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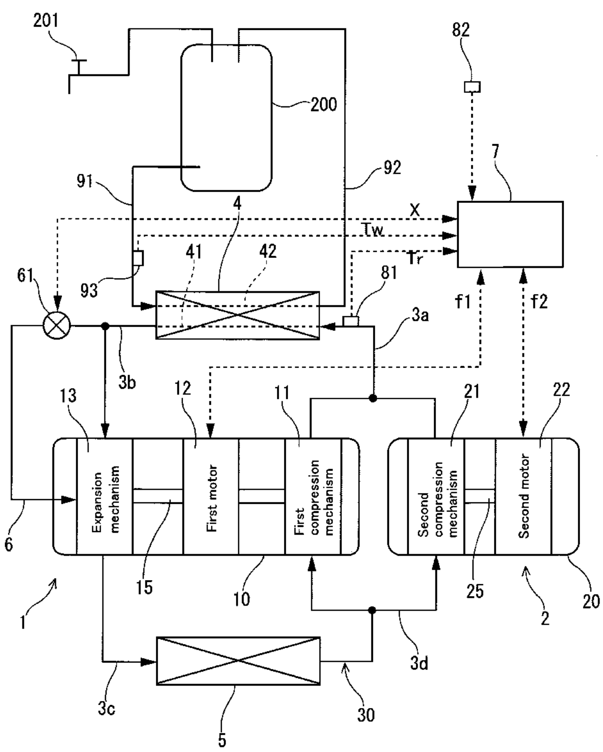
[Continued on next page]

(54) **Title**: REFRIGERATION CYCLE APPARATUS

FIG.1



(57) **Abstract**: A refrigeration cycle apparatus includes an expander-compressor unit (1) having a first motor (12), a second compressor (2) having a second motor (22), and a controller (7). The controller (7) determines the target rotational frequency F1 of the first motor (12) and the target rotational frequency F2 of the second motor (22) for a start-up operation, and determines whether the opening X of an injection valve (61) should be in a fully opened state or in a fully closed state during the start-up operation, based on an outside air temperature and other factors. Then, the controller (7) performs the start-up operation by controlling the rotational frequencies f1 and f2 of the first motor and the second motor to be the determined target rotational frequencies F1 and F2 while maintaining the opening X of the injection valve in the fully opened state or in the fully closed state.

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Description

Title of Invention: REFRIGERATION CYCLE APPARATUS

Technical Field

[0001] The present invention relates to a refrigeration cycle apparatus including an expansion mechanism and compression mechanisms, and used in a hot water heater, an air conditioner, and the like.

Background Art

[0002] In recent years, a power recovery type refrigeration cycle apparatus has been proposed as a refrigeration cycle apparatus for achieving more efficient performance. In a refrigeration cycle apparatus of this type, an expansion mechanism is used instead of an expansion valve to recover as mechanical energy the pressure energy of a refrigerant in its expansion process and reduce the electric power required for driving a compression mechanism by the amount of the recovered power. Such a refrigeration cycle apparatus includes an expander-compressor unit, in which a motor, a compression mechanism, and an expansion mechanism are coupled to each other by a shaft.

[0003] Since the expander-compressor unit includes the compression mechanism and the expansion mechanism coupled to each other by the shaft, it is subject to a so-called "constraint of constant density ratio", under which the ratio between the density of a refrigerant drawn into the compression mechanism and the density of a refrigerant drawn into the expansion mechanism is fixed at a constant ratio determined by their suction volumes. Therefore, the displacement of the compression mechanism or the displacement of the expansion mechanism may be insufficient under certain operating conditions. In order to retain the recovered power even under the operating conditions that may cause an insufficient displacement of the compression mechanism so as to keep the coefficient of performance (COP) of the refrigeration cycle apparatus high, there has been proposed a refrigeration cycle apparatus including a secondary compressor in addition to an expander-compressor unit (see, for example, PTL 1).

[0004] FIG. 8 is a diagram showing the configuration of the refrigeration cycle apparatus described in PTL 1. This refrigeration cycle apparatus includes a refrigerant circuit 140, in which a first compression mechanism 101 in an expander-compressor unit 100 as a first compressor and a second compression mechanism 111 in a second compressor 110 are placed in parallel. Specifically, the first compression mechanism 101 and the second compression mechanism 111 are connected to a radiator 120 by a first pipe 141 and connected to an evaporator 130 by a fourth pipe 144. An expansion mechanism 103 in the expander-compressor unit 100 is connected to the radiator 120 by a second pipe 142 and connected to the evaporator 130 by a third pipe 143. In this refrigeration cycle apparatus of PTL 1, the rotational frequency of a first motor 102 in the expander-compressor unit 100 and the rotational frequency of a second motor 112 in the second compressor 110 can be determined respectively according to the outside air temperature and other factors to prevent an excess or shortage of the amount of refrigerant flowing into the expansion mechanism 103.

[0005] The refrigeration cycle apparatus described in PTL 1 further is provided with a bypass passage 160 for bypassing the expansion mechanism 103 and an injection passage 150 for supplying additional refrigerant to the expansion mechanism 103 during the expansion process of the refrigerant. These bypass passage 160 and injection passage 150 are provided with a bypass valve 161 and an injection valve 151, respectively, to regulate the flow rate of the refrigerant. In this refrigeration cycle apparatus of PTL 1, the bypass valve 161 is closed and the injection valve 151 is opened during the winter season. The opening of the injection valve 151 is determined based on the outside air temperature and other factors. Such a configuration allows the refrigeration cycle apparatus to deal with an insufficient displacement of the expansion mechanism 103.

Citation List

Patent Literature

[0006] PTL 1: JP 2007-132622 A

Summary of Invention

Technical Problem

[0007] In the above-mentioned refrigeration cycle apparatus in which the compression mechanisms are placed in parallel, it is conceivable to rotate the first motor in the expander-compressor unit and the second motor in the second compressor at the same rotational frequency.

[0008] Generally, in a refrigeration cycle apparatus, the pressure on the lower pressure side in the winter season becomes lower than that in the intermediate season such as spring or autumn, as shown, for example, in FIG. 9. The low pressure of the refrigeration cycle declines as the outside air temperature decreases. For example, in the case where the refrigeration cycle apparatus is used in a hot water heater as a heat pump unit for heating water to generate hot water, the state of the refrigerant drawn into the expansion mechanism is almost constant because the temperature (for example, 20 deg C) of water to be heated and the temperature (for example 90 deg C) of hot water to be generated do not change much. As a result, as the outside air temperature decreases, the rotational frequencies of the first motor in the expander-compressor unit and the second motor in the second compressor increase, and at the same time, the apparent suction volume required for the expansion mechanism also decreases. Accordingly, the opening of the injection valve is reduced as the outside air temperature decreases.

[0009] For example, FIG. 10 shows the rotational frequencies of the first motor and the second motor as well as the openings of the injection valve at outside air temperatures of 2 deg C, 7 deg C, 12 deg C and 16 deg C, respectively, assuming that the first motor and the second motor rotate at the same rotational frequency. The data shown in FIG. 10 may be stored ahead of time in the form of a table in a controller of the refrigeration cycle apparatus. The controller determines how the rotational frequencies of the first motor and the second motor as well as the opening of the injection valve should be set for the start-up operation with reference to this table. In the case where an actual outside air temperature is between the two temperatures given in the table, each of the rotational frequencies and the opening is determined on a prorated basis using the two values corresponding to the two temperatures. That is to say, when the table of FIG. 10 is used, the opening of the injection valve is determined so that it changes continuously according to the outside air temperature.

[0010] On the other hand, in the refrigeration cycle apparatus provided with the injection passage, the refrigerant flowing through the injection passage is expanded to some extent in the injection valve unless the injection valve is opened fully. Therefore, a part of the expansion energy cannot be recovered.

[0011] FIG. 11 is a graph showing the results of experimental measurement of an energy loss (hereinafter referred to as an "injection loss") caused by a pressure drop occurring when the refrigerant passes through the injection valve in the refrigeration cycle apparatus provided with the injection passage. In FIG. 11, the horizontal axis indicates the injection flow rate (i.e., the flow rate of the refrigerant flowing through the injection passage), and the vertical axis indicates the injection loss. As shown in FIG. 11, the injection loss decreases as the injection flow rate decreases, that is, the opening of the injection valve decreases, or as the injection flow rate increases, that is, the opening of the injection valve increases.

[0012] These results show that the injection loss varies significantly depending on the injection flow rate, that is, the opening of the injection valve. Therefore, it is preferable that the opening of the injection valve is in a fully closed state or in a fully opened state. It is preferable that the opening of the injection valve is in the fully closed state or in the fully opened state also during the start-up operation.

[0013] In the case where the table shown in FIG. 10 is used, however, the opening of the injection valve is determined so that it changes continuously according to the outside air temperature, and during the start-up operation, the injection valve is controlled to have the determined opening. Therefore, an injection loss occurs during the start-up operation.

[0014] The present invention has been made in view of the above problems, and it is an object of the present invention to keep the injection loss low during a start-up operation in a refrigeration cycle apparatus including an expansion mechanism and compression mechanisms and provided with an injection passage.

Solution to Problem

[0015] In order to solve the above problems, the present invention provides a refrigeration cycle apparatus including:

a first compressor including: a first compression mechanism for compressing a refrigerant; an expansion mechanism for recovering power from an expanding refrigerant; a first motor coupled to the first compression mechanism and the expansion mechanism by a shaft; and a first closed casing for accommodating the first compression mechanism, the expansion mechanism and the first motor;

a second compressor including: a second compression mechanism for compressing the refrigerant, the second compression mechanism being connected in parallel with the first compression mechanism in a refrigerant circuit; a second motor coupled to the second compression mechanism by a shaft; and a second closed casing for accommodating the second compression mechanism and the second motor;

a radiator for radiating heat from the refrigerant discharged from the first compression mechanism and the second compression mechanism;

an evaporator for evaporating the refrigerant discharged from the expansion mechanism;

a first pipe for guiding the refrigerant from the first compression mechanism and the second compression mechanism to the radiator;

a second pipe for guiding the refrigerant from the radiator to the expansion mechanism;

a third pipe for guiding the refrigerant from the expansion mechanism to the evaporator;

a fourth pipe for guiding the refrigerant from the evaporator to the first compression mechanism and the second compression mechanism;

an injection passage, branched from the second pipe, for supplying the refrigerant additionally to the expansion mechanism during an expansion process;

an opening-adjustable injection valve provided in the injection passage;

an outside air temperature sensor for detecting an outside air temperature; and

a controller for determining a target rotational frequency of the first motor and a target rotational frequency of the second motor for a start-up operation and determining whether an opening of the injection valve should be in a fully opened state or in a fully closed state during the start-up operation, based on the outside air temperature detected by the outside air temperature sensor, and performing the start-up operation by controlling rotational frequencies of the first motor and the second motor to be the determined target rotational frequencies while maintaining the opening of the injection valve in the fully opened state or in the fully closed state.

[0016] The fully closed state here means a state in which the flow of the refrigerant substantially is shut off by the injection valve, for example, a state in which the opening is 5% or less. The fully opened state means a state in which the flow of the refrigerant substantially is not impeded by the injection valve, for example, a state in which the opening is 95% or more.

Advantageous Effects of Invention

[0017] With the configuration as described above, the refrigeration cycle apparatus of the present invention can keep the injection loss low during the start-up operation.

Brief Description of Drawings

[0018] [fig.1]FIG. 1 is a schematic diagram of a refrigeration cycle apparatus according to one embodiment of the present invention.

[fig.2]FIG. 2 is a diagram for explaining tables used in the embodiment of the present invention, in which the tables have target rotational frequencies of a first motor and a second motor and openings of an injection valve in association with preset discharge temperatures, water temperatures and outside air temperatures.

[fig.3]FIG. 3 shows one of the tables of FIG. 2 involving a preset discharge temperature of 110 deg C and a water temperature of 20 deg C.

[fig.4]FIG. 4 shows a steady operation table involving a preset discharge temperature of 110 deg C and a water temperature of 20 deg C.

[fig.5]FIG. 5 shows a graph obtained by plotting the values in the table of FIG. 3.

[fig.6]FIGS. 6A to 6C are diagrams for explaining how the rotational frequencies of the first motor and the second motor should be changed during a start-up operation.

[fig.7]FIG. 7 is a flow chart of the start-up operation performed by a controller.

[fig.8]FIG. 8 is a schematic diagram of a conventional refrigeration cycle apparatus.

[fig.9]FIG. 9 is a Mollier diagram representing an intermediate season and a winter season.

[fig.10]FIG. 10 is a diagram showing a table of the conventional refrigeration cycle apparatus, in which the table has rotational frequencies of a first motor and a second motor and openings of an injection valve in association with outside air temperatures, assuming that the first motor and the second motor rotate at the same rotational frequency.

[fig.11]FIG. 11 is a diagram showing a relationship between an injection flow rate and an injection loss.

Description of Embodiments

[0019] Hereinafter, embodiments of the present invention will be described with reference to the accompanying drawings.

[0020] FIG. 1 shows a refrigeration cycle apparatus according to one embodiment of the present invention. This refrigeration cycle apparatus includes a refrigerant circuit 30. The refrigerant circuit 30 includes an expander-compressor unit 1 as a first compressor, a second compressor 2, a radiator 4, an evaporator 5, and first to fourth pipes (refrigerant pipes) 3a to 3d for connecting these devices.

[0021] The expander-compressor unit 1 has a first closed casing 10 for accommodating a first compression mechanism 11, a first motor 12 and an expansion mechanism 13 that are coupled to each other by a first shaft 15. The second compressor 2 has a second closed casing 20 for accommodating a second compression mechanism 21 and a second motor 22 that are coupled to each other by a second shaft 25. The first compression mechanism 11 and the second compression mechanism 21 are connected to the radiator 4 via the first pipe 3a having two branch pipes and a main pipe connected thereto. The radiator 4 is connected to the expansion mechanism 13 via the second pipe 3b. The expansion mechanism 13 is connected to the evaporator 5 via the third pipe 3c. The evaporator 5 is connected to the first compression mechanism 11 and the second compression mechanism 21 via the fourth pipe 3d having a main pipe and two branch pipes connected thereto. In the refrigerant circuit 30, the first compression mechanism 11 and the second compression mechanism 21 are placed in parallel. In other words, the first compression mechanism 11 and the second compression mechanism 21 are connected in parallel to each other in the refrigerant circuit 30.

[0022] The refrigerant compressed in the first compression mechanism 11 and the refrigerant compressed in the second compression mechanism 21 are discharged respectively from the first and second compression mechanisms 11 and 21 to the first pipe 3a, and then join in the first pipe 3a. The joined refrigerant is guided to the radiator 4. The refrigerants compressed in the compression mechanisms 11 and 21 may be discharged once into the closed casings 10 and 20 separately and then discharged from the closed casings 10 and 20 to the first pipe 3a. The refrigerant guided to the radiator 4 radiates heat there, and then is guided to the expansion mechanism 13 through the second pipe 3b. The refrigerant guided to the expansion mechanism 13 expands there. At the same time, the expansion mechanism 13 recovers power from the expanding refrigerant. The expanded refrigerant is guided to the evaporator 5 through the third pipe 3c. The refrigerant guided to the evaporator 5 absorbs heat there, and then is split into two streams in the fourth pipe 3d, which are guided to the first compression mechanism 11 and the second compression mechanism 21.

[0023] It is preferable that the displacement volume of the first compression mechanism 11 is the same as that of the second compression mechanism 21. In this case, it is possible to construct the first and second compression mechanisms 11 and 12 with common members, which reduces the cost.

[0024] The refrigeration cycle apparatus further includes an injection passage 6, branched from the second pipe 3b, for supplying the refrigerant additionally to the expansion mechanism 13 in the expansion process of the refrigerant. An opening-adjustable injection valve 61 for regulating the flow rate is provided at an intermediate point of this injection passage 6.

[0025] The refrigeration cycle apparatus of the present embodiment is used as a heat pump unit for heating water to generate hot water, in a hot water heater for supplying hot water stored in a hot water tank 200 to a hot water tap 201. Specifically, the radiator 4 serves as a heat exchanger for exchanging heat between water and a refrigerant to heat the water, and includes a refrigerant passage 41 through which the refrigerant flows and a water passage (fluid passage) 42 through which the water (fluid) flows. The water flowing through the water passage 42 receives heat from the refrigerant flowing through the refrigerant passage 41. The refrigeration cycle apparatus further includes a supply pipe 91 for supplying the water from the hot water tank 200 to the water passage 42, and a return pipe 92 for returning the water (hot water) from the water passage 42 to the hot water tank 200.

[0026] The refrigeration cycle apparatus includes a controller 7 for controlling mainly the rotational frequencies of the first motor 12 and the second motor 22 as well as the opening of the injection valve 61. In the present embodiment, the controller 7 is connected to an outside air temperature sensor 82 for detecting the outside air temperature, a fluid temperature sensor 93 for detecting the temperature of water flowing through the supply pipe 91, and a refrigerant temperature sensor 81 for detecting the temperature of the refrigerant guided to the radiator 4 through the first pipe 3a (to be more specific, the temperature of the joined refrigerant).

[0027] The refrigerant circuit 30 is filled with a refrigerant that reaches a supercritical state in the high-pressure side thereof (specifically, in a path from the first compression mechanism 11 and the second compression mechanism 21 to the expansion mechanism 13 through the radiator 4). In the present embodiment, the refrigerant circuit 30 is filled with carbon dioxide (CO_2) as such a refrigerant. It should be noted that the type of the refrigerant is not particularly limited. The refrigerant may be a refrigerant that does not reach a supercritical state during operation (for example, a fluorocarbon refrigerant).

[0028] Next, the control performed by the controller 7 is described. As shown in FIG. 6A, the controller 7 first performs a start-up operation and then performs a steady operation. Specifically, the controller 7 starts up the first motor 12 and the second motor 22 so as to shift to the steady operation smoothly. This is the start-up operation. As described above in Technical Problem with reference to FIG. 11, it is preferable that the opening of the injection valve 61 is in the fully closed state or in the fully opened state not only during the steady operation but also during the start-up operation in order to keep the injection loss low. For that purpose, the controller 7 performs the following control. FIG. 7 is a flow chart of the control.

[0029] Immediately before the start-up operation, the controller 7 obtains a predetermined preset discharge temperature of the refrigerant guided to the radiator 4 through the first pipe 3a, the outside air temperature detected by the outside air temperature sensor 82, and the water temperature detected by the fluid temperature sensor 93 (Step S1). Then, the controller 7 determines the target rotational frequency F1 of the first motor 12 and the target rotational frequency F2 of the second motor 22 for the start-up operation and determines whether the opening X of the injection valve 61 should be in the fully closed state or in the fully opened state during the start-up operation, based on the obtained preset discharge temperature, outside air temperature and water temperature (Steps S2 to S4).

[0030] Specifically, tables for respective preset discharge temperatures (for example, from 80 deg C to 140 deg C in increments of 5 deg C) and respective water temperatures (for example, from 10 deg C to 30 deg C in increments of 2 deg C), as shown in FIG. 2, are stored ahead of time in the controller 7. FIG. 3 shows a table involving a preset discharge temperature of 110 deg C and a water temperature of 20 deg C as a typical example of the tables. In each table, the target rotational frequencies F1 of the first motor 12, the target rotational frequencies F2 of the second motor 22, and the openings X of the injection valve 61 (0% or 100% in the present embodiment) are defined for respective predetermined outside air temperatures (0 deg C, 2 deg C, 7 deg C, 9 deg C, 12 deg C, and 16 deg C in the present embodiment). In each of the tables of the present embodiment, the continuity of values is interrupted at the outside air temperature of 9 deg C, that is, 9 deg C is a threshold temperature. More specifically, as shown in FIG. 5, at the temperature of 9 deg C, the opening X of the injection valve is switched from the fully closed state to the fully opened state or vice versa, and the relationship between the target rotational frequency F1 of the first motor 12 and the target rotational frequency F2 of the second motor 22 is reversed. The table has two columns for the outside air temperature of 9 deg C. When the outside air temperature is 9 deg C, the values in the left column are used. When the outside air temperature is in a range of more than 9 deg C to 12 deg C, the values in the right column are used to determine the target rotational frequencies F1 and F2 of the first motor 12 and the second motor 22.

[0031] The preset discharge temperature is related to a target temperature of water to be heated (a temperature of hot water to be generated) in the radiator 4. A desired value of the preset discharge temperature is selected previously in accordance with the intended use or environment, and the selected value is stored in a memory of the controller 7. For example, in order to generate hot water of 90 deg C, a preset discharge temperature of 110 deg C is selected. The controller 7 reads the preset discharge temperature from the memory to obtain that temperature. It also is possible to determine a preset discharge temperature to be obtained, on a case-by-case basis, based on the target temperature of water to be heated in the radiator 4 and the outside air temperature.

[0032] The controller 7 identifies, among the tables, a group of tables corresponding to the obtained preset discharge temperature, immediately before it starts the start-up operation. The controller 7 further selects, from among the identified group of tables, a table involving a water temperature closest to the water temperature detected by the fluid temperature sensor 93 (Step S2). Subsequently, by using the selected table, the controller 7 determines the target rotational frequency F1 of the first motor 12 and the target rotational frequency F2 of the second motor 22 for the start-up operation based on the outside air temperature detected by the outside air temperature sensor 82 (Step S3). In the case where the detected outside air temperature coincides with the outside air temperature listed in the selected table, the target rotational frequencies F1 and F2 are determined to be the values defined in this table. In the case where the detected outside air temperature is between the two temperatures listed in the table, the target rotational frequencies F1 and F2 each are determined to be the value calculated on a prorated basis using the two values corresponding to the two temperatures. In the case where the detected outside air temperature is beyond the range of outside air temperatures listed in the table, the target rotational frequencies F1 and F2 are determined to be the values defined in a table in association with the closest outside air temperature. In the case where the detected outside air temperature is between the two temperatures listed in the table, the values corresponding to one of the two temperatures closer to the detected temperature may be adopted to determine the target rotational frequencies F1 and F2.

[0033] The controller 7 determines the target rotational frequency F1 of the first motor 12 and the target rotational frequency F2 of the second motor 22 for the start-up operation, and simultaneously determines whether the opening X of the injection valve 61 should be in the fully closed state or in the fully opened state during the start-up operation based on the outside air temperature detected by the outside air temperature sensor 82, by using the selected table (Step S4). In the present embodiment, if the detected outside air temperature is 9 deg C or lower, the controller 7 determines that the opening X of the injection valve 61 should be in the fully closed state (0%), and if the detected outside air temperature is higher than 9 deg C, the controller 7 determines that the opening X of the injection valve 61 should be in the fully opened state (100%).

As described above, in the case where the detected outside air temperature coincides with the threshold temperature, it is preferable to determine that the opening X of the injection valve 61 should be in the fully closed state in order to prevent the pressure loss in the injection passage 6.

[0034] The threshold temperature that defines a switching point between the fully closed state and the fully opened state for the opening X of the injection valve 61 does not necessarily have to be 9 deg C. The threshold temperature can be determined appropriately. For example, the threshold temperature may be determined in the following manner. As shown in FIG. 5, as the outside air temperature increases from 0 deg C, the target rotational frequency F1 of the first motor 12 increases but the target rotational frequency F2 of the second motor 22 decreases. Therefore, the threshold temperature may be determined to be an outside air temperature at the point when a ratio F1/F2 of the target rotational frequency F1 of the first motor 12 to the target rotational frequency F2 of the second motor 22 exceeds a value A. This is a method aimed at keeping the rotational frequency ratio F1/F2 at a certain low level to balance between the lubricating oil in the closed casing 10 and that in the closed casing 20. Alternatively, the threshold temperature may be determined to be an outside air temperature immediately before the target rotational frequency F1 of the first motor 12 exceeds the upper limit value of the allowable rotational frequency determined from the viewpoint of ensuring the reliability.

[0035] The values defined in the tables are described below in detail.

[0036] In the present embodiment, each of the target rotational frequencies F2 of the second motor 22 in the tables is higher than the corresponding rotational frequency F2' of the second motor 22 in a steady operation table for an ideal steady operation derived from a preset discharge temperature, an outside air temperature and a water temperature. The ideal steady operation here means a state in which the rotational frequency of one of the first motor 12 and the second motor 22 is increased and that of the other is decreased until the opening X of the injection valve 61 becomes 0% or 100% from the opening X that is optimized assuming that the rotational frequency of the first motor 12 is the same as that of the second motor 22 (see FIG. 10). Which one of the rotational frequencies should be increased or decreased, the rotational frequency of the first motor 12 or that of the second motor 22, is determined based on the optimized opening X of the injection valve 61. For example, when the optimized opening X of the injection valve 61 is less than 50%, the rotational frequency of the first motor 12 is increased and the rotational frequency of the second motor 22 is decreased so as to bring the opening X closer to 0%. When the optimized opening X of the injection valve 61 is 50% or more, the rotational frequency of the first motor 12 is decreased and the rotational frequency of the second motor 22 is increased so as to bring the opening

X closer to 100%. When the optimized opening X of the injection valve 61 is 0% or 100%, an ideal steady operation is a state in which the rotational frequency of the first motor is the same as that of the second motor.

[0037] FIG. 4 shows a steady operation table involving a preset discharge temperature of 110 deg C and a water temperature of 20 deg C. Hereinafter, the tables stored in the controller 7 are referred to as "start-up operation tables" to distinguish them from the steady operation table.

[0038] As shown in FIG. 3 and FIG. 4, in the start-up operation tables of the present embodiment, only the rotational frequencies of the second motor 22 are higher than those in the steady operation table. The steady operation tables may be stored in the controller 7 so that the controller 7 can determine the target rotational frequencies F1 and F2 of the first motor 12 and the second motor 22 for the start-up operation by using the stored steady operation tables. Since the opening X of the injection valve is set to 0% or 100% also in the steady operation tables, the injection loss can be suppressed during the start-up operation even if the steady operation tables were to be used. However, by using the start-up operation tables having higher target rotational frequencies of the second motor 22 as in the present embodiment, a pressure difference can be generated rapidly between the high pressure side and the low pressure side of the refrigeration cycle. As a result, the constituent members of the high pressure side of the refrigeration cycle apparatus can be heated quickly.

[0039] In order to generate rapidly a pressure difference between the high pressure side and the low pressure side of the refrigeration cycle, start-up operation tables, in which the rotational frequencies of the first motor 12 also are higher than those in the steady operation table, may be used. It is preferable that the ratio F1/F2 of each of the target rotational frequencies F1 of the first motor 12 to the counterpart target rotational frequency F2 of the second motor 22 in the start-up operation tables is lower than the corresponding ratio F1'/F2' of the rotational frequency F1' of the first motor 12 to the rotational frequency F2' of the second motor 22 in the steady operation table. With such a configuration, the rotational frequency of the expander-compressor unit 1 can be reduced relative to that of the second compressor 2. Therefore, the apparent specific volume of the expansion mechanism 13 decreases relative to those of the compression mechanisms 11 and 21, and as a result, a pressure difference can be generated rapidly between the high pressure side and the low pressure side of the refrigeration cycle.

[0040] Alternatively, each of the target rotational frequencies F1 of the first motor 12 in the start-up operation tables may be set lower than the corresponding rotational frequency F1' of the first motor 12 in the steady operation table, while each of the target rotational frequencies F2 of the second motor 22 in the start-up operation tables is maintained to be equal to the corresponding rotational frequency F2' of the first motor

22 in the steady operation table. It is preferable to use a start-up operation table in which at least the rotational frequencies of the second motor 22 are set higher than those in the steady operation table, because a sufficient amount of refrigerant can be circulated through the refrigerant circuit 30 during the start-up operation and thereby the constituent members of the refrigeration cycle apparatus can be heated quickly.

[0041] It is preferable that the difference between each of the target rotational frequencies F1 of the first motor 12 and the counterpart target rotational frequency F2 of the second motor 22 in the start-up operation tables is smaller than the upper limit value (for example, 40 Hz) of the allowable driving range under any conditions (i.e., at any preset discharge temperature, at any water temperature, and at any outside air temperature). Furthermore, it is preferable that the ratio F1/F2 of each of the target rotational frequencies F1 of the first motor 12 to the counterpart target rotational frequency F2 of the second motor 22 in the start-up operation tables is in a range between the lower limit value (for example, 0.5) and the upper limit value (for example, 2) of the allowable driving range. The allowable driving range here means a range that is determined arbitrarily based on factors to be considered from a design viewpoint, such as the allowable lowest rotational frequency and the allowable highest rotational frequency of the compression mechanism 11 and 21, and the degree of imbalance between the lubricating oil level in the closed casing 10 and that in the closed casing 20 generated from a difference between the rotational frequency of the first motor 12 and that of the second motor 22.

[0042] The controller 7 determines the target rotational frequency F1 of the first motor 12 and the target rotational frequency F2 of the second motor 22 for the start-up operation, and simultaneously determines whether the opening X of the injection valve should be in the fully opened state or in the fully closed state during the start-up operation, by using the start-up operation tables stored previously in the controller 7. Subsequently, the controller 7 drives the first and second motors 12 and 22 to start the start-up operation (Step S5). Then, the controller 7 performs the start-up operation by controlling the rotational frequencies f1 and f2 of the first motor 12 and the second motor 22 to be the determined target rotational frequencies F1 and F2 respectively until a predetermined time period for the start-up operation has elapsed (Step S6). In the present embodiment, the controller 7 increases continuously the rotational frequencies f1 and f2 of the first motor 12 and the second motor 22 to the determined target rotational frequencies F1 and F2 respectively, as shown in FIG. 6A. During the start-up operation, after increasing the rotational frequencies f1 and f2 of the first motor 12 and the second motor 22 to the determined target rotational frequencies F1 and F2, the controller 7 may maintain the target rotational frequencies F1 and F2 for a predetermined period of time.

[0043] In addition, when the controller 7 determines that the opening of the injection valve 61 should be in the fully closed state, it performs the start-up operation while maintaining the opening X of the injection valve 61 in the fully closed state. It should be noted that when the controller 7 determines that the opening of the injection valve 61 should be in the fully opened state, it performs the start-up operation while maintaining the opening X of the injection valve 61 in the fully opened state. When the controller 7 determines that the opening of the injection valve 61 should be in the fully opened state, it may control the opening of the injection valve to be in the fully closed state for a predetermined period of time after the start of the start-up operation and then switched to the fully opened state. With such a configuration, a pressure difference can be generated rapidly between the high pressure side and the low pressure side of the refrigeration cycle, and a time required to shift from the start-up operation to the steady operation can be reduced.

[0044] After the start-up operation is completed, the controller 7 performs the steady operation. Specifically, the controller 7 changes the rotational frequencies f1 and f2 of the first motor 12 and the second motor 22 to the rotational frequencies F1' and F2' respectively determined based on the steady operation table shown in FIG. 4 (in the present embodiment, the rotational frequency of the first motor 12 is maintained unchanged). Subsequently, the controller 7 adjusts the opening X of the injection valve 61 as well as the rotational frequencies f1 and f2 of the first motor 12 and the second motor 22 so that the high pressure of the refrigeration cycle can be maintained at an optimum high pressure by feedback control, in other words, that the refrigerant temperature detected by the refrigerant temperature sensor 81 becomes equal to the preset discharge temperature.

[0045] As described above, in the refrigeration cycle apparatus of the present embodiment, the start-up operation is performed while the opening X of the injection valve 61 is maintained in the fully closed state or in the fully opened state under any conditions. Therefore, the injection loss can be kept low during the start-up operation. In particular, if the opening X of the injection valve 61 is maintained at 0% or 100% as in the case of the present embodiment, the injection loss can be prevented from occurring.

[0046] (Modification 1)

In the above embodiment, the controller 7 increases continuously the rotational frequencies f1 and f2 of the first motor 12 and the second motor 22, as shown in FIG. 6A. The controller 7, however, may increase the rotational frequencies f1 and f2 of the first motor 12 and the second motor 22 in a stepwise manner, as shown in FIG. 6B.

[0047] Specifically, the controller 7 divides the time period of the start-up operation into time-based control sections (for example, every 180 seconds). Then, the controller 7 increases both the rotational frequency f1 of the first motor 12 and the rotational frequency f2 of the second motor 22 so as to bring the sum of the rotational frequencies f1 and f2 of the first motor 12 and the second motor 22 closer to the sum of the determined target rotational frequencies F1 and F2 of the first motor 12 and the second motor 22 step by step as the control section shifts from one to another. A rapid increase in the rotational frequencies f1 and f2 of the first motor 12 and the second motor 22 may cause in some cases a so-called overshoot, in which the actual discharge temperature of a refrigerant exceeds a preset discharge temperature. In contrast, if the rotational frequencies f1 and f2 of the first motor 12 and the second motor 22 are increased step by step, as described above, such an overshoot can be prevented.

[0048] It is preferable that the controller 7 calculates a difference between the preset discharge temperature and the refrigerant temperature detected by the refrigerant temperature sensor 81 every time the control section shifts from one to another, and when the difference is a relatively large value, increases relatively significantly the sum of the rotational frequency f1 of the first motor 12 and the rotational frequency f2 of the second motor 22. With such a configuration, the high pressure of the refrigeration cycle can be brought closer to the target value rapidly, and thereby the time period of the start-up operation can be reduced.

[0049] (Modification 2)

In the example shown in FIG. 6B, the controller 7 increases the rotational frequencies f1 and f2 of the first motor 12 and the second motor 22 as the control section shifts from one to another while maintaining the ratio f1/f2 of the rotational frequency f1 of the first motor 12 to the rotational frequency f2 of the second motor 22 equal to the determination ratio F1/F2 that is a ratio of the determined target rotational frequency F1 of the first motor 12 to the determined target rotational frequency F2 of the second motor 22. The controller 7 may, however, set the rotational frequency ratio f1/f2 lower than the determination ratio F1/F2 in the earliest control section and bring the ratio f1/f2 closer to the determination ratio F1/F2 step by step as the control section shifts from one to another in the control sections following the earliest section, as shown in FIG. 6C. With such a configuration, the rotational frequency of the expander-compressor unit 1 can be reduced relative to that of the second compressor 2. Therefore, the apparent specific volume of the expansion mechanism 13 decreases relative to those of the compression mechanisms 11 and 21, and as a result, a pressure difference can be generated rapidly between the high pressure side and the low pressure side of the refrigeration cycle.

[0050] In this case, it is preferable that the controller 7 calculates a difference between the preset discharge temperature and the refrigerant temperature detected by the refrigerant temperature sensor 81 every time the control section shifts from one to another, and when the difference is a relatively large value, increases the rotational frequency ratio f1/f2 at a slow rate. With such a configuration, a sufficient amount of refrigerant can be circulated through the refrigerant circuit 30 during the start-up operation, and a pressure difference can be generated rapidly between the high pressure side and the low pressure side. Therefore, the constituent members of the refrigeration cycle apparatus can be heated quickly, and thereby the actual discharge temperature of the refrigerant can be increased rapidly to the preset discharge temperature.

[0051] (Other Modifications)

In the above embodiment, the controller 7 terminates the start-up operation when a predetermined time period has elapsed. The controller 7 may, however, terminate the start-up operation when the actual discharge temperature of the refrigerant exceeds the preset discharge temperature. Furthermore, the controller 7 may perform the start-up operation several times successively. In this case, a start-up operation table may be prepared for each start-up operation to repeat the procedure from Step S2 through Step S6 of FIG. 7 after the first start-up operation is completed.

[0052] In the above embodiment, the controller 7 uses the preset discharge temperature to determine the target rotational frequencies F1 and F2 of the first motor 12 and the second motor 22 as well as the opening X of the injection valve 61 for the start-up operation. The controller 7 may, however, use a target temperature of water to be heated (temperature of hot water to be generated) in the radiator 4, instead of the preset discharge temperature.

[0053] Furthermore, in the above embodiment, the refrigeration cycle apparatus includes the fluid temperature sensor 93. However, the water temperature as a value that varies with the season may be inputted previously into the controller 7. The water temperature also may be a fixed value.

[0054] In the above embodiment, the radiator 4 serves as a heat exchanger for exchanging heat between a refrigerant and water. The radiator 4 may, however, be a heat exchanger for exchanging heat between a refrigerant and a fluid (for example, air) other than water.

[0055] The refrigeration cycle apparatus may be used in an air conditioner. In this case, the radiator 4 does not have the water passage 42 and dissipates heat from the refrigerant into the atmosphere.

[0056] The refrigerant circuit provided in the refrigeration cycle apparatus of the present invention is not limited to the refrigerant circuit 30 for allowing the refrigerant to flow in one direction only. It may be a refrigerant circuit in which the flow direction of the refrigerant can be changed, for example, a refrigerant circuit including four-way valves and thereby capable of switching between a heating operation and a cooling operation.

Industrial Applicability

[0057] The refrigeration cycle apparatus of the present invention is useful as a power recovery system for recovering the expansion energy of a refrigerant in a refrigeration cycle as mechanical energy.

Claims

[Claim 1] A refrigeration cycle apparatus comprising:
a first compressor including a first compression mechanism for compressing a refrigerant, an expansion mechanism for recovering power from an expanding refrigerant, a first motor coupled to the first compression mechanism and the expansion mechanism by a shaft, and a first closed casing for accommodating the first compression mechanism, the expansion mechanism and the first motor;
a second compressor including a second compression mechanism for compressing the refrigerant, the second compression mechanism being connected in parallel with the first compression mechanism in a refrigerant circuit, a second motor coupled to the second compression mechanism by a shaft, and a second closed casing for accommodating the second compression mechanism and the second motor;
a radiator for radiating heat from the refrigerant discharged from the first compression mechanism and the second compression mechanism;
an evaporator for evaporating the refrigerant discharged from the expansion mechanism;
a first pipe for guiding the refrigerant from the first compression mechanism and the second compression mechanism to the radiator;
a second pipe for guiding the refrigerant from the radiator to the expansion mechanism;
a third pipe for guiding the refrigerant from the expansion mechanism to the evaporator;
a fourth pipe for guiding the refrigerant from the evaporator to the first compression mechanism and the second compression mechanism;
an injection passage, branched from the second pipe, for supplying the refrigerant additionally to the expansion mechanism during an expansion process;
an opening-adjustable injection valve provided in the injection passage;
an outside air temperature sensor for detecting an outside air temperature; and
a controller for determining a target rotational frequency of the first motor and a target rotational frequency of the second motor for a start-up operation and determining whether an opening of the injection valve should be in a fully opened state or in a fully closed state during the start-up operation, based on the outside air temperature detected by the

outside air temperature sensor, and performing the start-up operation by controlling rotational frequencies of the first motor and the second motor to be the determined target rotational frequencies while maintaining the opening of the injection valve in the fully opened state or in the fully closed state.

[Claim 2] The refrigeration cycle apparatus according to claim 1, wherein the radiator is a heat exchanger for heating a fluid by the refrigerant, and includes a refrigerant passage through which the refrigerant flows and a fluid passage through which the fluid flows, and
the controller determines the target rotational frequencies of the first motor and the second motor for the start-up operation and determines whether the opening of the injection valve should be in the fully opened state or in the fully closed state during the start-up operation, based on a target temperature of the fluid to be heated in the radiator and the outside air temperature detected by the outside air temperature sensor, and performs the start-up operation by controlling the rotational frequencies of the first motor and the second motor to be the determined target rotational frequencies while maintaining the opening of the injection valve in the fully opened state or in the fully closed state.

[Claim 3] The refrigeration cycle apparatus according to claim 1, wherein the radiator is a heat exchanger for heating a fluid by the refrigerant, and includes a refrigerant passage through which the refrigerant flows and a fluid passage through which the fluid flows, and
the controller determines the target rotational frequencies of the first motor and the second motor for the start-up operation and determines whether the opening of the injection valve should be in the fully opened state or in the fully closed state during the start-up operation, based on a preset discharge temperature of the refrigerant to be guided to the radiator through the first pipe and the outside air temperature detected by the outside air temperature sensor, and performs the start-up operation by controlling the rotational frequencies of the first motor and the second motor to be the determined target rotational frequencies while maintaining the opening of the injection valve in the fully opened state or in the fully closed state.

[Claim 4] The refrigeration cycle apparatus according to claim 3, further comprising: a supply pipe for supplying the fluid to the fluid passage; and a fluid temperature sensor for detecting a temperature of the fluid that flows through the supply pipe, wherein the controller determines the target rotational frequencies of the first motor and the second motor for the start-up operation and determines whether the opening of the injection valve should be in the fully opened state or in the fully closed state during the start-up operation, based on the preset discharge temperature, the outside air temperature detected by the outside air temperature sensor, and the fluid temperature detected by the fluid temperature sensor, and performs the start-up operation by controlling the rotational frequencies of the first motor and the second motor to be the determined target rotational frequencies while maintaining the opening of the injection valve in the fully opened state or in the fully closed state.

[Claim 5] The refrigeration cycle apparatus according to claim 4, wherein tables are stored in the controller, the tables having target rotational frequencies of the first motor and the second motor and openings of the injection valve in association with preset discharge temperatures, outside air temperatures and fluid temperatures, and
the controller determines the target rotational frequencies of the first motor and the second motor for the start-up operation and determines whether the opening of the injection valve should be in the fully opened state or in the fully closed state during the start-up operation, based on the preset discharge temperature, the outside air temperature detected by the outside air temperature sensor, and the fluid temperature detected by the fluid temperature sensor, by using the tables.

[Claim 6] The refrigeration cycle apparatus according to claim 5, wherein each of the target rotational frequencies of the second motor in the tables is higher than a corresponding rotational frequency of the second motor in a steady operation table for an ideal steady operation derived from a preset discharge temperature, an outside air temperature and a fluid temperature.

[Claim 7] The refrigeration cycle apparatus according to claim 6, wherein a ratio of each of the target rotational frequencies of the first motor to a counterpart target rotational frequency of the second motor in the tables is lower than a corresponding ratio of a rotational frequency of the first motor to a rotational frequency of the second motor in the steady operation table.

[Claim 8] The refrigeration cycle apparatus according to claim 5, wherein a difference between each of the target rotational frequencies of the first motor and a counterpart target rotational frequency of the second motor in the tables is smaller than an upper limit value of an allowable driving range.

[Claim 9] The refrigeration cycle apparatus according to claim 5, wherein a ratio of each of the target rotational frequencies of the first motor to a counterpart target rotational frequency of the second motor in the tables is in a range between an upper limit value and a lower limit value of an allowable driving range.

[Claim 10] The refrigeration cycle apparatus according to any one of claims 3 to 9, wherein the controller divides a time period of the start-up operation into time-based control sections, and brings a sum of the rotational frequencies of the first motor and the second motor closer to a sum of the determined target rotational frequencies of the first motor and the second motor step by step as the control section shifts from one to another during the start-up operation.

[Claim 11] The refrigeration cycle apparatus according to claim 10, further comprising a refrigerant temperature sensor for detecting a temperature of the refrigerant guided to the radiator through the first pipe,
wherein the controller calculates a difference between the preset discharge temperature and the refrigerant temperature detected by the refrigerant temperature sensor every time the control section shifts from one to another, and when the difference is a relatively large value, increases relatively significantly the sum of the rotational frequencies of the first motor and the second motor.

[Claim 12] The refrigeration cycle apparatus according to any one of claims 3 to 9, wherein the controller divides a time period of the start-up operation into time-based control sections, and sets a ratio of the rotational frequency of the first motor to the rotational frequency of the second motor lower than a determination ratio that is a ratio of the determined target rotational frequency of the first motor to the determined target rotational frequency of the second motor in an earliest control section of the control sections, and brings the ratio closer to the determination ratio step by step as the control section shifts from one to another in the control sections following the earliest section during the start-up operation.

[Claim 13] The refrigeration cycle apparatus according to Claim 12, further comprising a refrigerant temperature sensor for detecting a temperature of the refrigerant guided to the radiator through the first pipe,
wherein the controller calculates a difference between the preset

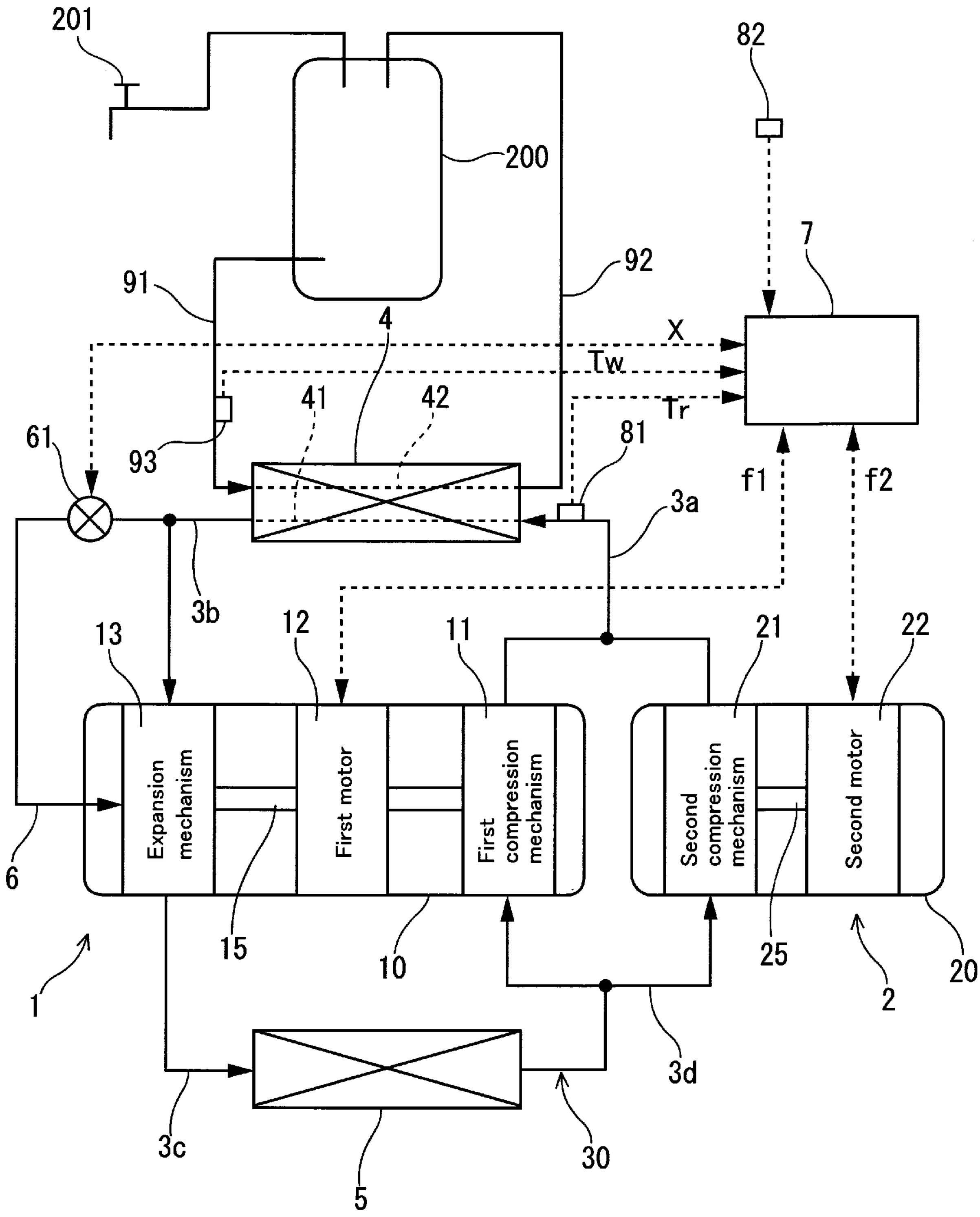
discharge temperature and the refrigerant temperature detected by the refrigerant temperature sensor every time the control section shifts from one to another, and when the difference is a relatively large value, increases the ratio of the rotational frequency of the first motor to the rotational frequency of the second motor at a slow rate.

[Claim 14] The refrigeration cycle apparatus according to any one of claims 10 to 13, wherein the controller increases both the rotational frequencies of the first motor and the second motor as the control section shifts from one to another.

[Claim 15] The refrigeration cycle apparatus according to any one of claims 1 to 14, wherein when determining that the opening of the injection valve should be in the fully opened state, the controller controls the opening of the injection valve to be in the fully closed state for a predetermined period of time after the start-up operation starts and then switched to the fully opened state.

[Fig. 1]

FIG.1


201
200
82
7
91
92
4
X
Tw
Tr
93
41
42
61
81
3a
f1
f2
3b
13
12
11
21
22
Expansion mechanism
First motor
First compression mechanism
Second compression mechanism
Second motor
6
15
10
25
2
20
1
3d
3c
30
5

[Fig. 2]

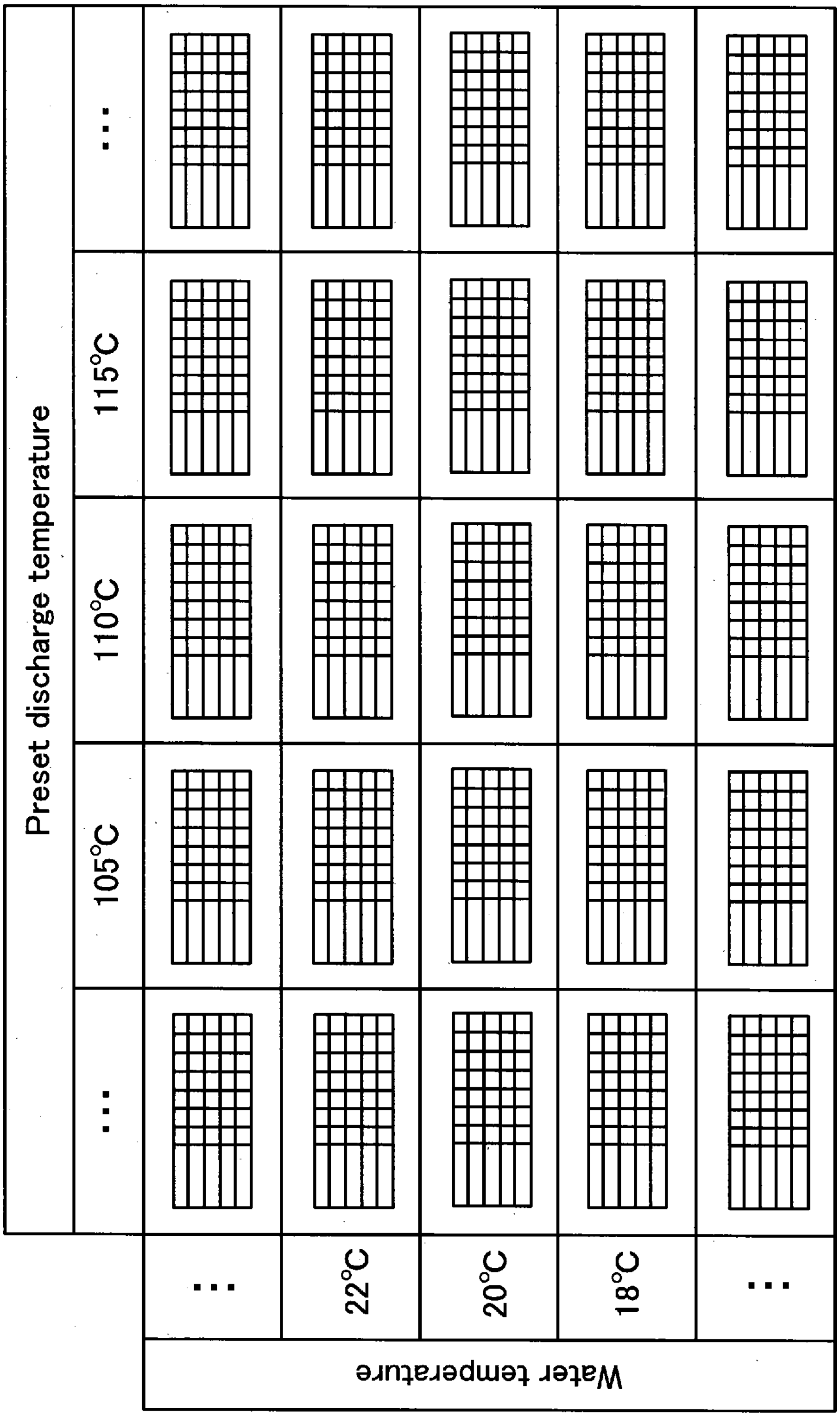

Preset discharge temperature
...
105°C
110°C
115°C
...
...
22°C
20°C
18°C
...
Water temperature

FIG.2

[Fig. 3]

FIG.3

Preset discharge temperature:110℃, Water temperature:20℃

Outside air temperature [℃]	0	2	7	9	9	12	16
Target rotaional frequency F1 of first motor [Hz]	63	64	71	72	42	42	42
Target rotaional frequency F2 of second motor [Hz]	90	69	50	45	75	67	55
Opening X of injection valve [%]	0	0	0	0	100	100	100
Same rotaional frequency [Hz]	74	64	58	56	56	52	46

[Fig. 4]

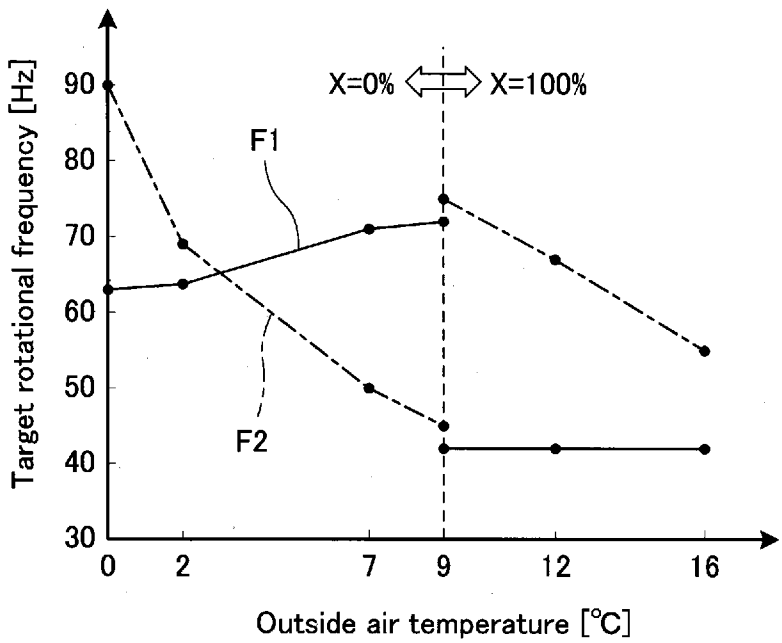
FIG.4

Preset discharge temperature:110℃, Water temperature:20℃

Outside air temperature [℃]	0	2	7	9	9	12	16
Rotaional frequency F1' of first motor [Hz]	63	64	71	72	42	42	42
Rotaional frequency F2' of second motor [Hz]	85	64	45	40	70	62	50
Opening X of injection valve [%]	0	0	0	0	100	100	100
Same rotaional frequency [Hz]	74	64	58	56	56	52	46

[Fig. 5]

FIG.5



[Fig. 6]

FIG.6A

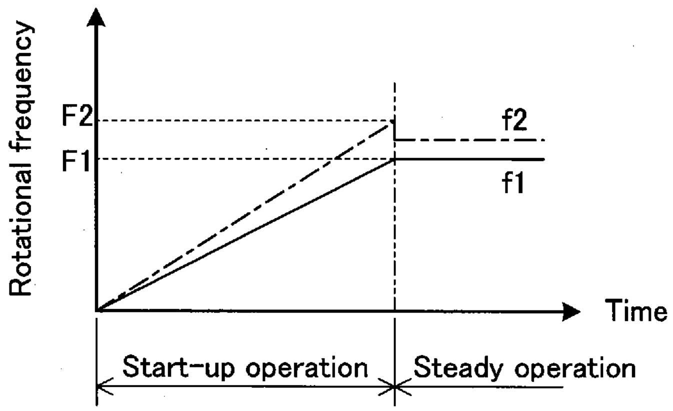


FIG.6B

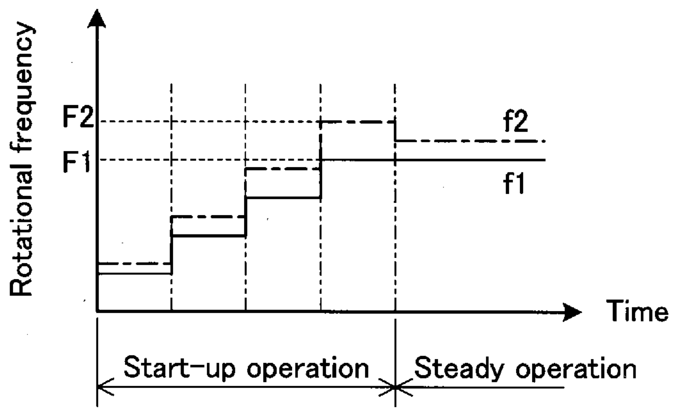
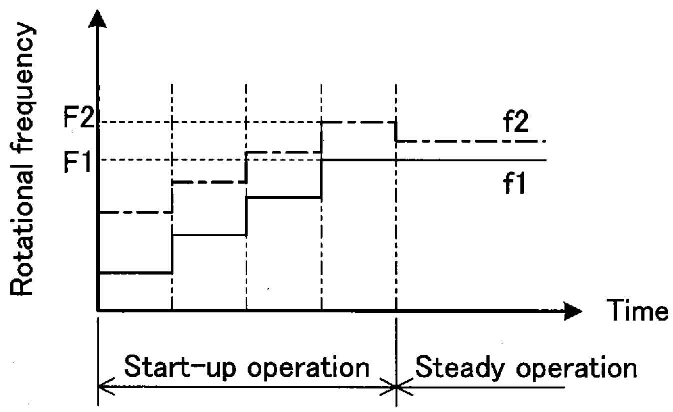


FIG.6C



[Fig. 7]

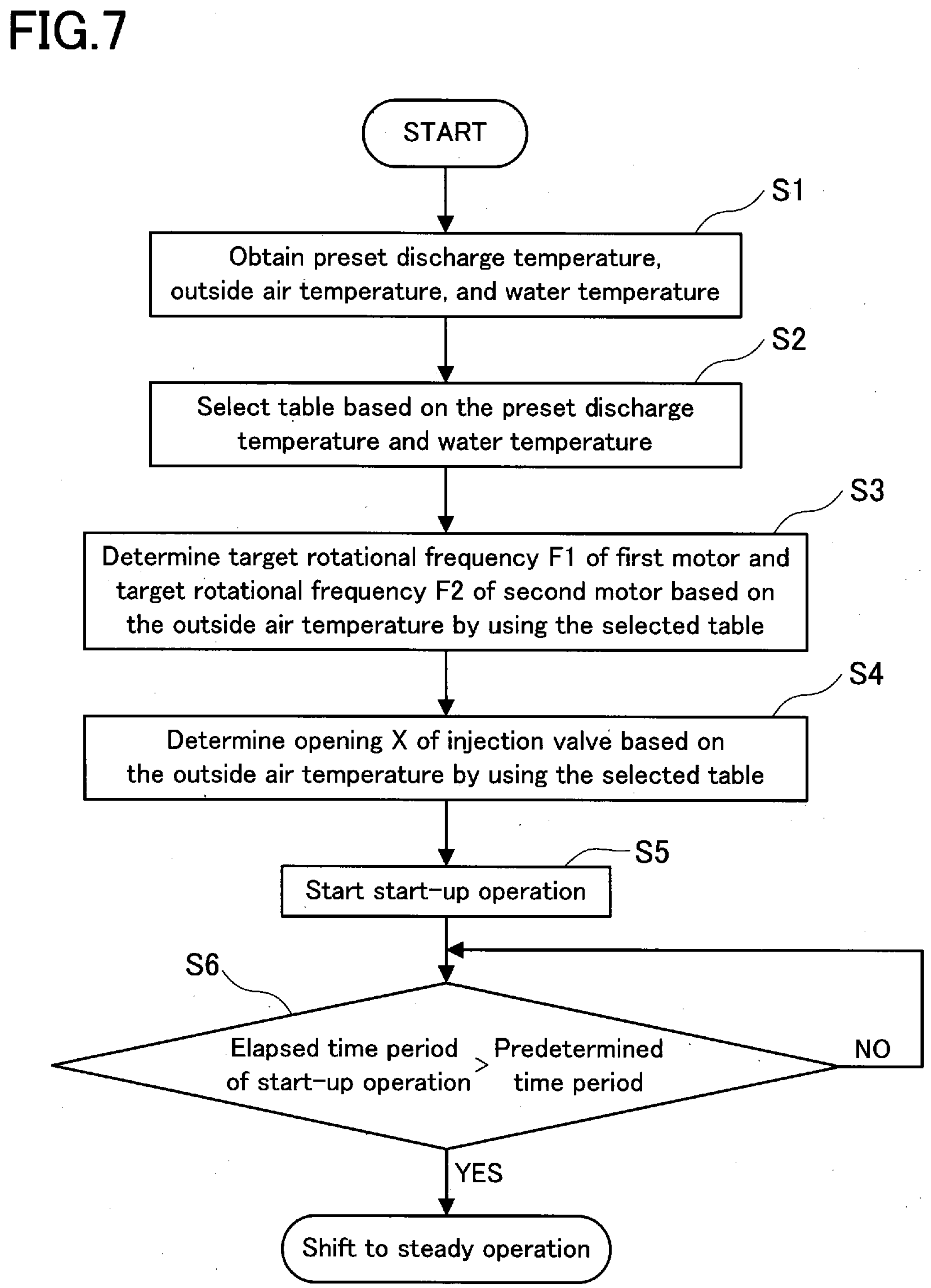
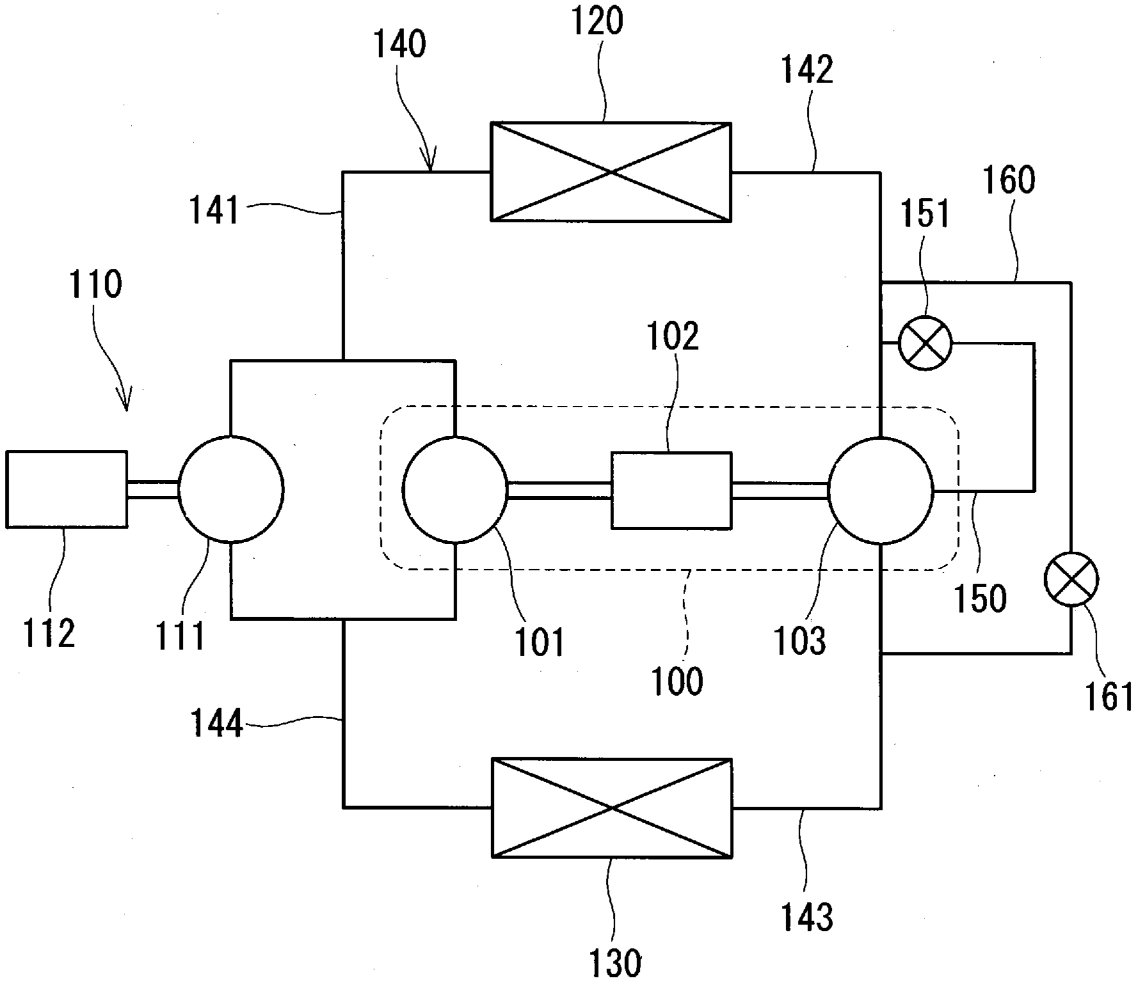


FIG.7
START
S1
Obtain preset discharge temperature, outside air temperature, and water temperature
S2
Select table based on the preset discharge temperature and water temperature
S3
Determine target rotational frequency F1 of first motor and target rotational frequency F2 of second motor based on the outside air temperature by using the selected table
S4
Determine opening X of injection valve based on the outside air temperature by using the selected table
S5
Start start-up operation
S6
Elapsed time period of start-up operation > Predetermined time period
NO
YES
Shift to steady operation

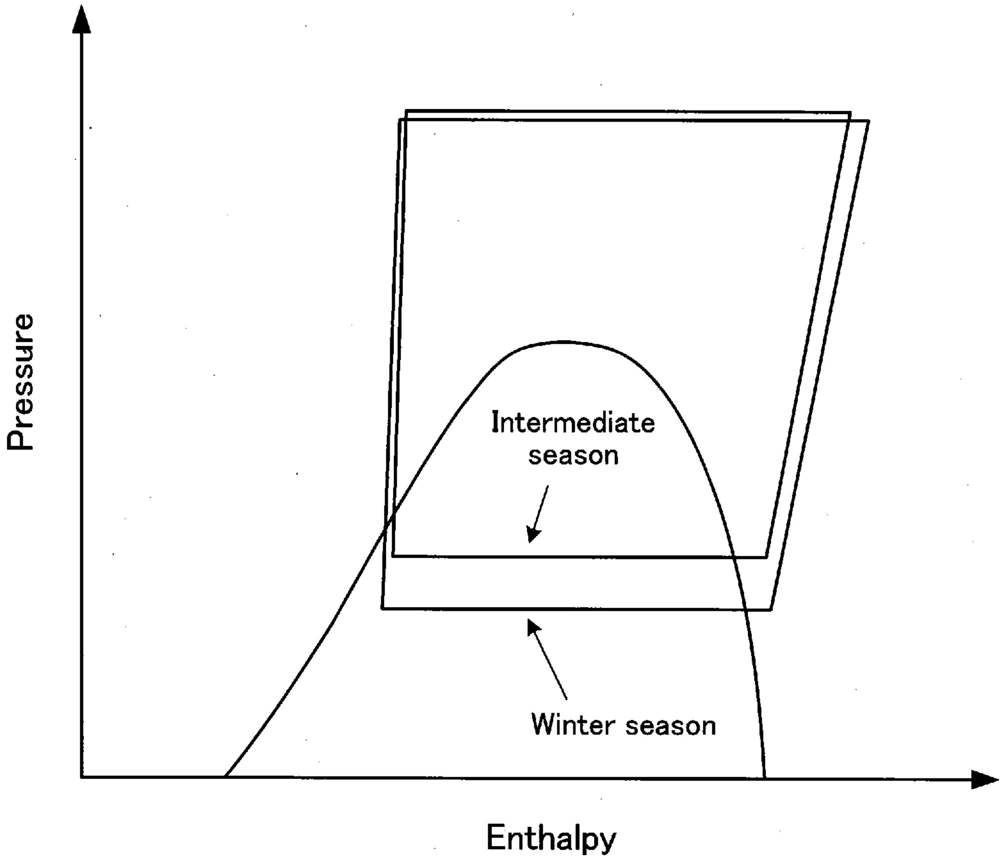
[Fig. 8]

FIG.8


140
120
142
141
160
151
110
102
150
112
111
101
100
103
161
144
143
130

[Fig. 9]

FIG.9



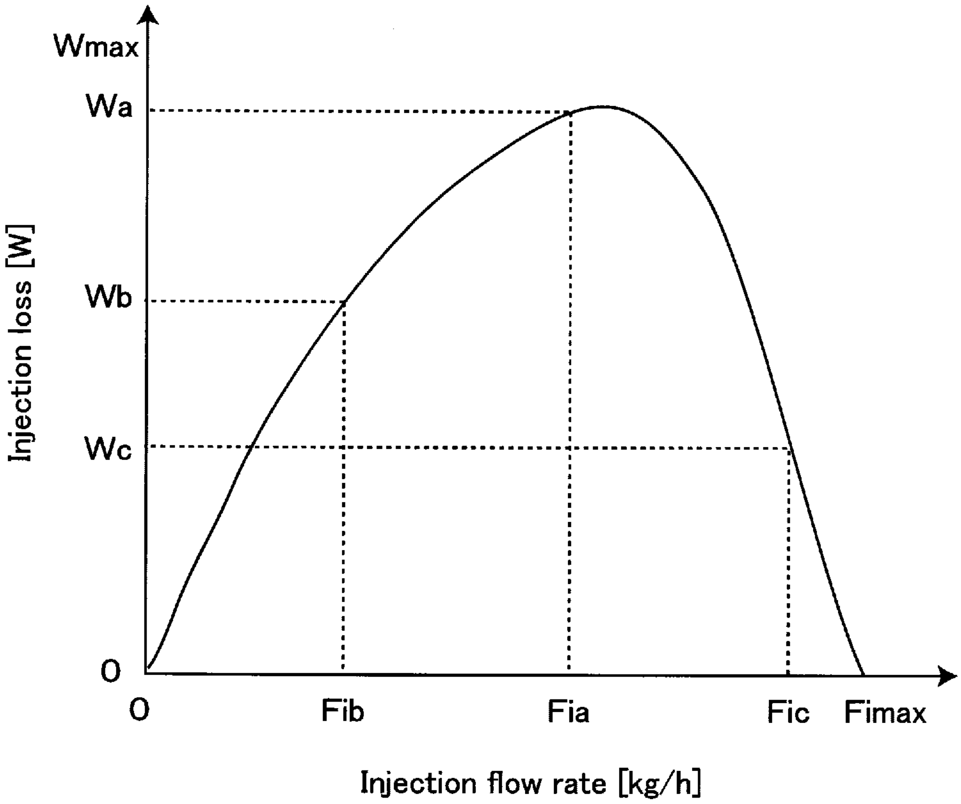
[Fig. 10]

FIG.10

Outside air temperature [°C]	2	7	12	16
Rotaional frequency of first motor [Hz]	64	58	52	46
Rotaional frequency of second motor [Hz]	64	58	52	46
Opening of injection valve [%]	0	30	60	90

[Fig. 11]

FIG.11


Wmax
Wa
Wb
Wc
0
Injection loss [W]
0
Fib
Fia
Fic
Fimax
Injection flow rate [kg/h]