof at least until the second compressor 3 is started up. Further, at least until the expander 5 starts up, the pressure on the outlet side of the expander 5 is made to be smaller than the pressure on the inlet side of the expander 5, and the refrigerant flowing to the inlet side of the expander 5 is made to be low in density. Accordingly, it is possible to start up the second compressor 3 and the expander 5 more reliably than the conventional refrigeration cycle apparatus.

[0052] Note that, it goes without saying that by merely making the pressure on the inlet side of the second compressor 3 to be larger than the pressure on the outlet side of the second compressor 3, the second compressor 3 and the expander 5 can be started up more reliably compared to conventional refrigeration cycle apparatuses. Further, it goes without saying that by merely making the pressure on the outlet side of the expander 5 to be smaller

than the pressure on the inlet side of the expander 5, the second compressor 3 and the expander 5 can be started up more reliably compared to conventional refrigeration cycle apparatuses.

[0053] Furthermore, the invention may be embodied by providing a four-way valve in the refrigeration cycle apparatus so that the flows of the refrigerant may be switched.

[0054] Fig. 6 is another refrigerant circuit diagram of the refrigeration cycle apparatus according to Embodiment 1 of the invention. In this refrigeration cycle apparatus 51, a four-way valve 14 is disposed on an outlet side of a second compressor 3. With this four-way valve 14, a passage of a refrigerant discharged from a second compressor 3 is switched between a passage flowing to a radiator 4 and a passage flowing to an evaporator 6. Further, the four-way valve 14 switches a refrigerant passage flowing into a first compressor 2 between the passage from the evaporator 6 and the passage from the radiator 4. Note that when the refrigerant discharged from the second compressor 3 flows into the evaporator 6 (when the refrigerant flows from the radiator 4 into the first compressor 2), the radiator 4 turns into an evaporator, and the evaporator 6 turns into a radiator.

[0055] Further, a four-way valve 15 is disposed on an inlet side of an expander 5. The four-way valve 15 switches the refrigerant passage flowing into the expander 5 between a passage from the radiator 4 and a passage from the evaporator 6.

[0056] When the above refrigeration cycle apparatus is used in an air-conditioning apparatus, the air-conditioning apparatus will be capable of carrying out both a cooling operation and a heating operation.

[0057] Note that since the expander 5 is of a positive displacement type, the refrigerant can only be allowed to flow in one direction. Therefore, a check valve 10 may be provided in the vicinity of the inlet port of the expander 5, and a bypass 8 may be provided between the check valve 10 and the expander 5.

[0058] Additionally, in order to further increase the energy efficiency of the refrigeration cycle apparatus of Embodiment 1, an intercooler 22 may be provided between the first compressor 2 and the second compressor 3. Note that in Fig. 7, an exemplary case in which the intercooler 22 is disposed in the refrigeration cycle apparatus 1 is shown.

[0059] By cooling a high-temperature middle-pressure refrigerant that has been discharged from the first compressor 2, the inclination of the isentropic line of this refrigerant in the Mollier chart becomes steep. That is, the power required for the second compressor 3 to compress the refrigerant can be reduced. Note that the connecting portion of the bypass 8 between the first compressor 2 and the second compressor 3 may be on the upstream side of the intercooler 22 or the downstream side of the intercooler 22. In the former case, a sudden pressure rise of the discharge pressure of the first compressor 2 until the expander 5 starts up can be suppressed. This

effect may be achieved by replacing an on-off valve 9 with a flow control valve and by controlling the opening degree of the flow control valve.

[0060] Further, in Embodiment 1, the heat medium that exchanges heat with the radiator 4 and the evaporator 6 is air, but other heat mediums may be used. For example, the heat medium exchanging heat with the radiator 4 may be water, and the refrigeration cycle apparatus according to Embodiment 1 may be used for supplying hot water. Further, the heat medium exchanging heat with the radiator 4 and the evaporator 6 may be water or brine, and this heat medium may be conveyed to the conditioned space to air-condition the conditioned space.

[0061] Furthermore, in Embodiment 1, carbon dioxide, which has zero ozone depleting potential and has an outstandingly small global warming potential compared to chlorofluorocarbon, is used, but the type of the refrigerant is arbitrary. However, the operating efficiency (COP) of the refrigeration cycle apparatus that employs carbon dioxide is lower compared to refrigeration cycle apparatuses that uses conventional refrigerants. Therefore, it is highly advantageous to employ the invention to a refrigeration cycle apparatus that uses carbon dioxide. Note that when using a refrigerant that is not compressed into a supercritical state, the radiator 4 functions as a condenser.

[0062] Further, in Embodiment 1, although the expander 5 and the second compressor 3 is mechanically connected (with shaft 7), the expander 5 and the second compressor 3 may be connected electrically. For example, the expander 5 may be connected to a power generator, and the power recovered by the expander 5 may be converted into electric power that is supplied to the second compressor 3.

[0063] Furthermore, in Embodiment 1, although the refrigeration cycle apparatus 1 (refrigeration cycle apparatus 51) determined whether steady operation is capable by using the temperature sensor 21, a pressure sensor may be used to determine whether steady operation is capable or not. More specifically, a pressure sensor may be disposed on both the discharge side and the suction side of the second compressor 3. Additionally, when the detection values of these pressure sensors are above or equal to a certain threshold value, the refrigeration cycle apparatus 1 (refrigeration cycle apparatus 51) may determine that steady operation is possible.

Embodiment 2

[0064] The invention can be embodied not only in the refrigeration cycle apparatus illustrated in Embodiment 1, but can be embodied in a refrigeration cycle apparatus with a configuration as below, for example. Note that unless otherwise stated, Embodiment 2 is the same as Embodiment 1.

[0065] Fig. 8 is a refrigerant circuit diagram of a refrigeration cycle apparatus of Embodiment 2 of the invention. A refrigeration cycle apparatus 52 according to Embod-

iment 2 is different with the refrigeration cycle apparatus 1 according to Embodiment 1 in the following points. Other configurations of the refrigeration cycle apparatus 52 is the same as that of the refrigeration cycle apparatus 1.

[0066] First, the location of the first compressor 2 and the second compressor 3 are opposite. Further, a check valve 13 is provided in place of the check valve 10. Furthermore, a bypass 11 and an on-off valve 12 are provided replacing the bypass 8 and the on-off valve 9.

[0067] The check valve 13 is disposed between an expander 5 and an evaporator 6, and regulates the refrigerant from flowing from the evaporator 5 to the expander 5.

[0068] One end of the bypass 11 is connected between the second compressor 3 and the first compressor 2, and the other end is connected between the expander 5 and the check valve 13. This bypass 11 is provided with the on-off valve 12 that closes and opens the bypass 11.

<Description of Operation>

[0069] Description of the operation of the refrigeration cycle apparatus 52 configured as above will be made. First, the operation of the refrigeration cycle apparatus 52 during steady operation will be described. Then, the operation of the refrigeration cycle apparatus 52 during start up will be described.

(Operation During Steady Operation)

[0070] The operation of the refrigeration cycle apparatus 52 during the steady operation will be described.

[0071] Fig. 9 is a refrigerant circuit diagram showing a refrigerant flow during a steady state of the refrigeration cycle apparatus of Embodiment 2 of the invention. During the steady state, the on-off valve 12 is in a closed state. That is, in the steady state, the refrigerant is not allowed to flow in the bypass 11. Note that in Fig. 9, piping in which the refrigerant flows is depicted with thick lines.

[0072] The refrigerant that has been compressed into a high-temperature middle-pressure refrigerant in the second compressor 3 is discharged from the second compressor 3. This high-temperature middle-pressure refrigerant is compressed in the first compressor 2 into a high-temperature high-pressure state (supercritical state), and flows into a radiator 4. The refrigerant that has flowed into the radiator 4 transfers heat to the air sent by a fan 4a and turns into a low-temperature high-pressure refrigerant. This low-temperature high-pressure refrigerant flows into the expander 5. The refrigerant that has flowed into the expander 5 is decompressed into a low-pressure refrigerant with low dryness. During this decompression process, the expander 5 recovers power. Then, the recovered power is supplied to the second compressor 3 through the shaft 7. The low-pressure refrigerant with low dryness that has flowed out from the expander 5 flows into the evaporator 6 through the check valve 13. The refrigerant that has flowed into the evap-

orator 6 receives heat from the air sent from a fan 6a and turns into a low-pressure refrigerant with high dryness or a low-pressure super-heated gas refrigerant. The refrigerant that has flowed out of the evaporator 6 is sucked into the second compressor 3.

[0073] Since the power recovered by the expander 5 is used as compression power in the second compressor 3, the power required in the first compressor is reduced by the amount of power recovered. Hence, the refrigeration cycle apparatus 52 achieves energy saving.

(Operation During Start Up)

[0074] Next, the operation of the refrigeration cycle apparatus 1 during start up will be described.

[0075] Fig. 10 is a refrigerant circuit diagram showing a refrigerant flow during the start up of the refrigeration cycle apparatus of Embodiment 2 of the invention. During the start up, the on-off valve 12 is in an opened state. That is, in the start up, the refrigerant is allowed to flow in the bypass 11. Further, the fan 4a that is sending air to the radiator is stopped or has a speed of rotation (rotation speed) lower than that of a steady state. Note that in Fig. 10, piping in which the refrigerant flows is depicted with thick lines.

[0076] The refrigerant that has been condensed in the first compressor 2 passes through the radiator 4 and reaches the expander 5. Further, with the start up of the first compressor 2, the refrigerant on the outlet side of the expander 5 passes through the bypass 11 and is sucked into the first compressor 2. Here, the check valve 13 prevents the refrigerant in the suction side of the second compressor 3 to be sucked into the first compressor 2. That is, during the start up in which the second compressor 3 is suspended, the pressure on the suction side of the second compressor 3 becomes higher than the pressure on the discharge side of the second compressor 3.

[0077] Note that during the state in which the second compressor 3 is suspended, even if the check valve 13 is not provided, the pressure on the suction side of the second compressor 3 is higher than the pressure on the discharge side of the second compressor 3. The time for the second compressor 3 to start up after the first compressor 2 has started up is a few seconds (with the refrigeration cycle apparatus 52 of Embodiment 2, about two to three seconds, for example). Accordingly, most of the refrigerant that is sucked into the suction side of the second compressor 3 is the refrigerant stored in the evaporator 6 (the evaporator 6 serving as a buffer), and therefore the pressure rise on the suction side of the second compressor 3 becomes slack.

[0078] That is, the bypass 11 and the on-off valve 12 are the pressure regulating device of the invention. In Embodiment 2, in order to reliably obtain the pressure difference between the suction side of the second compressor 3 and the pressure of the discharge side thereof, the check valve 13 is provided.

[0079] That is, when the expander 5 is in a suspended state, the pressure on the discharge side of the expander 5 becomes smaller than the inlet side of the expander 5. Further, since the refrigerant flowing into the inlet side of the expander 5 exchanges small amount of heat in the radiator 4, the refrigerant is low in density. That is, the controller 100 that controls the bypass 11 and the on-off valve 12, and the rotation speed of the fan 4a is the expander startup facilitating device of the invention. Note that the check valve 13 does not have to be a constitution of the expander startup facilitating device.

[0080] When the pressure difference of the expander 5 becomes large, the expander starts up (driving starts). At this time, the pressure in the expansion chamber of the expander 5 is as shown in Fig. 4 (same as Embodiment 1). Since the pressure difference of the expander 5 during the start up is smaller than the pressure difference of the expander 5 during the steady state, the refrigerant is slightly over-expanded, but power (positive power) corresponding to "area D - area E" can be obtained. Thus, the driving of the expander 5 can be continued.

[0081] Meanwhile, the pressure of the compression chamber of the second compressor 3 that is connected to the expander 5 via the shaft 7 changes as shown in Fig. 5 (same as Embodiment 1). Since the pressure on the suction side of the second compressor 3 is larger than the pressure on the discharge side thereof (the pressure is inverse), it is supercompressed. The compression power at this time is the power corresponding to the "area A - area B", and is smaller than that of the conventional refrigeration cycle apparatus that equalizes the pressure on the discharge side and the suction side of the compressor (Patent Literature 1, for example). Accordingly, it is easier to start up the second compressor 3 than the conventional refrigeration cycle apparatus. Further, depending on the extent of the inverse pressure, a power recovery corresponding to area B - area A can be obtained. The power in proportion to this will contribute to the stable start up of the second compressor 3.

[0082] Once the expander 5 and the second compressor 3 is started up, it is possible to continue the driving of the expander 5 and the second compressor 3 even when the on-off valve 12 is closed. However, in Embodiment 2, in order to reliably continue the driving of the expander 5 and the second compressor 3, the on-off valve 12 is in an opened state until the refrigeration cycle apparatus 52 is capable of operating in the steady state.

[0083] More specifically, the controller 100 controls the on-off valve 12 as below. When the second compressor 3 is driven continuously, the refrigerant temperature discharged from the second compressor 3 rises. Additionally, the pressure on the discharge side of the second compressor 3 becomes larger or equal to the pressure on the suction side. That is, it is possible to operate the refrigeration cycle apparatus 52 in the steady state.

[0084] In the refrigeration cycle apparatus 52, the temperature of the refrigerant discharged from the second

compressor 3 is detected with a temperature sensor 21. In addition, the controller 100 determines that the refrigeration cycle apparatus 1 is capable of operating in the steady state when the detection temperature of the temperature sensor 21 is above or equal to a certain threshold value, and closes the on-off valve 12. Furthermore, the rotation speed of the fan 4a is changed to the rotation speed for the steady state. A pressure sensor may be used to determine whether the refrigeration cycle apparatus 52 is capable of the steady operation or not.

[0085] Note that even if a delay occurs in determining that the refrigeration cycle apparatus 52 is capable of operating in the steady state, because the check valve 13 is provided, the refrigerant flows to the expander 5 without the suction pressure of the second compressor 3 dropping suddenly. Accordingly, it is possible to reliably start up the refrigeration cycle apparatus 52 without the operation of a protective device for low pressure and low temperature.

[0086] As described above, in the above-configured refrigeration cycle apparatus 52, the pressure on the suction side of the second compressor 3 is made to be larger than the pressure on the discharge side thereof at least until the second compressor 3 is started up. Further, at least until the expander 5 starts up, the pressure on the outlet side of the expander 5 is made to be smaller than the pressure on the inlet side of the expander 5, and the refrigerant flowing to the inlet side of the expander 5 is made to be low in density. Accordingly, it is possible to start up the second compressor 3 and the expander 5 more reliably than the conventional refrigeration cycle apparatus.

[0087] Note that, it goes without saying that by merely making the pressure on the inlet side of the second compressor 3 to be larger than the pressure on the outlet side of the second compressor 3, the second compressor 3 and the expander 5 can be started up more reliably compared to conventional refrigeration cycle apparatuses. Further, it goes without saying that by merely making the pressure on the outlet side of the expander 5 to be smaller than the pressure on the inlet side of the expander 5, the second compressor 3 and the expander 5 can be started up more reliably compared to conventional refrigeration cycle apparatuses.

Reference Signs List

[0088] 1 refrigeration cycle apparatus; 2 first compressor; 3 second compressor; 4 radiator; 4a fan; 5 expander; 6 evaporator; 6a fan; 7 shaft; 8 bypass; 9 on-off valve; 10 check valve; 11 bypass; 12 on-off valve; 13 check valve; 14 four-way valve; 15 four-way valve; 21 temperature sensor; 22 intercooler; 51 refrigeration cycle apparatus; 52 refrigeration cycle apparatus; 100 controller.

Claims

1. A refrigeration cycle apparatus (1, 51, 52), comprising:

a refrigerant circuit connecting a first compressor (2), a first heat exchanger that serves as a radiator (4) or a condenser, an expander (5), and a second heat exchanger that serves as an evaporator (6) in series with a piping; a second compressor (3) that is driven by power recovered by the expander (5), wherein the second compressor (3) is being disposed

i) between the first compressor (2) and the first heat exchanger in the refrigerant circuit; or

ii) between the first compressor (2) and the second heat exchanger in the refrigerant circuit; **characterised in that** the second compressor (3) is a positive displacement compressor,

the refrigeration cycle apparatus (1) further comprising a pressure regulating device that maintains a pressure on a discharge side of the second compressor (3) to be lower than a pressure on a suction side of the second compressor (3) at least until the second compressor (3) is started up, wherein the pressure regulating device includes:

a bypass (8, 11) having one end connected between the first compressor (2) and the second compressor (3) and the other end connected between the first heat exchanger and the expander (5); and

an on-off valve (9, 12) provided in the bypass (8, 11), and

wherein the on-off valve (9, 12) is maintained in an opened state at least until the second compressor (3) is started up.

2. The refrigeration cycle apparatus (1) of alternative i) of claim 1, further comprising a check valve (10) provided at a position, which is closer to the first heat exchanger than the connection point of the bypass (8), on a passage between the first heat exchanger and the expander (5), the check valve (10) regulating a flow of the refrigerant to the first heat exchanger.
3. The refrigeration cycle apparatus (1) of alternative ii) of claim 1, further comprising a check valve (13) provided at a position, which is closer to the second heat exchanger than the connection point of the bypass (11), on a passage between the second heat

exchanger and the expander (5), the check valve (13) regulating a flow of the refrigerant to the expander (5).

4. The refrigeration cycle apparatus (1) of alternative i) of claim 1, further comprising a heat medium sending device that sends a heat medium, which exchanges heat with the refrigerant flowing in the first heat exchanger, to the first heat exchanger, wherein at least until the second compressor (3) is started up, the rotation speed of the heat medium sending device is reduced under the target rotation speed or the heat medium sending device is stopped.
5. The refrigeration cycle apparatus (1) of any one of claims 1 to 4, wherein the refrigerant flowing in the refrigerant circuit is carbon dioxide.

Patentansprüche

1. Kältekreislaufvorrichtung (1, 51, 52), umfassend:

einen Kältemittelkreislauf, verbindend einen ersten Verdichter (2), einen ersten Wärmetauscher, der als ein Radiator (4) oder ein Kondensator dient, einen Expandierer (5) und einen zweiten Wärmetauscher, der als ein Verdampfer (6) dient, in Reihe mit einer Rohrleitung; einen zweiten Verdichter (3), der durch vom Expandierer (5) zurückgewonnene Leistung angetrieben wird, wobei der zweite Verdichter (3)

- i) zwischen dem ersten Verdichter (2) und dem ersten Wärmetauscher im Kältemittelkreislauf; oder
- ii) zwischen dem ersten Verdichter (2) und dem zweiten Wärmetauscher im Kältemittelkreislauf angeordnet ist;

dadurch gekennzeichnet, dass

der zweite Verdichter (3) ein Verdrängungsverdichter ist,

wobei die Kältekreislaufvorrichtung (1) ferner umfasst: eine Druckregelungseinrichtung, die einen Druck an einer Auslassseite des zweiten Verdichters (3) niedriger als ein Druck an einer Ansaugseite des zweiten Verdichters (3) hält, zumindest bis der zweite Verdichter (3) gestartet wird,

wobei die Druckregelungseinrichtung umfasst:

- einen Bypass (8, 11), aufweisend ein Ende, das zwischen dem ersten Verdichter (2) und dem zweiten Verdichter (3) verbunden ist, und das andere Ende, das zwischen dem

ersten Wärmetauscher und dem Expandierer (5) verbunden ist; und
ein Auf/Zu-Ventil (9, 12), das im Bypass (8, 11) bereitgestellt ist, und wobei das Auf/Zu-Ventil (9, 12) in einem geöffneten Zustand gehalten wird, zumindest bis der zweite Verdichter (3) gestartet wird.

2. Kältekreislaufvorrichtung (1) gemäß Alternative i) nach Anspruch 1, ferner umfassend ein Rückschlagventil (10), das an einer Position bereitgestellt ist, die näher zum ersten Wärmetauscher ist als der Verbindungspunkt des Bypasses (8), an einem Durchlass zwischen dem ersten Wärmetauscher und dem Expandierer (5), wobei das Rückschlagventil (10) eine Strömung des Kältemittels zum ersten Wärmetauscher regelt.
3. Kältekreislaufvorrichtung (1) gemäß Alternative ii) nach Anspruch 1, ferner umfassend ein Rückschlagventil (13), das an einer Position bereitgestellt ist, die näher zum zweiten Wärmetauscher ist als der Verbindungspunkt des Bypasses (11), an einem Durchlass zwischen dem zweiten Wärmetauscher und dem Expandierer (5), wobei das Rückschlagventil (13) eine Strömung des Kältemittels zum Expandierer (5) regelt.
4. Kältekreislaufvorrichtung (1) gemäß Alternative i) nach Anspruch 1, ferner umfassend eine Wärmemediumzuführungseinrichtung, die ein Wärmemedium, welches Wärme mit dem im ersten Wärmetauscher strömenden Kältemittelaustauscht, zum ersten Wärmetauscher zuführt, wobei zumindest bis der zweite Verdichter (3) gestartet wird, die Rotationsgeschwindigkeit der Wärmemediumzuführungseinrichtung unter die Zielrotationsgeschwindigkeit verringert wird oder die Wärmemediumzuführungseinrichtung gestoppt wird.
5. Kältekreislaufvorrichtung (1) nach einem der Ansprüche 1 bis 4, wobei das im Kältemittelkreislauf strömende Kältemittel Kohlenstoffdioxid ist.

Revendications

1. Appareil à cycle de réfrigération (1, 51, 52), comprenant :

un circuit de fluide frigorigène reliant un premier compresseur (2), un premier échangeur de chaleur qui sert en tant que radiateur (4) ou condenseur, un détendeur (5), et un deuxième échangeur de chaleur qui sert en tant qu'évaporateur (6) en série avec une tuyauterie ;
un deuxième compresseur (3) qui est commandé par la puissance récupérée par le détendeur

(5),
dans lequel le deuxième compresseur (3) est
disposé

- (i) entre le premier compresseur (2) et le 5
premier échangeur de chaleur dans le cir-
cuit de fluide frigorigène ; ou
- (ii) entre le premier compresseur (2) et le
deuxième échangeur de chaleur dans le cir- 10
cuit de fluide frigorigène ;

caractérisé en ce que

le deuxième compresseur (3) est un compres-
seur volumétrique,
l'appareil à cycle de réfrigération (1) comprenant 15
en outre un dispositif de régulation de pression
qui maintient une pression d'un côté de déchar-
ge du deuxième compresseur (3) à une valeur
inférieure à une pression d'un côté d'aspiration
du deuxième compresseur (3) au moins jusqu'à 20
ce que le deuxième compresseur (3) ait été dé-
marré,
dans lequel le dispositif de régulation de pres-
sion comprend :

- une dérivation (8, 11) ayant une extrémité 25
reliée entre le premier compresseur (2) et
le deuxième compresseur (3) et l'autre ex-
trémité reliée entre le premier échangeur de
chaleur et le détendeur (5) ; et 30
- une vanne tout ou rien (9, 12) prévue dans
la dérivation (8, 11), et
dans lequel la vanne tout ou rien (9, 12) est
maintenue dans un état ouvert au moins jus-
qu'à ce que le deuxième compresseur (3) 35
ait été démarré.

2. Appareil à cycle de réfrigération (1) de la variante (i)
de la revendication 1, comprenant en outre un clapet
anti-retour (10) prévu à une position, qui est plus 40
proche du premier échangeur de chaleur que le point
de liaison de la dérivation (8), sur un passage entre
le premier échangeur de chaleur et le détendeur (5),
le clapet anti-retour (10) régulant un écoulement du
fluide frigorigène vers le premier échangeur de cha- 45
leur.
3. Appareil à cycle de réfrigération (1) de la variante (ii)
de la revendication 1, comprenant en outre un clapet
anti-retour (13) prévu à une position, qui est plus 50
proche du deuxième échangeur de chaleur que le
point de liaison de la dérivation (11), sur un passage
entre le deuxième échangeur de chaleur et le détec-
teur (5), le clapet anti-retour (13) régulant un écou-
lement du fluide frigorigène vers le détendeur (5). 55
4. Appareil à cycle de réfrigération (1) de la variante (i)
de la revendication 1, comprenant en outre un dis-

positif d'envoi de milieu de chaleur qui envoie un
milieu de chaleur, qui échange de la chaleur avec le
fluide frigorigène s'écoulant dans le premier échan-
geur de chaleur, au premier échangeur de chaleur,
dans lequel
au moins jusqu'à ce que le deuxième compresseur
(3) ait été démarré, la vitesse de rotation du dispositif
d'envoi de milieu de chaleur est réduite au-dessous
de la vitesse de rotation cible ou le dispositif d'envoi
de milieu de chaleur est arrêté.

5. Appareil à cycle de réfrigération (1) selon l'une quel-
conque des revendications 1 à 4, dans lequel le fluide
frigorigène s'écoulant dans le circuit de fluide frigo-
rigène est du dioxyde de carbone.

FIG. 1

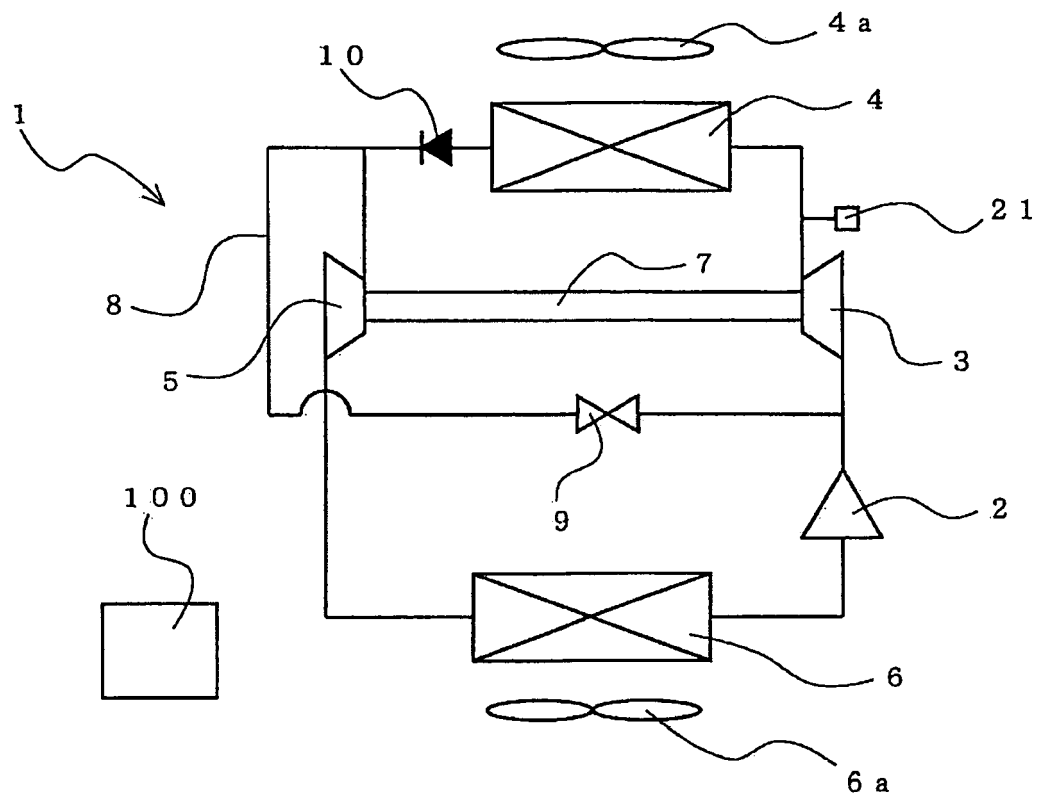
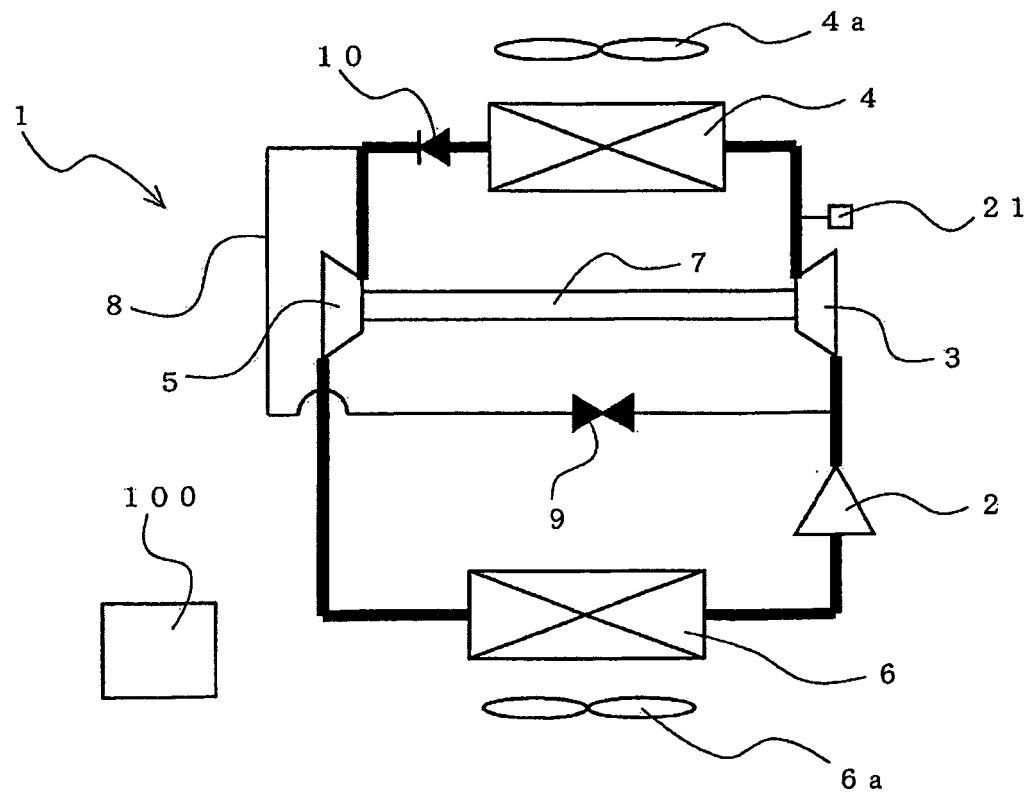


FIG. 2



REPLACEMENT SHEET

FIG. 3

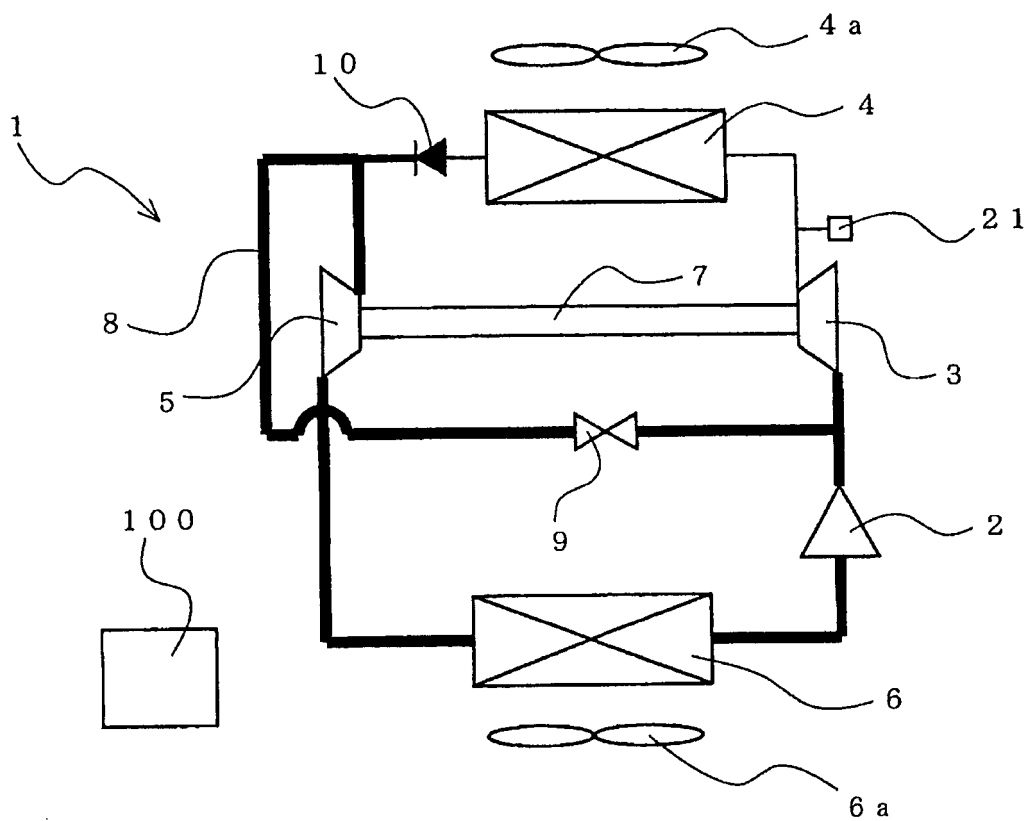


FIG. 4

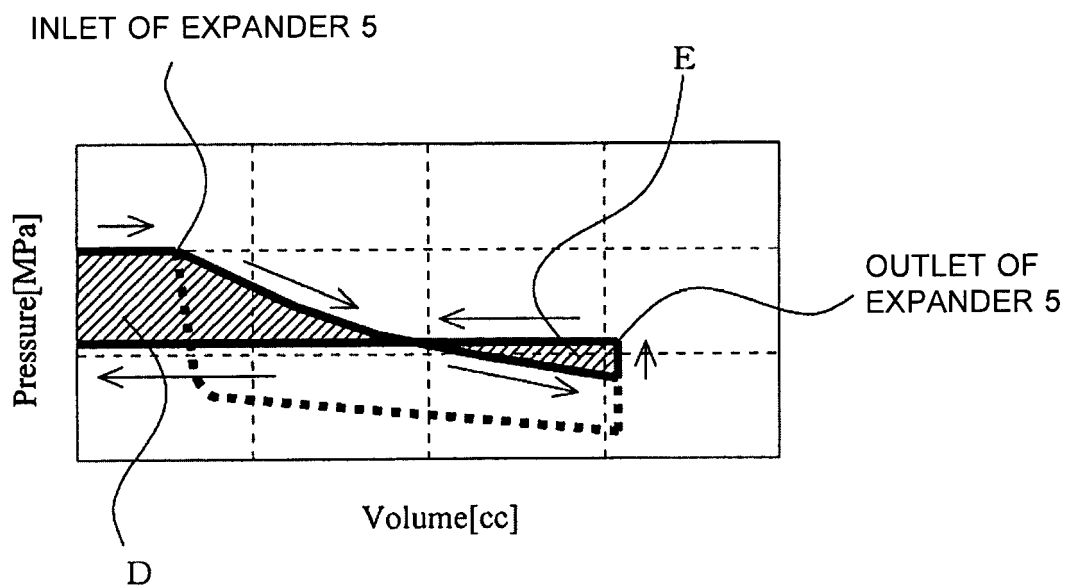


FIG. 5

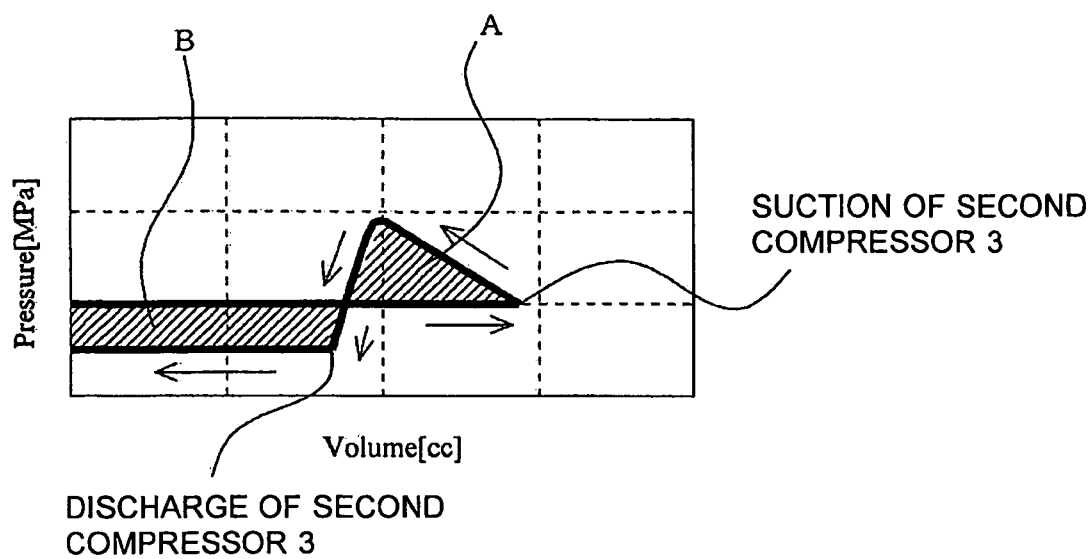


FIG. 6

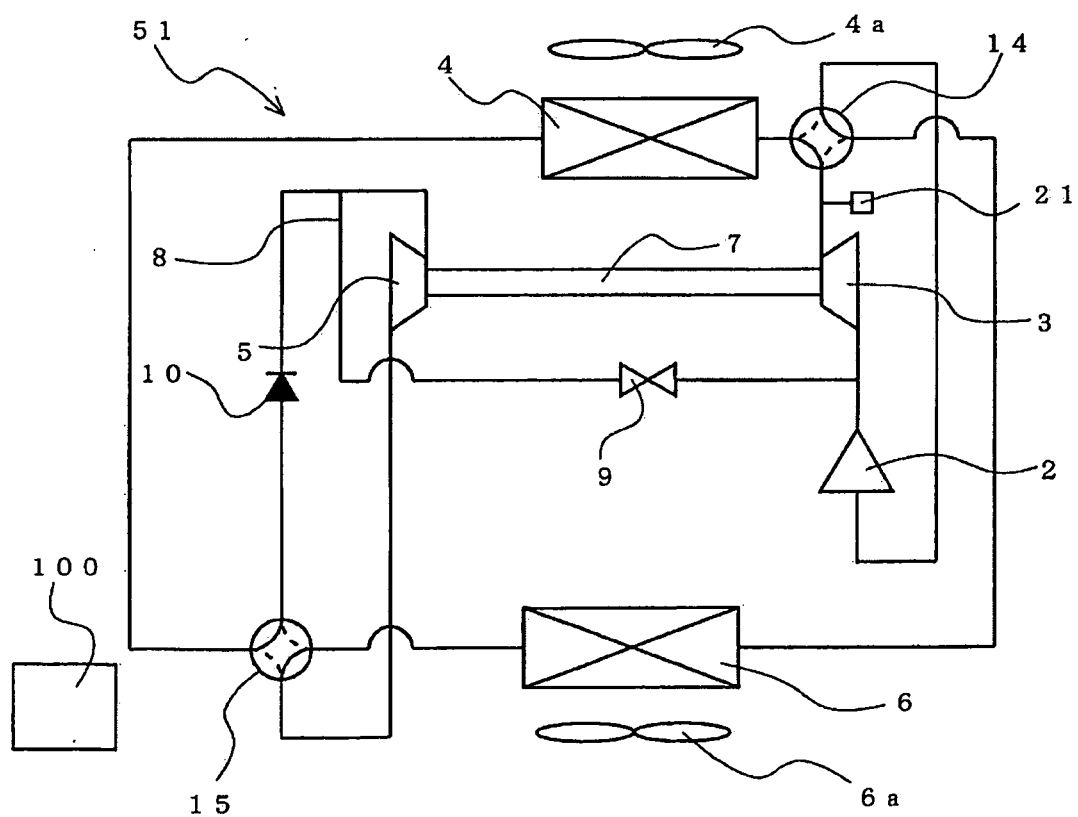


FIG. 7

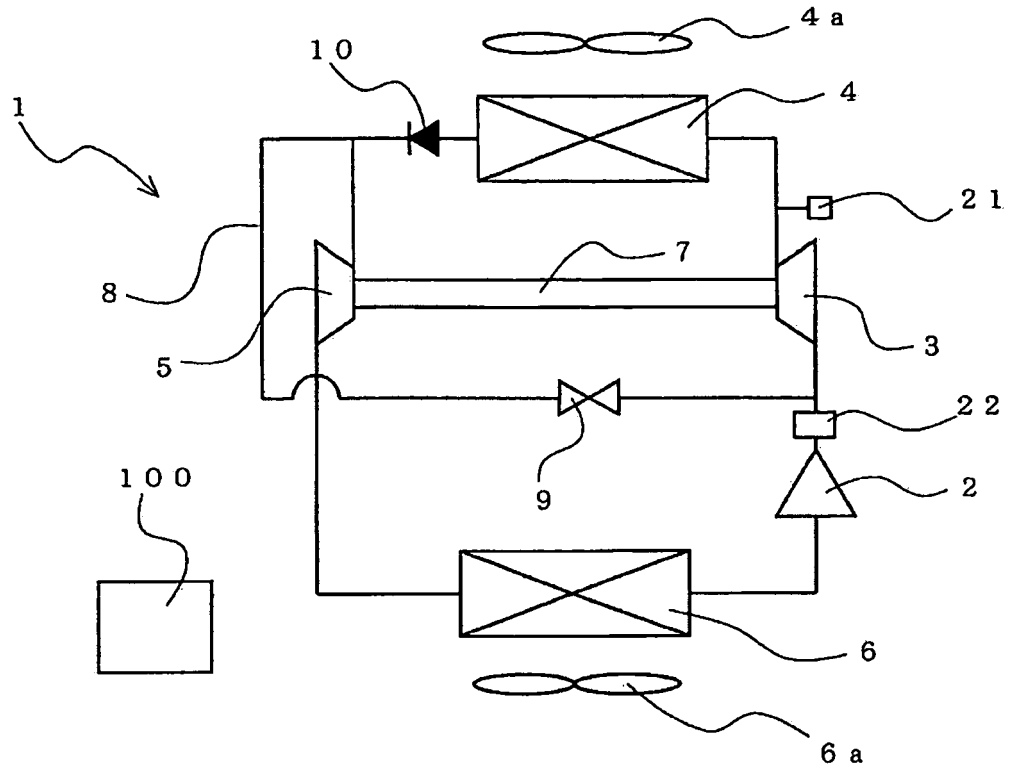


FIG. 8

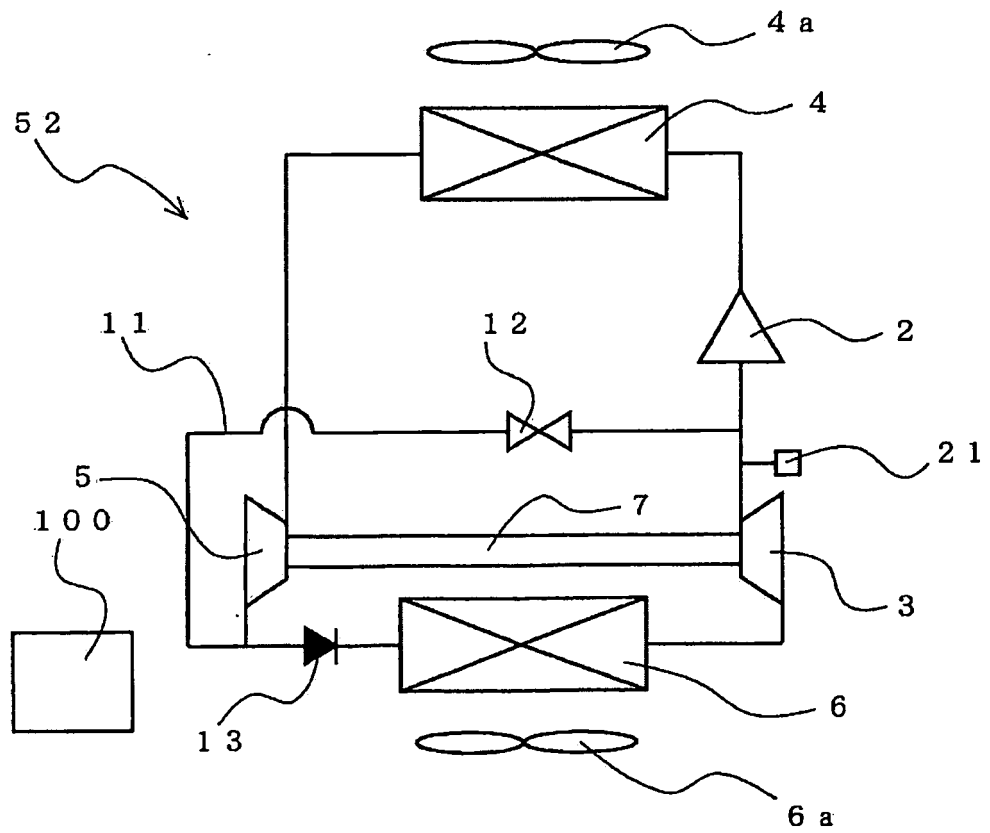


FIG. 9

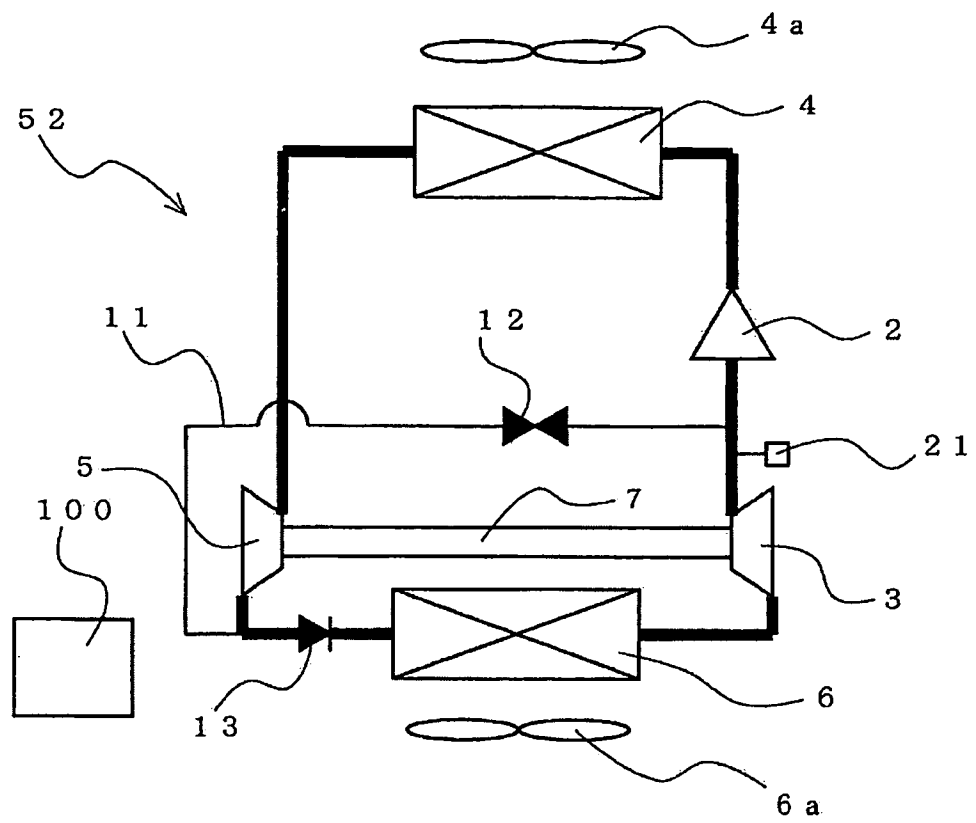


FIG. 10

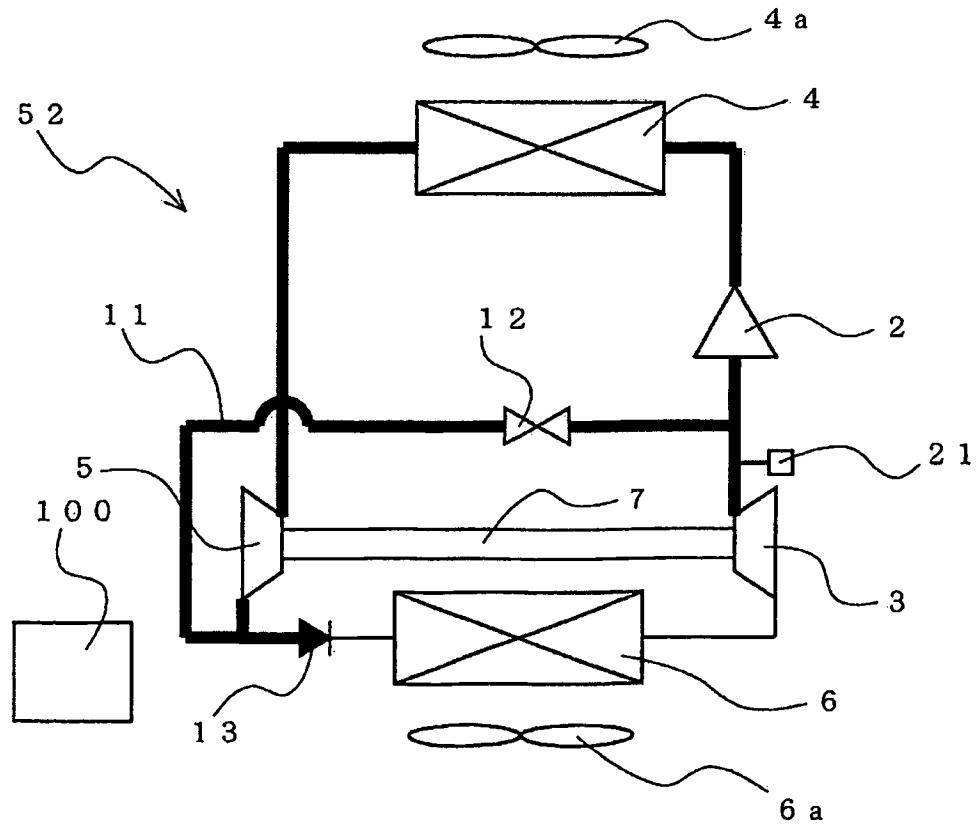


FIG. 11

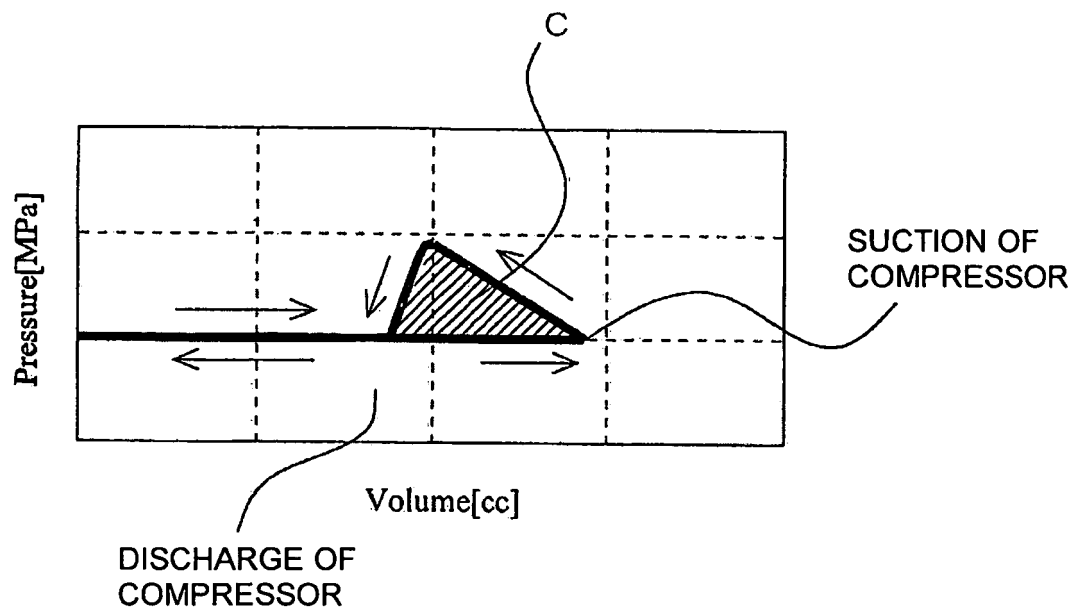
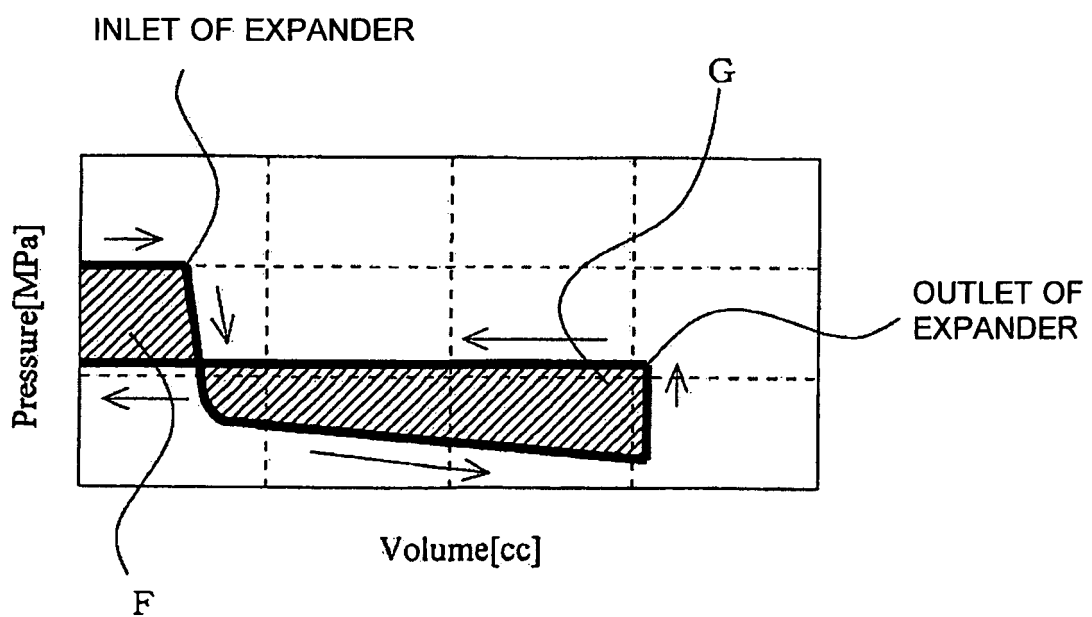


FIG. 12



REFERENCES CITED IN THE DESCRIPTION

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