

SPECIFICATION

TITLE OF THE INVENTION: REFRIGERATION SYSTEM

TECHNICAL FIELD

5 [0001] The present disclosure relates to a refrigeration system utilizing a Brayton refrigeration cycle.

BACKGROUND

[0002] As a refrigeration cycle, a refrigeration system utilizing a Brayton refrigeration
10 cycle is known. The Brayton refrigeration cycle is a thermodynamic cycle consisting of an
adiabatic compression process, an isobaric heating process, an adiabatic expansion process, and
an isobaric cooling process, with elements corresponding to each process arranged on a
refrigerant line through which a refrigerant circulates. The elements constituting the
refrigeration cycle are designed according to the refrigerating capacity required for a
15 refrigerator.

[0003] Patent Document 1 discloses an example of the refrigeration system utilizing a
Brayton refrigeration cycle. In Patent Document 1, as the compressor unit corresponding to
the adiabatic compression process, multiple stages of compressors connected in series are
provided on the refrigerant line to achieve an appropriate compression ratio and meet the
20 required refrigerating capacity. Further, some of the multiple stages of compressors is
configured as an expander-integrated compressor having a common rotational shaft shared with
an expander corresponding to the adiabatic expansion process to use the power generated by
the expander as part of power for driving the compressor, whereby the efficiency is improved.
Furthermore, in Patent Document 1, the compressors constituting the compressor unit are
25 arranged in parallel to increase the amount of refrigerant circulating in the refrigeration cycle,
whereby the refrigerating capacity is improved.

Citation List

Patent Literature

[0004] Patent Document 1: JP2014-219125A

SUMMARY

5 Problems to be Solved

[0005] In this type of refrigeration system, for developing variations of product specifications with different refrigerating capacities, generally, the components of the refrigeration system are newly designed, and reducing the cost and time required for development is a challenge. For example, different models of compressors and expanders
10 constituting the refrigeration system need to be prepared according to the product specifications of the refrigeration system, and if existing models are not suitable, new models need to be newly developed, which requires much cost and time.

[0006] As a method to reduce the cost and time required for such new development, for example, when developing a refrigerator with higher refrigerating capacity than the existing
15 refrigerator, it is conceivable to parallelize the existing configurations of the refrigeration cycle, as in Patent Document 1 described above, but this leads to an inevitable increase in the number of necessary parts and the occupied area and cannot be said sufficient.

[0007] At least one embodiment of the present disclosure was made in view of the above circumstances, and an object thereof is to provide a refrigeration system that allows for flexible
20 design changes while suppressing the cost and time required for development according to the required refrigerating capacity as well as the occupied area for installation.

Solution to the Problems

[0008] In order to solve the above-described problems, at least one embodiment of the
25 present disclosure provides a refrigeration system utilizing a Brayton cycle which generates cold heat by using a refrigerant compressed by a compressor unit arranged on a refrigerant path. The compressor unit includes: a plurality of compressors arranged in parallel to each other on the refrigerant path; a plurality of first motors for driving the plurality of compressors,

respectively; an expander-integrated compressor configured integrally with an expander capable of expanding the refrigerant compressed by the compressor unit; and a second motor for driving the expander-integrated compressor. The number of the plurality of compressors is larger than the number of the expander-integrated compressor.

5

Advantageous Effects

[0009] At least one embodiment of the present disclosure provides a refrigeration system that allows for flexible design changes while suppressing the cost and time required for development according to the required refrigerating capacity as well as the occupied area for
10 installation.

BRIEF DESCRIPTION OF DRAWINGS

[0010] FIG. 1 is a schematic overall configuration diagram of a refrigeration system according to an embodiment.

15 FIG. 2 is a diagram schematically showing a cross-sectional structure of a common-shaft compressor of FIG. 1.

FIG. 3 is a diagram schematically showing a cross-sectional structure of an expander-integrated compressor of FIG. 1.

FIG. 4 is a flowchart showing a method of starting the refrigeration system of FIG. 1.

20 FIG. 5A is a schematic diagram showing one aspect of a refrigeration system including two common-shaft compressors and one expander-integrated compressor.

FIG. 5B is a schematic diagram showing another aspect of a refrigeration system including two common-shaft compressors and one expander-integrated compressor.

25 FIG. 6A is a schematic diagram showing one aspect of a refrigeration system including three common-shaft compressors and one expander-integrated compressor.

FIG. 6B is a schematic diagram showing another aspect of a refrigeration system including three common-shaft compressors and one expander-integrated compressor.

FIG. 6C is a schematic diagram showing another aspect of a refrigeration system

including three common-shaft compressors and one expander-integrated compressor.

FIG. 7A is a schematic diagram showing one aspect of a refrigeration system including three common-shaft compressors and two expander-integrated compressors.

FIG. 7B is a schematic diagram showing another aspect of a refrigeration system including three common-shaft compressors and two expander-integrated compressors.

FIG. 7C is a schematic diagram showing another aspect of a refrigeration system including three common-shaft compressors and two expander-integrated compressors.

FIG. 8A is a schematic diagram showing one aspect of a refrigeration system including four common-shaft compressors and two expander-integrated compressors.

FIG. 8B is a schematic diagram showing another aspect of a refrigeration system including four common-shaft compressors and two expander-integrated compressors.

FIG. 8C is a schematic diagram showing another aspect of a refrigeration system including four common-shaft compressors and two expander-integrated compressors.

FIG. 8D is a schematic diagram showing another aspect of a refrigeration system including four common-shaft compressors and two expander-integrated compressors.

DETAILED DESCRIPTION

[0011] A refrigeration system according to some embodiments of the present disclosure will be described below with reference to the accompanying drawings.

It is intended, however, that unless particularly identified, dimensions, materials, shapes, relative positions, and the like of components described in the embodiments shall be interpreted as illustrative only and not intended to limit the scope of the present invention.

For instance, an expression of relative or absolute arrangement such as “in a direction”, “along a direction”, “parallel”, “orthogonal”, “centered”, “concentric” and “coaxial” shall not be construed as indicating only the arrangement in a strict literal sense, but also includes a state where the arrangement is relatively displaced by a tolerance, or by an angle or a distance whereby it is possible to achieve the same function.

For instance, an expression of an equal state such as “same” “equal” and “uniform” shall

not be construed as indicating only the state in which the feature is strictly equal, but also includes a state in which there is a tolerance or a difference that can still achieve the same function.

Further, for instance, an expression of a shape such as a rectangular shape or a cylindrical shape shall not be construed as only the geometrically strict shape, but also includes a shape with unevenness or chamfered corners within the range in which the same effect can be achieved.

On the other hand, an expression such as “comprise”, “include”, “have”, “contain” and “constitute” are not intended to be exclusive of other components.

10 [0012] First, with reference to FIG. 1, an overall configuration of a refrigeration system 100 according to an embodiment will be described. FIG. 1 is a schematic overall configuration diagram of the refrigeration system 100 according to an embodiment.

[0013] The refrigeration system 100 includes, on a refrigerant path 101 through which a refrigerant flows, a compressor unit 102 (110A, 110B, 110C) for compressing the refrigerant, an expander 103 for expanding the refrigerant, a cooling part 104 composed of a heat exchanger for performing heat exchange between the refrigerant and an object to be cooled, and a cold heat recovery heat exchanger 105 for recovering cold heat remaining in the refrigerant having passed through the cooling part 104, thereby forming a Brayton cycle of a countercurrent heat exchanger system with a refrigeration cycle of steady circulation flow.

20 [0014] The refrigeration system 100 has a superconducting device 106 using a superconductor capable of exhibiting superconductivity in a cryogenic state as the object to be cooled. The superconducting device 106 is, for example, a superconducting cable. The refrigeration system 100 has a refrigerant path 107 through which liquid nitrogen cooled by the cooling part 104 circulates to maintain the cryogenic state of the superconducting device 106.

25 The refrigerant path 107 is configured to be capable of heat exchange with the refrigerant flowing through the refrigerant path 101 of the refrigeration system 100 via the cooling part 104, and is provided with a pump 108 for circulating liquid nitrogen. Thus, the liquid nitrogen flowing through the refrigerant path 107 heated by the heat load of the superconducting device

106 is cooled by heat exchange with the refrigerant flowing through the refrigerant path 101 cooled by the refrigeration system 100.

[0015] As the refrigerant in the refrigerant path 101 of the refrigeration system 100, neon may be used, for example, but the refrigerant is not limited thereto, and the type of gas can be
5 appropriately changed according to the cooling temperature or the like.

[0016] In the refrigeration system 100, the expander 103, through which relatively low-temperature refrigerant flows, the cooling part 104, and the cold heat recovery heat exchanger 105 are accommodated in a cold box 109 that can be insulated from the outside.

The cold box 109 has, for example, a vacuum heat insulating layer between the inner and
10 outer surfaces to prevent heat leak from the outside, thereby reducing heat loss in the expander 103, the cooling part 104, and the cold heat recovery heat exchanger 105 accommodated in the cold box 109. On the other hand, the compressor unit 102 of the refrigeration system 100, through which relatively high-temperature refrigerant flows, is arranged outside the cold box 109.

[0017] The cold box 109 is arranged at a position closer to the superconducting device 106
15 to be cooled than the compressor unit 102. As a result, cold heat generated in the cold box 109 can be supplied to the object to be cooled with little loss, and good refrigeration efficiency can be achieved. The compressor unit 102 is a separate structure from the cold box 109, which increases the degree of freedom in layout; for example, the refrigeration system can be arranged
20 on the cold box to reduce the installation space.

[0018] The compressor unit 102 includes a plurality of compressors 110 connected in series on the refrigerant path 101. In the present embodiment, the compressor unit 102 includes a low-stage compressor 110A capable of compressing a fluid, an intermediate-stage compressor 110B capable of further compressing the fluid compressed by the low-stage compressor 110A,
25 and a high-stage compressor 110C capable of further compressing the fluid compressed by the intermediate-stage compressor 110B, which are connected in series on the refrigerant path 101, to allow multi-stage compression over three stages.

The number of compression stages in the compressor unit 102 may be any number.

[0019] In the compressor unit 102, a heat exchanger 112 is provided downstream of each of the plurality of compressors 110 to cool the refrigerant heated through adiabatic compression by heat exchange with cooling water. Specifically, a heat exchanger 112A is disposed downstream of the low-stage compressor 110A, a heat exchanger 112B is disposed downstream of the intermediate-stage compressor 110B, and a heat exchanger 112C is disposed downstream of the high-stage compressor 110C.

[0020] The refrigerant flowing through the refrigerant path 101 is first adiabatically compressed by the low-stage compressor 110A on the most upstream side, thus rises in temperature, and then is cooled by exchanging heat with cooling water in the heat exchanger 112A disposed downstream. Then, the refrigerant is again adiabatically compressed by the intermediate-stage compressor 110B, thus rises in temperature, and then is cooled by exchanging heat with cooling water in the heat exchanger 112B disposed downstream. Further, the refrigerant is again adiabatically compressed by the high-stage compressor 110C, thus rises in temperature, and then is cooled by exchanging heat with cooling water in the heat exchanger 112C disposed downstream.

[0021] Thus, in the compressor unit 102, efficiency is improved by repeating adiabatic compression with the compressors 110 and cooling with the heat exchangers 112 over multiple stages. That is, by repeating adiabatic compression and cooling over multiple stages, the compression process of the Brayton cycle approaches ideal isothermal compression. The greater the number of stages, the better the approximation to isothermal compression, but the number of stages should be determined by taking into consideration the compression ratio selection, complexity of the device configuration, and simplicity of operation as the number of stages increases.

[0022] The refrigerant compressed by the compressor unit 102 is cooled by the cold heat recovery heat exchanger 105 and then adiabatically expanded by the expander 103 to generate cold heat. The refrigerant discharged from the expander 103 exchanges heat in the cooling part 104 with the liquid nitrogen flowing through the refrigerant path 107 on the cooling target side, so that the temperature rises due to the heat load.

[0023] The refrigerant heated in the cooling part 104 is introduced into the cold heat recovery heat exchanger 105, where the remaining cold heat is recovered by heat exchange with the hot compressed refrigerant that has passed through the heat exchanger 112C in the compressor unit 102. As a result, the temperature of the refrigerant introduced into the expander 103 is lowered to obtain cold heat at a lower temperature.

[0024] Thus, in the refrigeration system 100, the Brayton cycle is configured by using a plurality of rotating machines such as the plurality of compressors 110 and the expander 103 included in the compressor unit 102. Here, the low-stage compressor 110A and the high-stage compressor 110C are configured as a common-shaft compressor 118 by connecting them to both ends of an output shaft 116A (see FIG. 2) of a first motor 114A, which is a common power source, thus enabling a reduction in the number of parts and installation in a smaller space. Similarly, the intermediate-stage compressor 110B and the expander 103 are configured as an expander-integrated compressor 120 by connecting them to both ends of an output shaft 116B (see FIG. 3) of a second motor 114B, which is a common power source, thus enabling a reduction in the number of parts and installation in a smaller space. In addition, this allows the power generated by the expander 103 to contribute to the compression power of the intermediate-stage compressor 110B, thus improving efficiency.

[0025] Of the plurality of compressors 110 included in the compressor unit 102, it is possible to arbitrarily change which one is configured as the common-shaft compressor 118 and which one is configured as the expander-integrated compressor 120.

[0026] Here, the configurations of the common-shaft compressor 118 and the expander-integrated compressor 120 will be described with reference to FIGs. 2 and 3. FIG. 2 is a diagram schematically showing a cross-sectional structure of the common-shaft compressor 118 of FIG. 1. FIG. 3 is a diagram schematically showing a cross-sectional structure of the expander-integrated compressor 120 of FIG. 1.

[0027] As shown in FIG. 2, the common-shaft compressor 118 is constructed by connecting the low-stage compressor 110A and the high-stage compressor 110C to both sides of the output shaft 116A of the first motor 114A. In this embodiment, the first motor 114A is disposed

between the low-stage compressor 110A and the high-stage compressor 110C, but in other embodiments, the first motor 114A may be disposed outside the low-stage compressor 110A and the high-stage compressor 110C (for example, in the axial direction of the output shaft 116A, the first motor 114A, the low-stage compressor 110A, and the high-stage compressor 110C may be arranged in this order).

[0028] The output shaft 116A of the first motor 114A is rotatably supported by radial magnetic bearings 122-1 and a thrust magnetic bearing 126-1 arranged between the low-stage compressor 110A and the high-stage compressor 110C in a non-contact manner with a motor casing 130-1. The radial magnetic bearings 122-1 are disposed on both sides of the first motor 114A in the axial direction of the output shaft 116A, and levitate the output shaft 116A by magnetic force to bear the radial load. The thrust magnetic bearing 126-1 is disposed on one side of the first motor 114A in the axial direction of the output shaft 116A (between the first motor 114A and the low-stage compressor 110A in the embodiment shown in FIG. 2), and bears the thrust load of the output shaft 116A by magnetic force so as to form a gap with an axial rotor disk 127-1 disposed on the output shaft 116A.

The thrust magnetic bearing 126-1 and the axial rotor disk 127-1 may be disposed between the high-stage compressor 110C and the first motor 114A. In this embodiment, the axial rotor disk 127-1 is provided on one side of the first motor 114A mainly to suppress fluid friction loss, but if the outer diameter of the output shaft 116A of the first motor 114A is large, the axial rotor disks may be provided on both sides for assembly reasons or the like.

[0029] A casing 128-1 of the common-shaft compressor 118 is constructed by connecting a motor casing 130-1, a low-stage compressor impeller casing 132-1, and a high-stage compressor impeller casing 132-3 along the axial direction of the output shaft 116A. The motor casing 130-1 is a casing that defines the outer shell of the first motor 114A, and houses a rotor 136A formed integrally with the output shaft 116A and a stator 138A disposed around the rotor 136A (the rotor 136A is formed integrally with the output shaft 116A). The low-stage compressor impeller casing 132-1 houses an impeller 140A of the low-stage compressor 110A attached to one end of the output shaft 116A. The high-stage compressor impeller casing

132-3 houses an impeller 140C of the high-stage compressor 110C attached to the other end of the output shaft 116A.

[0030] As shown in FIG. 3, the expander-integrated compressor 120 is constructed by connecting the intermediate-stage compressor 110B and the expander 103 to both sides of the output shaft 116B of the second motor 114B. In this embodiment, the second motor 114B is disposed between the intermediate-stage compressor 110B and the expander 103, but in other embodiments, the second motor 114B may be disposed outside the intermediate-stage compressor 110B and the expander 103 (for example, in the axial direction of the output shaft 116B, the second motor 114B, the intermediate-stage compressor 110B, and the expander 103 may be arranged in this order).

[0031] The output shaft 116B of the second motor 114B is rotatably supported by radial magnetic bearings 122-2 and a thrust magnetic bearing 126-2 arranged between the intermediate-stage compressor 110B and the expander 103 in a non-contact manner with a motor casing 130-2. The radial magnetic bearings 122-2 are disposed on both sides of the second motor 114B in the axial direction of the output shaft 116B, and levitate the output shaft 116B by magnetic force to bear the radial load. The thrust magnetic bearing 126-2 is disposed on one side of the second motor 114B in the axial direction of the output shaft 116B (between the second motor 114B and the intermediate-stage compressor 110B in the embodiment shown in FIG. 3), and bears the thrust load of the output shaft 116B by magnetic force so as to form a gap with an axial rotor disk 127-2 disposed on the output shaft 116B.

The thrust magnetic bearing 126-2 and the axial rotor disk 127-2 may be disposed between the expander 103 and the second motor 114B. In this embodiment, the axial rotor disk 127-2 is provided on one side of the second motor 114B mainly to suppress fluid friction loss, but if the outer diameter of the output shaft 116B of the second motor 114B is large, the axial rotor disks may be provided on both sides for assembly reasons or the like.

[0032] A casing 128-2 of the expander-integrated compressor 120 is constructed by connecting a motor casing 130-2, an intermediate-stage compressor impeller casing 132-2, and an expander impeller casing 134-1 along the axial direction of the output shaft 116B. The

motor casing 130-2 is a casing that defines the outer shell of the second motor 114B, and houses a rotor 136B formed integrally with the output shaft 116B and a stator 138B disposed around the rotor 136B (the rotor 136B is formed integrally with the output shaft 116B). The intermediate-stage compressor impeller casing 132-2 houses an impeller 140B of the intermediate-stage compressor 110B attached to one end of the output shaft 116B. The expander impeller casing 134-1 houses an impeller 142 of the expander 103 attached to the other end of the output shaft 116B.

[0033] Referring to FIG. 1 again, the compressor unit 102 includes a plurality of common-shaft compressors 118 connected in series on the refrigerant path 101. The common-shaft compressors 118 included in the compressor unit 102 are common (same specifications), and the number thereof is larger than the number of expander-integrated compressors 120 included in the compressor unit 102 and is set according to the refrigerating capacity required for the refrigeration system 100. In the present embodiment, the compressor unit 102 includes one expander-integrated compressor 120 and two common-shaft compressors 118A and 118B, but may include three or more common-shaft compressors 118 to meet even larger refrigerating capacity. Furthermore, when the compressor unit includes two expander-integrated compressors 120, it may include three or more common-shaft compressors 118.

[0034] The number of common-shaft compressors 118 included in the compressor unit 102 is set according to the refrigerating capacity required for the refrigeration system 100. For example, as the refrigerating capacity required for the refrigeration system 100 increases, the flow rate of the refrigerant flowing through the refrigerant path 101 increases, which can be handled by increasing the number of common-shaft compressors 118. Thus, in the refrigeration system 100, by adjusting the number of common-shaft compressors 118 included in the compressor unit 102, specifications with different refrigerating capacities can be achieved with a small development burden. Since the expander-integrated compressor 120 can be accommodated by changing the design of only parts (impeller casings 132-2 and 134-1) related to the impeller 140B of the intermediate-stage compressor 110B and the expander impeller 142, it is possible to effectively reduce the type of parts required for the refrigeration system 100 and

the development period and cost of the common-shaft compressors according to the refrigerating capacity. In addition, the occupied area can be reduced compared to the case where multiple refrigeration systems 100 are arranged in parallel to meet the required refrigerating capacity.

5 [0035] In the refrigeration system 100, the first motor 114A of the common-shaft compressor 118 and the second motor 114B of the expander-integrated compressor 120 are common. Thus, by using drive motors with a common specification even between the common-shaft compressor 118 and the expander-integrated compressor 120, the refrigeration system 100 with different refrigerating capacities can be achieved with a reduced development
10 burden.

[0036] The fact that the plurality of first motors and the second motor are “common” means that at least some of their specifications are common. The fact that at least some of the specifications are common may mean that, for example, at least some of the motor power, rotational speed, dimensions, or other specifications are the same, or that they can be substituted
15 for each other, or that the design is the same to the extent that it does not affect the assembly of components other than the motor.

[0037] To illustrate with an example, we assume, for example, that when the required refrigerating capacity of the refrigeration system 100 is 5 kW, the required output for the first motor used in the common-shaft compressor 118 is 45 kW, and the required output for the
20 second motor used in the expander-integrated compressor 120 is 15 kW. Based on these assumptions, when the refrigeration system 100 with double the refrigerating capacity, i.e., 10 kW, is developed, since the amount of refrigerant flowing through the refrigerant path 101 is doubled, the required output for the first motor is 90 kW ($= 45 \text{ kW} \times 2$), and the required output for the second motor is 30 kW ($= 15 \text{ kW} \times 2$). In the refrigeration system 100 according to
25 the present embodiment, to meet such requirements, as shown in FIG. 1, two common-shaft compressors 118 having first motors of 45 kW output with the same specifications as the base design are provided in parallel to each other on the refrigerant path 101, without requiring a new common-shaft compressor design. In this case, in the expander-integrated compressor

120, a motor of 45 kW output may be used as the second motor 114B as in the first motor 114A to provide the required output of 30 kW.

[0038] By using common motors (with the same specifications) as the first motor 114A and the second motor 114B, it is possible to standardize the peripheral configurations of the first motor 114A and the second motor 114B. For example, when the first motor 114A and the second motor 114B are common (same specifications), the output shaft 116A and the output shaft 116B have the same shaft diameter, so that bearings (radial magnetic bearing 122-1, thrust magnetic bearing 126-1) that support the output shaft 116A in the common-shaft compressor 118 and bearings (radial magnetic bearing 122-2, thrust magnetic bearing 126-2) that support the output shaft 116B in the expander-integrated compressor 120 can be common (same specifications). Further, the motor casing 130-1 of the first motor 114A and the motor casing 130-2 of the second motor 114B can also be common (same specifications).

[0039] The fact that the bearings and the motor casings are “common” means that at least some of their specifications are common. The fact that at least some of the specifications are common may mean that they can be substituted for each other, or that the design is the same to the extent that it does not affect the assembly of components other than the motor.

[0040] The low-stage compressor impeller casing 132-1 and the high-stage compressor impeller casing 132-3 of the first motor 114A and the intermediate-stage compressor impeller casing 132-2 and the expander impeller casing 134-1 of the second motor 114B may be of different designs depending on the shape of the impeller housed in each casing.

[0041] Thus, by making the first motor 114A and the second motor 114B in the compressor unit 102 and their peripheral configurations common (same specifications) in the refrigeration system 100, the refrigeration system 100 can be designed efficiently with a small development burden, even when the refrigerating capacity required for the system changes.

[0042] FIG. 1 shows the case where the compressor unit 102 includes two common-shaft compressors 118. The two common-shaft compressors 118 are arranged in parallel to each other on the refrigerant path 101. The refrigerant path 101 includes: a first line 144 through which the refrigerant is supplied from the cold heat recovery heat exchanger 105 to the

compressor unit 102; second lines 146A, 146B branching from the downstream side of the first line 144 to each of the low-stage compressors 110A of the two common-shaft compressors 118; third lines 148A, 148B through which the refrigerant compressed by the two low-stage compressors 110A flows; a fourth line 150 where the third lines 148A, 148B merge downstream and connected to the intermediate-stage compressor 110B; a fifth line 152 through which the refrigerant compressed by the intermediate-stage compressor 110B flows; sixth lines 154A, 154B branching from the downstream side of the fifth line 152 to each of the high-stage compressors 110C of the two common-shaft compressors 118; seventh lines 156A, 156B through which the refrigerant compressed by the high-stage compressors 110C flows; and an eighth line 158 where the seventh lines 156A, 156B merge downstream and connected to the cold heat recovery heat exchanger 105 on the cold box 109 side.

[0043] One of the second lines 146A, 146B (in FIG. 1, the second line 146B) is provided with a first valve 160 so that the distribution ratio of the refrigerant to the low-stage compressors 110A of the two common-shaft compressors 118 can be adjusted. Further, one of the third lines 148A, 148B (in FIG. 1, the third line 148B), through which the refrigerant compressed by the two low-stage compressors 110A flows, is provided with a second valve 162 so that the discharge ratio of the refrigerant from the two low-stage compressors 110A can be adjusted.

Each of the third lines 148A, 148B is provided with the above-described heat exchanger 112A.

[0044] One of the seventh lines 156A, 156B (in FIG. 1, the seventh line 156B) is provided with a third valve 164 so that the discharge ratio of the refrigerant from the high-stage compressors 110C of the two common-shaft compressors 118 can be adjusted.

Each of the seventh lines 156A, 156B is provided with the above-described heat exchanger 112C.

[0045] Further, in the refrigeration system 100, a first bypass line 166 connecting the upstream side and the downstream side of the low-stage compressors 110A of the two common-shaft compressors 118 is provided. The first bypass line 166 is provided with a first bypass valve 168. Further, a second bypass line 170 connecting the upstream side and the

downstream side of the intermediate-stage compressor 110B is provided. The second bypass line 170 is provided with a second bypass valve 172. Further, a third bypass line 174 connecting the upstream side and the downstream side of the high-stage compressors 110C of the two common-shaft compressors 118 is provided. The third bypass line 174 is provided with a third bypass valve 176.

[0046] Further, a fourth bypass line 182 connecting a high-pressure refrigerant line 178 of the refrigerant path 101 between the downstream side of the high-stage compressor 110C and the cold heat recovery heat exchanger 105 and a low-pressure refrigerant line 180 between the cold heat recovery heat exchanger 105 and the low-stage compressor 110A is provided. The fourth bypass line 182 is provided with a buffer tank 184 capable of storing the refrigerant, a fourth valve 186 disposed upstream of the buffer tank 184, and a fifth valve 188 disposed downstream of the buffer tank 184.

[0047] The opening degrees of these valves are controlled based on control signals from a control device 200, which is a control unit of the refrigeration system 100, so that the flow path of the refrigerant in the refrigerant path 101 can be appropriately switched. The control device 200 is configured by installing a program for executing predetermined control in a hardware configuration including an electronic arithmetic device such as a computer.

[0048] The arrangement of the valves and bypass valves in the refrigeration system 100 described above can be changed as appropriate within a range in which equivalent control can be achieved.

[0049] Next, a startup method of the refrigeration system 100 having the above configuration will be described. FIG. 4 is a flowchart showing a method of starting the refrigeration system 100 of FIG. 1.

[0050] First, as an initial state of the refrigeration system 100, we assume that the refrigerant temperature at the inlet of the expander 103 is room temperature (about 300 K). In the refrigeration system 100 in the stopped state, the temperature of the refrigerant remaining in the refrigerant path 101 rises to near room temperature (about 300 K), so that the pressure of the refrigerant in the refrigerant path 101 increases. In this state, the refrigerant pressure in

the refrigerant path 101 is balanced between the high-pressure refrigerant line 178 from the high-stage compressor 110C to the expander 103 and the low-pressure refrigerant line 180 from the expander 103 to the low-stage compressor 110A (high and low pressures are equalized). In such a state, the pressure in the low-pressure refrigerant line 180 increases compared to normal operation, and if the refrigeration system 100 is started and operated with the refrigerant pressure increased, the pressure in the high-pressure refrigerant line 178 tends to rise excessively. In particular, the configuration including the motor-driven expander-integrated compressor 120 may increase the motor load.

[0051] Therefore, the control device 200 controls, if the pressure difference ΔP between the pressure in the high-pressure refrigerant line 178 and the pressure in the buffer tank 184 exceeds a predetermined threshold $\Delta P1$ (e.g., 10 kPa) (step S1: YES), the fourth valve 186 to open (step S2) to recover the refrigerant flowing through the refrigerant path 101 partially to the buffer tank 184 (step S3). This reduces the pressure difference ΔP and prevents the pressure in the high-pressure refrigerant line 178 from increasing excessively, thus suitably avoiding an excessive motor load. Then, if the pressure difference ΔP becomes equal to or less than the threshold $\Delta P1$ (step S4: YES), the control device 200 controls the fourth valve 186 to close (step S5).

If the pressure difference ΔP is more than the threshold $\Delta P1$ (step S4: NO), the control device 200 returns the control to step S2.

[0052] The pressure difference ΔP can be obtained, for example, from the difference between detected values of a pressure sensor provided in the high-pressure refrigerant line 178 and a pressure sensor provided in the buffer tank 184.

[0053] Here, the refrigerant path 101 has a minimum cross-section near the inlet of the expander 103 where the density is highest under rated operating conditions. During precooling, since the intake temperature of the expander 103 rises (the refrigerant density decreases) as compared to rated conditions, compressor surging may occur due to the choking phenomenon of the expander 103 where the flow rate of the refrigerant decreases at that location. In the subsequent step S6, to solve such problems, only one of the two common-shaft

compressors 118 (common-shaft compressor 118A) included in the compressor unit 102 is started together with the expander-integrated compressor 120 (i.e., only one of the two common-shaft compressors 118 is operated together with the expander-integrated compressor 120, so-called machine number control operation). This enables startup with a low refrigerant flow rate in the expander 103, effectively preventing the occurrence of surging in the compressor.

[0054] Then, the control device 200 controls the opening degree of the second bypass valve 172 based on the temperature T_{in} of the refrigerant at the inlet of the expander 103 (step S7). In step S7, the opening degree of the second bypass valve 172 is controlled based on the temperature T_{in} of the refrigerant at the inlet of the expander 103 so that part of the refrigerant flowing through the refrigerant path 101 flows through the second bypass line 170 to bypass the intermediate-stage compressor 110B. As a result, the flow rate of the refrigerant supplied to the intermediate-stage compressor 110B increases, and the surging in the compressor as described above can be prevented more effectively.

[0055] The opening degree control of the second bypass valve 172 in step S7 may be performed continuously or in stages (stepwise) based on the temperature T_{in} of the refrigerant at the inlet of the expander 103. The rotational speed of at least one of the common-shaft compressor 118 or the expander-integrated compressor 120 started in step S6 may be cooperatively controlled so that the cooling rate of the refrigerant in the cold heat recovery heat exchanger 105 is approximately constant (e.g., 60 K/h).

[0056] The temperature T_{in} of the refrigerant at the inlet of the expander 103 can be obtained by a temperature sensor (not shown) installed at the inlet of the expander 103.

[0057] In step S7, the first valve 160, the second valve 162, the third valve 164, the first bypass valve 168, and the third bypass valve 176 are controlled to close.

[0058] Then, if the temperature T_{in} at the inlet of the expander 103 becomes equal to or lower than the first target value T_1 (e.g., 180 to 200 K) (step S8: YES), the control device 200 controls the first bypass valve 168, the third bypass valve 176, and the first valve 160 to open (step S9).

[0059] Then, it is determined whether there is surging (step S10), and if it is determined that there is surging (step S10: YES), the control device 200 controls the rotational speed of the common-shaft compressor 118A started in step S6 to decrease (step S11). The rotational speed of the common-shaft compressor 118A controlled in step S11 is decreased to a speed at which surging does not occur in each compressor when both of the two common-shaft compressors 118 in the compressor unit 102 are operated.

In step S11, the one common-shaft compressor 118A may be temporarily stopped as a result of decreasing the rotational speed. Further, if it is determined that there is no surging (step S10: NO), the rotational speed decrease control in step S11 is not performed. For example, when the rotational speed is relatively low (for example, when the rotational speed during precooling is low due to restrictions such as the cooling rate of the heat exchanger), surging tends to be less likely to occur, so the rotational speed decrease control as in step S11 may be unnecessary depending on the operating conditions.

[0060] Then, the control device 200 controls the first bypass valve 168 and the third bypass valve 176 to open (step S12), and starts the other common-shaft compressor 118B included in the compressor unit 102 (step S13). At this time, the rotational speed of the other common-shaft compressor 118B is controlled so as to be equal to the rotational speed of the one common-shaft compressor 118A decreased in step S6. Further, if the pressure conditions of the two common-shaft compressors 118 become equal (step S14: YES), the control device controls the first bypass valve 168 and the third bypass valve 176 to close (step S15).

[0061] Then, the control device 200 controls the second valve 162 and the third valve 164 to open and completes the connection of the other common-shaft compressor 118B to the refrigerant path 101 (step S16). By starting the other common-shaft compressor 118B with the rotational speed of the one common-shaft compressor 118A, which has been started earlier in step S3, temporarily decreased, the system can smoothly transition from one-sided operation with one common-shaft compressor 118A to two-sided operation with two common-shaft compressors 118A and 118B, while preventing the occurrence of surging in each compressor.

[0062] The control device 200 proceeds with the precooling operation while controlling the

opening degree of the second bypass valve 172 and the rotational speed of at least one of the common-shaft compressor 118 or the expander-integrated compressor 120 based on the temperature T_{in} of the refrigerant at the inlet of the expander 103 and the cooling rate of the refrigerant in the cold heat recovery heat exchanger 105. Then, if the temperature T_{in} at the inlet of the expander 103 becomes equal to or lower than a second target value T2 (e.g., 100 to 120 K) (step S17: YES), the control device 200 controls the second bypass valve 172 to close (step S18), completes precooling, and shifts to normal operation, thereby completing the series of startup control of the refrigeration system 100 (step S19).

[0063] When the refrigeration system 100 includes three or more common-shaft compressors 118, the temperature T_{in} can be adjusted to a desired value by control so as to sequentially increase the number of operating common-shaft compressors 118 in the same manner as the above-described control.

[0064] As described above, in the startup method of the refrigeration system 100, at the initial stage of startup, some of the common-shaft compressors 118 included in the compressor unit 102 is started, and the control is performed so that the number of operating common-shaft compressors 118 increases as precooling progresses (the temperature T_{in} at the inlet of the expander 103 decreases). The number of operating common-shaft compressors 118 in each stage may be controlled as follows, for example, according to the temperature T_{in} at the inlet of the expander 103.

[0065] From the relationship between the speed of sound, Mach number, and adiabatic flow, the mass flow rate G of the refrigerant passing through the expander 103 can be expressed as a function of the temperature T_{in} of the refrigerant at the inlet of the expander 103 as follows (assuming here that the refrigerant passing through the expander 103 is not in a critical state, that is, the nozzle outlet flow rate of the expander 103 has not reached the speed of sound, and the refrigerant is an ideal gas).

(Expression 1)

$$G = A \cdot P_{in} \sqrt{\frac{2\kappa}{\kappa - 1} \cdot \frac{1}{R \cdot T_{in}} \left[\left(\frac{P_{ex}}{P_{in}} \right)^{2/\kappa} - \left(\frac{P_{ex}}{P_{in}} \right)^{(\kappa + 1)/\kappa} \right]} \quad (1)$$

where A is the nozzle throat area of the expander 103, P_{in} and P_{ex} are the pressures at the inlet and outlet of the expander 103, respectively, κ is the specific heat ratio of the refrigerant, and R is the gas constant of the ideal gas. The refrigerant flow rate G with respect to the temperature T_{in} at the inlet of the expander 103 can be roughly calculated from the expression (1). Therefore, when the discharge flow rate per common-shaft compressor 118 is R, the number D of common-shaft compressors 118 to be operated can be obtained by the following equation (fractions are rounded up).

$$D = G/R \quad (2)$$

[0066] When the compressor unit 102 includes two common-shaft compressors 118 as shown in FIG. 1, until the temperature T_{in} at the inlet of the expander 103 reaches the first target value T1 (e.g., 180 to 200 K), efficient precooling can be achieved by operating only one common-shaft compressor 118, but at the second target value T2 (e.g., 120 to 200 K), the efficiency decreases, so it is preferable to start the other common-shaft compressor 118 and operate with two units. When the number of common-shaft compressors 118 is changed according to the temperature range in this way, by temporarily decreasing the rotational speed of the operating common-shaft compressor 1 as described above under operating conditions where surging may occur, the number of operating compressors can be smoothly changed while preventing the occurrence of surging.

[0067] In the above embodiment, the refrigeration system 100 includes one expander-integrated compressor and two common-shaft compressors 118, but the number of expander-integrated compressors 120 and common-shaft compressors 118 of the refrigeration system 100 may be any number. Hereinafter, some variations of the refrigeration system 100 will be described specifically with reference to FIGs. 5 to 8.

In FIGs. 5 to 8, the common-shaft compressors 118, the expander-integrated compressors

120, the first motors 114A, and the second motors 114B of the refrigeration system 100 are extracted and shown in simplified form, and other details of the configuration are omitted as they follow the above embodiment.

[0068] FIGs. 5A and 5B are schematic diagrams showing refrigeration systems 100A-1 and 100A-2 each including two common-shaft compressors 118A, 118B and one expander-integrated compressor 120. In the refrigeration system 100A-1 shown in FIG. 5A, as with the above embodiment, the first motor 114A-1 for driving the common-shaft compressor 118A, the first motor 114A-2 for driving the common-shaft compressor 118B, and the second motor 114B for driving the expander-integrated compressor 120 are all common. In this case, since all first motors 114A and second motors 114B are common, the types of motors used in the refrigeration system 100A can be minimized, and the development cost and time can be reduced effectively.

[0069] In the refrigeration system 100A-2 shown in FIG. 5B, the first motor 114A-1 for driving the common-shaft compressor 118A and the second motor 114B for driving the expander-integrated compressor 120 are common, while the first motor 114A-2 for driving the common-shaft compressor 118B is different (different specifications). Thus, the first motor 114A and the second motor 114B used in the refrigeration system 100 may be as much standardized as possible, while only some of the motors are made to different specifications, which allows for flexibility in responding to the specifications required for the refrigeration system 100.

[0070] Next, FIGs. 6A to 6C are schematic diagrams showing refrigeration systems 100B-1 to 100B-3 each including three common-shaft compressors 118A, 118B, 118C and one expander-integrated compressor 120. In the refrigeration system 100B-1 shown in FIG. 6A, the first motor 114A-1 for driving the common-shaft compressor 118A, the first motor 114A-2 for driving the common-shaft compressor 118B, the first motor 114A-3 for driving the common-shaft compressor 118C, and the second motor 114B for driving the expander-integrated compressor 120 are all common. In this case, since all first motors 114A and second motors 114B are common, the types of motors used in the refrigeration system 100A can be

minimized, and the development cost and time can be reduced effectively.

[0071] In the refrigeration system 100B-2 shown in FIG. 6B, the first motor 114A-1 for driving the common-shaft compressor 118A, the first motor 114A-2 for driving the common-shaft compressor 118B, and the second motor 114B for driving the expander-integrated compressor 120 are common, while the first motor 114A-3 for driving the common-shaft compressor 118C is different (different specifications). Thus, the first motor 114A and the second motor 114B used in the refrigeration system 100 may be as much standardized as possible, while only some of the motors are made to different specifications, which allows for flexibility in responding to the specifications required for the refrigeration system 100.

[0072] In the refrigeration system 100B-3 shown in FIG. 6C, the first motor 114A-1 for driving the common-shaft compressor 118A and the second motor 114B for driving the expander-integrated compressor 120 are common to each other, while the first motor 114A-2 for driving the common-shaft compressor 118B and the first motor 114A-3 for driving the common-shaft compressor 118C are common to each other. Thus, the motors used in the refrigeration system 100 may be standardized to different specifications, which allows for flexibility in responding to the specifications required for the refrigeration system 100.

[0073] Next, FIGs. 7A to 7C are schematic diagrams showing refrigeration systems 100C-1 to 100C-3 each including three common-shaft compressors 118A, 118B, 118C and two expander-integrated compressors 120A, 120B. In the refrigeration system 100C-1 shown in FIG. 7A, the first motor 114A-1 for driving the common-shaft compressor 118A, the first motor 114A-2 for driving the common-shaft compressor 118B, the first motor 114A-3 for driving the common-shaft compressor 118C, the second motor 114B-1 for driving the expander-integrated compressor 120A, and the second motor 114B-2 for driving the expander-integrated compressor 120B are all common. In this case, since all first motors 114A and second motors 114B are common, the types of motors used in the refrigeration system 100A can be minimized, and the development cost and time can be reduced effectively.

[0074] In the refrigeration system 100C-2 shown in FIG. 7B, the first motor 114A-1 for driving the common-shaft compressor 118A, the first motor 114A-2 for driving the common-

shaft compressor 118B, the second motor 114B-1 for driving the expander-integrated compressor 120A, and the second motor 114B-2 for driving the expander-integrated compressor 120B are common, while the first motor 114A-3 for driving the common-shaft compressor 118C is different (different specifications). Thus, the first motor 114A and the
5 second motor 114B used in the refrigeration system 100 may be as much standardized as possible, while only some of the motors are made to different specifications, which allows for flexibility in responding to the specifications required for the refrigeration system 100.

[0075] In the refrigeration system 100C-3 shown in FIG. 7C, the first motor 114A-1 for driving the common-shaft compressor 118A, the second motor 114B-1 for driving the expander-integrated compressor 120A, and the second motor 114B-2 for driving the expander-integrated compressor 120B are common to each other, while the first motor 114A-2 for driving the common-shaft compressor 118B and the first motor 114A-3 for driving the common-shaft compressor 118C are common to each other. Thus, the motors used in the refrigeration system 100 may be standardized to different specifications, which allows for flexibility in responding
10 to the specifications required for the refrigeration system 100.

[0076] FIGs. 8A to 8D are schematic diagrams showing refrigeration systems 100D-1 to 100D-4 each including four common-shaft compressors 118A, 118B, 118C, 118D and two expander-integrated compressors 120A, 120B. In the refrigeration system 100D-1 shown in FIG. 8A, the first motor 114A-1 for driving the common-shaft compressor 118A, the first motor
20 114A-2 for driving the common-shaft compressor 118B, the first motor 114A-3 for driving the common-shaft compressor 118C, the first motor 114A-4 for driving the common-shaft compressor 118D, the second motor 114B-1 for driving the expander-integrated compressor 120A, and the second motor 114B-2 for driving the expander-integrated compressor 120B are all common. In this case, since all first motors 114A and second motors 114B are common,
25 the types of motors used in the refrigeration system 100A can be minimized, and the development cost and time can be reduced effectively.

[0077] In the refrigeration system 100D-2 shown in FIG. 8B, the first motor 114A-1 for driving the common-shaft compressor 118A, the first motor 114A-2 for driving the common-

shaft compressor 118B, the first motor 114A-3 for driving the common-shaft compressor 118C, the second motor 114B-1 for driving the expander-integrated compressor 120A, and the second motor 114B-2 for driving the expander-integrated compressor 120B are common, while the first motor 114A-4 for driving the common-shaft compressor 118D is different (different specifications). Thus, the first motor 114A and the second motor 114B used in the refrigeration system 100 may be as much standardized as possible, while only some of the motors are made to different specifications, which allows for flexibility in responding to the specifications required for the refrigeration system 100.

[0078] In the refrigeration system 100D-3 shown in FIG. 8C, the first motor 114A-1 for driving the common-shaft compressor 118A, the first motor 114A-2 for driving the common-shaft compressor 118B, the second motor 114B-1 for driving the expander-integrated compressor 120A, and the second motor 114B-2 for driving the expander-integrated compressor 120B are common to each other, while the first motor 114A-3 for driving the common-shaft compressor 118C and the first motor 114A-4 for driving the common-shaft compressor 118D are common to each other. Thus, the motors used in the refrigeration system 100 may be standardized to different specifications, which allows for flexibility in responding to the specifications required for the refrigeration system 100.

[0079] In the refrigeration system 100D-4 shown in FIG. 8D, the first motor 114A-1 for driving the common-shaft compressor 118A, the second motor 114B-1 for driving the expander-integrated compressor 120A, and the second motor 114B-2 for driving the expander-integrated compressor 120B are common to each other, while the first motor 114A-2 for driving the common-shaft compressor 118B, the first motor 114A-3 for driving the common-shaft compressor 118C and the first motor 114A-4 for driving the common-shaft compressor 118D are common to each other. Thus, the motors used in the refrigeration system 100 may be standardized to different specifications, which allows for flexibility in responding to the specifications required for the refrigeration system 100.

[0080] The contents described in the above embodiments would be understood as follows, for instance.

[0081] (1) A refrigeration system according to one aspect is a refrigeration system (e.g., the above-described refrigeration system 100) utilizing a Brayton cycle which generates cold heat by using a refrigerant compressed by a compressor unit (e.g., the above-described compressor unit 102) arranged on a refrigerant path (e.g., the above-described refrigerant path 101). The compressor unit includes: a plurality of compressors (e.g., the above-described plurality of common-shaft compressors 118) arranged in parallel to each other on the refrigerant path; a plurality of first motors (e.g., the above-described plurality of first motors 114A) for driving the plurality of compressors, respectively; an expander-integrated compressor (e.g., the above-described expander-integrated compressor 120) configured integrally with an expander (e.g., the above-described expander 103) capable of expanding the refrigerant compressed by the compressor unit; and a second motor (e.g., the above-described second motor 114B) for driving the expander-integrated compressor. The number of the plurality of compressors is larger than the number of the expander-integrated compressor.

[0082] According the above aspect (1), the development of refrigeration systems with different refrigerating capacities can be achieved by changing the number of compressors that partially constitute the compressor unit, so it is possible to satisfactorily suppress an increase in the number of parts and the occupied area due to design changes.

[0083] (2) In another aspect, in the above aspect (1), the plurality of first motors and the second motor are common.

[0084] According the above aspect (2), the plurality of first motors for respectively driving the plurality of compressors included in the compressor unit and the second motor for driving the expander-integrated compressor are common. Thus, the types of motors used in the refrigeration system can be reduced, and the development cost and time can be reduced effectively.

[0085] Herein, the fact that the plurality of first motors and the second motor are “common” means that the plurality of first motors and the second motor are separate motors, but at least some of their specifications are common. The fact that the specifications are common may mean that, for example, at least some of the motor power, rotational speed, or dimensions are

the same, or that they can be substituted for each other, or that the design is the same to the extent that it does not affect the assembly of components other than the motor.

[0086] (3) In another aspect, in the above aspect (1) or (2), the refrigeration system includes a control device (e.g., the above-described control device 200) for controlling the plurality of compressors. The control device is configured to control the plurality of compressors to operate some of the plurality of compressors, based on a temperature of the refrigerant at an inlet of the expander at startup of the refrigeration system.

[0087] According to the above aspect (3), by operating some of the plurality of compressors at startup of the refrigeration system, the occurrence of surging in the common-shaft compressor can be effectively prevented.

[0088] (4) In another aspect, in the above aspect (3), the control device is configured to perform control to decrease a rotational speed of an operating compressor and then control to change the number of operating compressors of the plurality of compressors.

[0089] According to the above aspect (4), when changing the number of operating compressors, by decreasing the rotational speed of the compressor that has been started earlier, the number of operating compressors can be smoothly changed while preventing the occurrence of surging in each compressor.

[0090] (5) In another aspect, in any one of the above aspects (1) to (4), the refrigerant path includes: a bypass line (e.g., the above-described second bypass line 170) connecting upstream and downstream sides of a compressor (e.g., the above-described intermediate-stage compressor 110B) of the expander-integrated compressor to bypass the compressor, and a bypass valve (e.g., the above-described second bypass valve 172) disposed on the bypass line.

[0091] According to the above aspect (5), by adjusting the opening degree of the bypass valve disposed on the bypass line, surging in each compressor can be effectively prevented.

[0092] (6) In another aspect, in the above aspect (5), the bypass valve is configured to set a flow rate of the refrigerant in the compressor of the expander-integrated compressor to a predetermined value or more, based on a temperature of the refrigerant at an inlet of the expander.

[0093] According to the above aspect (6), if there is a risk of surging due to a rise in the temperature of the refrigerant at the inlet of the expander, by controlling the opening degree of the bypass valve to keep the refrigerant flow rate in the compressor of the expander-integrated compressor to a predetermined value or higher, the occurrence of surging can be prevented.

5 [0094] (7) In another aspect, in the above aspect (6), a rotational speed of the compressor or the expander-integrated compressor is controlled in cooperation with an opening degree of the bypass valve so that a cooling rate of the refrigerant is substantially constant.

[0095] According to the above aspect (7), by controlling the rotational speed of the compressor or the expander-integrated compressor in cooperation with the opening degree

10 control of the bypass valve, the cooling rate of the refrigerant flowing through the refrigerant path is made substantially constant. As a result, it is possible to adjust/correct the cooling rate and control the refrigerant temperature with high accuracy during the precooling period from startup to normal operation.

[0096] (8) In another aspect, in any one of the above aspects (1) to (7), each of the plurality

15 of compressors is a common-shaft compressor (e.g., the above-described common-shaft compressor 118) including a plurality of compressors connected in series on the refrigerant path.

[0097] According to the above aspect (8), since the common-shaft compressor (multi-stage compressor) is used as the plurality of compressors, it is possible to obtain a higher compression ratio than a single-stage compressor and to achieve high efficiency.

20

Reference Signs List

[0098]

100	Refrigeration system
101	Refrigerant path
25 102	Compressor unit (110A, 110B, 110C)
103	Expander
104	Cooling part
105	Cold heat recovery heat exchanger

	106	Superconducting device
	107	Refrigerant path
	108	Pump
	109	Cold box
5	110	Compressor
	110A	Low-stage compressor
	110B	Intermediate-stage compressor
	110C	High-stage compressor
	112 (112A, 112B, 112C)	Heat exchanger
10	114A	First motor
	114B	Second motor
	116A, 116B	Output shaft
	118 (118A, 118B)	Common-shaft compressor
	120	Expander-integrated compressor
15	122-1, 122-2	Radial magnetic bearing
	126	Thrust magnetic bearing
	127-1, 127-2	Axial rotor disk
	128	Casing
	130	Motor casing
20	132-1	Low-stage compressor impeller casing
	132-2	Intermediate-stage compressor impeller casing
	132-3	High-stage compressor impeller casing
	134-1	Expander impeller casing
	136A, 136B	Rotor
25	138A, 138B	Stator
	140A, 140B, 140C, 142	Impeller
	144	First line
	146A, 146B	Second line

	148A, 148B	Third line
	150	Fourth line
	152	Fifth line
	154A, 154B	Sixth line
5	156A, 156B	Seventh line
	158	Eighth line
	160	First valve
	162	Second valve
	164	Third valve
10	166	First bypass line
	168	First bypass valve
	170	Second bypass line
	172	Second bypass valve
	174	Third bypass line
15	176	Third bypass valve
	178	High-pressure refrigerant line
	180	Low-pressure refrigerant line
	182	Fourth bypass line
	184	Buffer tank
20	186	Fourth valve
	188	Fifth valve
	200	Control device

CLAIMS

[Claim 1] A refrigeration system utilizing a Brayton cycle which generates cold heat by using a refrigerant compressed by a compressor unit arranged on a refrigerant path,

5 wherein the compressor unit includes:

 a plurality of compressors arranged in parallel to each other on the refrigerant path;

 a plurality of first motors for driving the plurality of compressors, respectively;

 an expander-integrated compressor configured integrally with an expander capable of expanding the refrigerant compressed by the compressor unit; and

10 a second motor for driving the expander-integrated compressor, and

 wherein the number of the plurality of compressors is larger than the number of the expander-integrated compressor.

[Claim 2] The refrigeration system according to claim 1,

15 wherein the plurality of first motors and the second motor are common.

[Claim 3] The refrigeration system according to claim 1 or 2, comprising a control device for controlling the plurality of compressors,

 wherein the control device is configured to control the plurality of compressors to operate
20 some of the plurality of compressors, based on a temperature of the refrigerant at an inlet of the expander at startup of the refrigeration system.

[Claim 4] The refrigeration system according to claim 3,

 wherein the control device is configured to perform control to decrease a rotational speed
25 of an operating compressor and then control to change the number of operating compressors of the plurality of compressors.

[Claim 5] The refrigeration system according to any one of claims 1 to 4,

wherein the refrigerant path includes:

a bypass line connecting upstream and downstream sides of a compressor of the expander-integrated compressor to bypass the compressor, and

a bypass valve disposed on the bypass line.

5

[Claim 6] The refrigeration system according to claim 5,

wherein the bypass valve is configured to set a flow rate of the refrigerant in the compressor of the expander-integrated compressor to a predetermined value or more, based on a temperature of the refrigerant at an inlet of the expander.

10

[Claim 7] The refrigeration system according to claim 6,

wherein a rotational speed of the compressor or the expander-integrated compressor is controlled in cooperation with an opening degree of the bypass valve so that a cooling rate of the refrigerant is substantially constant.

15

[Claim 8] The refrigeration system according to any one of claims 1 to 7,

wherein each of the plurality of compressors is a common-shaft compressor including a plurality of compressors connected in series on the refrigerant path.