

## DESCRIPTION

### Title of Invention

TURBO REFRIGERATOR, CONTROL DEVICE THEREFOR, AND CONTROL  
METHOD THEREFOR

### Technical Field

[0001]

The present invention relates to a turbo refrigerator, a control device for the turbo refrigerator, and a control method for the turbo refrigerator.

### Background Art

[0002]

In the related art, a turbo refrigerator 100 as shown in Fig. 9 is known. The turbo refrigerator 100 is provided with a main circuit of a refrigeration cycle, in which a two-stage turbo compressor 102, a condenser 103, an economizer 104, a main expansion valve 105, and an evaporator 107 are sequentially connected to each other. A gas refrigerant having a high temperature and high pressure due to being compressed in the turbo compressor 102 is sent to the condenser 103. The condenser 103 is a plate-type heat exchanger and performs heat exchange between hot water circulating in a hot water circuit 111 and the gas refrigerant, thereby increasing the

temperature of the hot water to a predetermined temperature.

[0003]

The refrigerant condensed and liquefied in the condenser 103 is supplied to the economizer 104. The economizer 104 is a plate-type refrigerant/refrigerant heat exchanger which performs heat exchange between a liquid refrigerant (a liquefied refrigerant flowing in the main circuit) from the condenser 103 and a refrigerant diverted from the main circuit and decompressed by an auxiliary expansion valve 113 and supercools the liquid refrigerant flowing in the main circuit using evaporation latent heat of the refrigerant. The economizer 104 is provided with a gas circuit for injecting a gas refrigerant evaporated by supercooling of the liquid refrigerant from an intermediate intake port 102C of the two-stage turbo compressor 102 into a compressed refrigerant having an intermediate pressure. The main expansion valve 105 expands the refrigerant supercooled through the economizer 104 and supplies the expanded refrigerant to the evaporator 107. The evaporator 107 is a plate-type heat exchanger, and performs heat exchange between the refrigerant introduced from the main expansion valve 105 and heat source water circulating in a heat source water circuit 115, thereby evaporating the

refrigerant, and cooling the heat source water using the evaporation latent heat of the refrigerant.

[0004]

As measurement means for measuring the temperature or the pressure of the refrigerant, the hot water, and the heat source water, pressure gauges 141, 142, and 143 and thermometers 131, 132, and 133 are provided at an intake port 102A, a discharge port 102B, and the intermediate intake port 102C of the two-stage turbo compressor 2, thermometers 135, 136, 137, and 138 are provided at an inlet and an outlet of the hot water circuit 111 and an inlet and an outlet of the heat source water circuit 15, and a thermometer 134 is provided at an inlet of the main expansion valve 105.

#### Citation List

##### Patent Literature

[0005]

[PTL 1] Japanese Unexamined Patent Application Publication No. 2012-77971

#### Summary of Invention

#### Technical Problem

[0006]

In a thermometer which is not limited to the turbo refrigerator 100 as described above and is generally used in a turbo refrigerator or the like, it is known that

responsiveness is poor and delay of several minutes occurs. This is because in terms of safety, ease of maintenance, or the like, it is not possible to directly insert a temperature measurement section into a tube. For example, configuration examples of a thermometer are shown in Figs. 10A and 10B. Fig. 10A shows an example in which a resistance temperature detector with a protective tube (a thermometer having a dual structure) is inserted into a tube, and Fig. 10B shows an example in which a temperature is indirectly measured by welding a thermometer to an outer wall of a tube.

As described above, due to a poor response of a thermometer, the following problems occur.

For example, if the turbo refrigerator 100 shown in Fig. 9 is taken as an example, in a case where a rapid temperature change occurs in the hot water circulating in the hot water circuit 111 (for example, a case where an inlet-side hot water temperature of the condenser 103 is rapidly lowered due to a large amount of water being added to the hot water by a user, or the like), it is necessary to promptly detect the temperature change and narrow the degrees of opening of the main expansion valve 105 and the auxiliary expansion valve 113. However, the control of the main expansion valve 105 and the auxiliary expansion valve 113 is delayed due to measurement delay of the

thermometer, and therefore, the degree of opening of the expansion valve becomes larger than that for the actual temperature, and the liquid refrigerant which is not fully evaporated from the evaporator 107 or the economizer 104 is suctioned into the two-stage turbo compressor 102, and thus there is a concern that the two-stage turbo compressor 102 may be damaged.

[0007]

The present invention has an object to provide a turbo refrigerator, a control device for the turbo refrigerator, and a control method for the turbo refrigerator, in which it is possible to reduce control delay of an expansion valve due to measurement delay of a thermometer.

Solution to Problem

[0008]

According to a first aspect of the present invention, there is provided a control device for a turbo refrigerator, which is applied to a turbo refrigerator which includes a main circuit of a refrigeration cycle, in which a compressor, a condenser, an expansion valve, and an evaporator are sequentially connected and a refrigerant circulates, first temperature measurement means for measuring an inlet temperature of a heat transfer medium which flows into the condenser, second temperature

measurement means for measuring an outlet temperature of the heat transfer medium which flows out from the condenser, and pressure measurement means for measuring a condensation pressure, the control device including: temperature correction means for correcting temperatures measured by the first temperature measurement means and the second temperature measurement means; and expansion-valve control means for performing opening degree control of the expansion valve by using the heat transfer medium inlet temperature and the heat transfer medium outlet temperature corrected by the temperature correction means, in which the temperature correction means includes condensation-temperature acquisition means for acquiring a condensation temperature from a condensation pressure which is acquired by the pressure measurement means, temperature-difference calculation means for calculating a temperature difference by subtracting a condensation temperature at a certain period of time earlier from a current condensation temperature, determination means for determining whether or not an absolute value of the temperature difference is greater than or equal to a threshold value set in advance, and correction means for adding the temperature difference to the respective temperatures measured by the first temperature measurement means and the second temperature measurement means in a

case where the absolute value of the temperature difference is greater than or equal to the threshold value.

[0009]

According to the control device for a turbo refrigerator, a condensation temperature based on a condensation pressure is acquired by the condensation-temperature acquisition means, and a temperature difference between a current condensation temperature and a condensation temperature at a certain period of time earlier is calculated by the temperature-difference calculation means. Then, whether or not the absolute value of the temperature difference is greater than or equal to a predetermined threshold value is determined by the determination means, and in a case where the absolute value of the temperature difference is greater than or equal to the threshold value, the temperature difference is added to the respective temperatures measured by the first temperature measurement means and the second temperature measurement means by the correction means, whereby temperature correction is performed. In this way, it becomes possible to detect a temperature change early, and thus it becomes possible to reduce measurement delay of the temperature measurement means. Further, control of the expansion valve using the temperature after the correction is performed by the expansion-valve control

means, whereby it becomes possible to reduce control delay of the expansion valve due to measurement delay in the first temperature measurement means and the second temperature measurement means.

[0010]

In the control device for a turbo refrigerator, the certain period of time may be set to a period in which a refrigerant cycles through the main circuit once.

[0011]

According to the control device for a turbo refrigerator, it becomes possible to accurately capture a variation in the inlet temperature of the heat transfer medium.

[0012]

The control device for a turbo refrigerator may be provided with a heat exchanger which is provided between the condenser and the expansion valve and performs heat exchange between a liquid refrigerant flowing through the main circuit and a refrigerant which is diverted from the main circuit and decompressed by an auxiliary expansion valve to supercool the liquid refrigerant flowing through the main circuit, and a gas circuit which returns the refrigerant that has been subjected to heat exchange with the liquid refrigerant flowing through the main circuit in the heat exchanger to the compressor, and in the control

device, the expansion-valve control means may perform opening degree control of the auxiliary expansion valve by using a heat transfer medium inlet temperature and a heat transfer medium outlet temperature corrected by the temperature correction means.

[0013]

According to the control device for a turbo refrigerator, control of the auxiliary expansion valve is performed by using the temperature after the correction, and therefore, it becomes possible to reduce control delay of the auxiliary expansion valve due to measurement delay in the first temperature measurement means and the second temperature measurement means.

[0014]

According to a second aspect of the present invention, there is provided a control device for a turbo refrigerator, which is applied to a turbo refrigerator which includes a main circuit of a refrigeration cycle, in which a compressor, a condenser, an expansion valve, and an evaporator are sequentially connected and a refrigerant circulates, heat source water inlet temperature measurement means for measuring an inlet temperature of heat source water which flows into the evaporator, and heat source water outlet temperature measurement means for measuring an outlet temperature of the heat source water

which flows out from the evaporator, the control device including: evaporation temperature correction means for calculating an evaporation temperature such that a ratio of a value obtained by subtracting the evaporation temperature from the heat source water inlet temperature to a value obtained by subtracting the heat source water inlet temperature from the heat source water outlet temperature coincides with a target ratio at the time of stability; and expansion-valve control means for performing opening degree control of the expansion valve by using an evaporation pressure obtained from the evaporation temperature corrected by the evaporation temperature correction means.

[0015]

According to the control device for a turbo refrigerator, an evaporation temperature is calculated by the evaporation temperature correction means such that a ratio of a value obtained by subtracting an evaporation temperature from the heat source water inlet temperature to a value obtained by subtracting the heat source water inlet temperature from the heat source water outlet temperature coincides with a target ratio at the time of stability. Then, by reflecting the evaporation temperature calculated by the evaporation temperature correction means in the valve opening degree control of

the expansion valve, it becomes possible to prevent the valve opening degree of the expansion valve from becoming too large.

[0016]

According to a third aspect of the present invention, there is provided a turbo refrigerator including: the above control device.

[0017]

According to a fourth aspect of the present invention, there is provided a control method for a turbo refrigerator, which is applied to a turbo refrigerator which includes a main circuit of a refrigeration cycle, in which a compressor, a condenser, an expansion valve, and an evaporator are sequentially connected and a refrigerant circulates, first temperature measurement means for measuring an inlet temperature of a heat transfer medium which flows into the condenser, second temperature measurement means for measuring an outlet temperature of the heat transfer medium which flows out from the condenser, and pressure measurement means for measuring a condensation pressure, the control method including: a temperature correction step of correcting temperatures measured by the first temperature measurement means and the second temperature measurement means; and an expansion-valve control step of performing opening degree

control of the expansion valve by using a heat transfer medium inlet temperature and a heat transfer medium outlet temperature corrected in the temperature correction step, in which the temperature correction step includes a condensation-temperature acquisition step of acquiring a condensation temperature from a condensation pressure which is acquired by the pressure measurement means, a temperature-difference calculation step of calculating a temperature difference by subtracting a condensation temperature at a certain period of time earlier from a current condensation temperature, a determination step of determining whether or not an absolute value of the temperature difference is greater than or equal to a threshold value set in advance, and a temperature correction step of adding the temperature difference to the respective temperatures measured by the first temperature measurement means and the second temperature measurement means in a case where the absolute value of the temperature difference is greater than or equal to the threshold value.

[0018]

According to a fifth aspect of the present invention, there is provided a control method for a turbo refrigerator, which is applied to a turbo refrigerator which includes a main circuit of a refrigeration cycle, in

which a compressor, a condenser, an expansion valve, and an evaporator are sequentially connected and a refrigerant circulates, heat source water inlet temperature measurement means for measuring an inlet temperature of heat source water which flows into the evaporator, and heat source water outlet temperature measurement means for measuring an outlet temperature of the heat source water which flows out from the evaporator, the control method including: an evaporation temperature correction step of calculating an evaporation temperature such that a ratio of a value obtained by subtracting the evaporation temperature from the heat source water inlet temperature to a value obtained by subtracting the heat source water inlet temperature from the heat source water outlet temperature coincides with a target ratio at the time of stability; and an expansion-valve control step of performing opening degree control of the expansion valve by using an evaporation pressure obtained from the evaporation temperature corrected in the evaporation temperature correction step.

#### Advantageous Effects of Invention

[0019]

According to the present invention, an effect of reducing control delay of an expansion valve due to measurement delay of a thermometer is exhibited.

## Brief Description of Drawings

[0020]

Fig. 1 is a diagram showing a schematic configuration of a turbo refrigerator according to a first embodiment of the present invention.

Fig. 2 is a functional block diagram of a control device according to the first embodiment of the present invention.

Fig. 3 is a diagram showing a flowchart of processing which is executed by a current-flow-rate calculation unit.

Fig. 4 is a flowchart showing processing which is executed by a main expansion valve opening-degree calculation unit.

Fig. 5 is a flowchart showing processing which is executed by an auxiliary expansion valve opening-degree calculation unit.

Fig. 6 is a diagram for describing control of the control device according to the first embodiment of the present invention.

Fig. 7 is a diagram showing an example of temporal transitions of a heat source water inlet temperature  $T_{swi}$  measured by a temperature sensor, a heat source water outlet temperature  $T_{swo}$  measured by a temperature sensor,

an evaporation temperature ET converted from an evaporation pressure Ps, and a compressor discharge temperature.

Fig. 8 is a functional block diagram of a control device according to a second embodiment of the present invention.

Fig. 9 is a diagram showing a configuration example of a turbo refrigerator of the related art.

Figs. 10A and 10B are diagrams showing a configuration example of a thermometer.

## Description of Embodiments

[0021]

[First Embodiment]

Hereinafter, a turbo refrigerator, and a control device and a control method for the turbo refrigerator according to a first embodiment of the present invention will be described with reference to the drawings.

Fig. 1 is a diagram showing a schematic configuration of the turbo refrigerator according to the first embodiment of the present invention. As shown in Fig. 1, a turbo refrigerator 1 is provided with a refrigerant main circuit 8 that is a closed circuit in which a compressor 2, a condenser 3, an economizer 4, a main expansion valve 5, and an evaporator 7 are

sequentially connected.

[0022]

The compressor 2 is a multistage centrifugal compressor which is driven by an inverter motor 6, and includes, in addition to an intake port 2A and a discharge port 2B, an intermediate intake port 2C which is provided between a first impeller and a second impeller, and is configured so as to sequentially centrifugally compress a low-pressure gas refrigerant suctioned from the intake port 2A, by the rotation of the first impeller and the second impeller, and discharge a compressed high-pressure gas refrigerant from the discharge port 2B.

[0023]

The high-pressure gas refrigerant discharged from the discharge port 2B of the compressor 2 is led to the condenser 3. The condenser 3 is, for example, a plate-type heat exchanger and performs heat exchange between the high-pressure gas refrigerant which is supplied from the compressor 2 and hot water (a heat transfer medium) circulating in a hot-water circuit, thereby increasing the temperature of the hot water to a predetermined temperature. The refrigerant condensed and liquefied in the condenser 3 is supplied to the economizer 4.

[0024]

The economizer 4 is a plate-type

refrigerant/refrigerant heat exchanger which performs heat exchange between a liquid refrigerant flowing in the refrigerant main circuit 8 and a refrigerant diverted from the refrigerant main circuit 8 and decompressed by an auxiliary expansion valve 9 and supercools the liquid refrigerant flowing in the refrigerant main circuit 8 by evaporation latent heat of the refrigerant after the decompression. The economizer 4 is provided with a gas circuit 10 for injecting a gas refrigerant (an intermediate-pressure refrigerant) evaporated by supercooling of the liquid refrigerant from the intermediate intake port 2C of the compressor 2 into a compressed refrigerant having an intermediate pressure, and thereby configures an intermediate cooler type economizer cycle.

[0025]

The refrigerant supercooled through the economizer 4 is expanded by passing through the main expansion valve 5 and supplied to the evaporator 7. The evaporator 7 is a heat exchanger (for example, a plate-type heat exchanger) and is for performing heat exchange between the refrigerant introduced from the main expansion valve 5 and heat source water circulating in a heat source water circuit 15, thereby evaporating the refrigerant, and cooling the heat source water by evaporation latent heat

of the refrigerant.

[0026]

The turbo refrigerator 1 is provided with a temperature sensor 12 which measures a hot-water inlet temperature  $T_{hwi}$  that is the temperature of the hot water flowing into the condenser 3, a temperature sensor 13 which measures a hot-water outlet temperature  $T_{hwo}$  that is the temperature of the hot water flowing out from the condenser 3, a temperature sensor 14 which is provided on the refrigerant outlet side of the condenser 3 and measures a condenser outlet temperature  $T_c$ , a temperature sensor 19 which is provided between the economizer 4 and the main expansion valve 5 in the refrigerant main circuit 8 and measures a main expansion valve inlet temperature  $T_{ecoh}$ , a temperature sensor 16 which measures an intermediate-pressure refrigerant temperature  $T_m$  that is the temperature of the intermediate-pressure refrigerant flowing through the gas circuit 10, a temperature sensor 17 which measures a heat source water inlet temperature  $T_{swi}$  that is the temperature of the heat source water flowing into the evaporator 7, and a temperature sensor 18 which measures a heat source water outlet temperature  $T_{swo}$  that is the temperature of the heat source water flowing out from the evaporator 7. The turbo refrigerator 1 is provided with a pressure sensor 20 which measures a

condensation pressure (a compressor discharge pressure)  $P_d$ , a pressure sensor 21 which measures intermediate-pressure refrigerant pressure  $P_m$  that is the pressure of the intermediate-pressure refrigerant flowing through the gas circuit 10, and a pressure sensor 22 which measures an evaporation pressure (a compressor intake pressure)  $P_s$ .

[0027]

The measurement values of various sensors described above are transmitted to a control device 30 and are used for the control of the rotational frequency of the compressor, the control of the degrees of opening of the main expansion valve 5 and the auxiliary expansion valve 9, or the like.

The control device 30 is, for example, a computer and is provided with a central processing unit (CPU), a main storage device such as a random access memory (RAM), an auxiliary storage device, a communication device which performs sending and receiving of information by performing communication with an external device, and the like.

The auxiliary storage device is a computer-readable recording medium and is, for example, a magnetic disk, a magneto-optical disk, a CD-ROM, a DVD-ROM, a semiconductor memory, or the like. Various programs are stored in the auxiliary storage device, and the CPU reads a program from

the auxiliary storage device into the main storage device and executes the program, thereby realizing a variety of processing.

[0028]

Fig. 2 is a functional block diagram of the control device 30. As shown in Fig. 2, the control device 30 is provided with a temperature correction unit 31 and an expansion-valve control unit 32.

The temperature correction unit 31 corrects the hot-water inlet temperature  $Th_{wi}$  and the hot-water outlet temperature  $Th_{wo}$ . That is, as described above, measurement delay occurs in the temperature sensors 12 and 13 and the like. The temperature correction unit 31 has a configuration for correcting the measurement delay in the temperature sensors 12 and 13.

Specifically, the temperature correction unit 31 is provided with a condensation-temperature acquisition unit 41, a temperature-difference calculation unit 42, a determination unit 43, and a correction unit 44.

[0029]

The condensation-temperature acquisition unit 41 acquires the condensation temperature  $T_c$  from the condensation pressure  $P_d$  measured by the pressure sensor 20. Specifically, the condensation-temperature acquisition unit 41 has correspondence information (a

function or a table) in which the condensation pressure  $P_d$  and the condensation temperature  $CT$  are uniquely correlated with each other, and obtains the condensation temperature  $CT$  from the condensation pressure  $P_d$  by using this correspondence information.

The temperature-difference calculation unit 42 calculates a temperature difference  $\Delta CT$  by subtracting a condensation temperature obtained at a certain period of time earlier from a current condensation temperature obtained by the condensation-temperature acquisition unit 41. Here, a certain period of time is equivalent to, for example, a period in which the refrigerant cycles through the refrigerant main circuit 8 once, and is obtained by dividing a refrigerant filling amount [kg] by a refrigerant circulation amount [kg/min]. A period in which a predetermined margin is taken into account with respect to this value may be determined as a certain period of time.

[0030]

The determination unit 43 determines whether or not an absolute value  $|\Delta CT|$  of the temperature difference  $\Delta CT$  is greater than or equal to a threshold value set in advance. The threshold value is, for example, a value which is derived from a change rate which is determined by the specifications of the main expansion valve 5. For

example, in a case where a change rate of the main expansion valve 5 is 10 [%]/60 [sec] at the maximum, the hot-water inlet temperature  $Th_{wi}$  is about 70 [°C], the hot-water outlet temperature  $Th_{wo}$  is 80 [°C], and the above-described certain period of time is determined to be 30 [sec], the threshold value is set by the following expression (1).

[0031]

Threshold

$$\text{value} = (10[\%] \times 10[^\circ\text{C}] \times 30[\text{sec}] / 60[\text{sec}]) + \alpha = 0.5 + \alpha[^\circ\text{C}] \quad (1)$$

[0032]

Here,  $\alpha$  is a margin, and may be a fixed value, and may also be a value which is determined according to the values in parentheses in the above expression (1).

[0033]

The correction unit 44 corrects the hot-water inlet temperature  $Th_{wi}$  and the hot-water outlet temperature  $Th_{wo}$  by adding the temperature difference  $\Delta T$  to the hot-water inlet temperature  $Th_{wi}$  and the hot-water outlet temperature  $Th_{wo}$  in a case where the absolute value  $|\Delta T|$  of the temperature difference is greater than or equal to the threshold value.

[0034]

The expansion-valve control unit 32 performs calculation of the expansion valve opening degree by using

the hot-water inlet temperature  $Th_{wi}$  after the correction and the hot-water outlet temperature  $Th_{wo}$  after the correction, in a period in which the temperature correction is performed by the temperature correction unit 31, and performs calculation of the expansion valve opening degree by using the hot-water inlet temperature  $Th_{wi}$  and the hot-water outlet temperature  $Th_{wo}$  measured by the temperature sensors 12 and 13, in a period in which the temperature correction is not performed by the temperature correction unit 31. Hereinafter, the expansion-valve control unit 32 will be described.

[0035]

The expansion-valve control unit 32 is provided with, for example, a current-flow-rate calculation unit 51, a setting-flow-rate calculation unit 52, a main expansion valve opening-degree calculation unit 53, and an auxiliary expansion valve opening-degree calculation unit 54. With respect to the expansion-valve control, it is not limited to a method shown below and it is possible to adopt various known control methods. In a case where the hot-water inlet temperature  $Th_{wi}$  and the hot-water outlet temperature  $Th_{wo}$  are used as parameters in that case, the hot-water inlet temperature  $Th_{wi}$  and the hot-water outlet temperature  $Th_{wo}$  after the correction are used in a case where the temperature correction has been performed by the

temperature correction unit 31.

[0036]

The current-flow-rate calculation unit 51 performs flow rate calculation by using the hot-water inlet temperature  $Thwi$  and the hot-water outlet temperature  $Thwo$  as parameters. A flowchart of the processing which is executed by the current-flow-rate calculation unit 51 is shown in Fig. 3. As shown in Fig. 3, the current-flow-rate calculation unit 51 calculates current heating capacity  $Qcon$  [kW] by using the hot-water inlet temperature  $Thwi$  and the hot-water outlet  $Thwo$  (Step SA1). Subsequently, the current-flow-rate calculation unit 51 calculates a condenser flow rate  $Gcon$  [kg/s] by using the following expression (2) (Step SA2).

[0037]

$$Gcon = Qcon / (Hd - Hc) \quad (2)$$

[0038]

In the expression (2),  $Hd$  is a discharge enthalpy [kJ/kg], and  $Hc$  is a condenser outlet enthalpy [kJ/kg].

Subsequently the current-flow-rate calculation unit 51 calculates a current flow rate  $Geva$  of the main expansion valve 5 by using the following expression (3) (Step SA3).

[0039]

$$Geva = (Gcon - Gmo - Goc) / (1 + x) \quad (3)$$

Here,  $x = (H_c - H_{ecoh}) / (H_{ecom} - H_c)$  (4)

[0040]

In the expression (3),  $G_{con}$  is a condenser flow rate [kg/s],  $G_{mo}$  is a motor cooling flow rate [kg/s], and  $G_{oc}$  is an oil cooling refrigerant flow rate [kg/s]. In the expression (4),  $H_c$  is a condenser outlet enthalpy [kJ/kg],  $H_{ecoh}$  is a main expansion valve inlet enthalpy [kJ/kg], and  $H_{ecom}$  is an intermediate intake gas enthalpy [kJ/kg].

[0041]

Next, the current-flow-rate calculation unit 51 calculates a current flow rate  $G_{eco}$  of the auxiliary expansion valve 9 by using the condenser flow rate  $G_{con}$  (Step SA4). Specifically, the calculation is performed by using the following expression (5).

[0042]

$G_{eco} = x \times G_{eva}$  (5)

[0043]

In the expression (5),  $x$  is as described in the above expression (4).  $G_{eva}$  is the current flow rate  $G_{eva}$  of the main expansion valve calculated in the above expression (3).

The current flow rate  $G_{eva}$  of the main expansion valve and the current flow rate  $G_{eco}$  of the auxiliary expansion valve calculated in this way are output to the main expansion valve opening-degree calculation unit 53

and the auxiliary expansion valve opening-degree calculation unit 54.

[0044]

The setting-flow-rate calculation unit 52 calculates a setting flow rate  $G_{eva}^*$  of the main expansion valve 5 and a setting flow rate  $G_{eco}^*$  of the auxiliary expansion valve 9. Here, in the calculation by the setting-flow-rate calculation unit 52, only the point that in the arithmetic expression using in the current-flow-rate calculation unit 51 described above, a hot-water outlet setting temperature  $Thwo^*$  set in advance is used instead of the hot-water outlet temperature  $Thwo$  is different, and the other is the same. Therefore, the detailed description thereof is omitted.

The setting flow rate  $G_{eva}^*$  of the main expansion valve 5 and the setting flow rate  $G_{eco}^*$  of the auxiliary expansion valve 9 are output to the main expansion valve opening-degree calculation unit 53 and the auxiliary expansion valve opening-degree calculation unit 54.

[0045]

The main expansion valve opening-degree calculation unit 53 calculates a feedforward opening degree command by performing feedforward control by using the current flow rate  $G_{eva}$  of the main expansion valve 5 and the current flow rate  $G_{eco}$  of the auxiliary expansion valve 9

calculated by the current-flow-rate calculation unit 51, and the setting flow rate  $G_{eva}^*$  of the main expansion valve 5 and the setting flow rate  $G_{eco}^*$  of the auxiliary expansion valve 9 set by the setting-flow-rate calculation unit 52, calculates a feedback opening degree command by performing feedback control by using an evaporator termination temperature, and adds these commands together, thereby generating an opening degree command.

Fig. 4 is a flowchart showing the processing which is executed by the main expansion valve opening-degree calculation unit 53.

First, in the feedforward control, the main expansion valve opening-degree calculation unit 53 calculates a current opening degree  $C_{eva}$  of the main expansion valve 5 by using the current flow rate  $G_{eva}$  of the main expansion valve, differential pressure  $\Delta P2 (= P_d - P_s)$  between the condensation pressure and the evaporation pressure, and the like as parameters (Step SB1). Next, the main expansion valve opening-degree calculation unit 53 calculates a setting opening degree  $C_{eva}^*$  of the main expansion valve by using the setting flow rate  $G_{eva}^*$  of the main expansion valve 5, the differential pressure  $\Delta P2$ , and the like as parameters (Step SB2).

Then, the main expansion valve opening-degree calculation unit 53 calculates an opening degree command

OP\_FF in the feedforward control by prorating the current opening degree Cveva and the setting opening degree Cveva\* of the main expansion valve 5 (Step SB3).

[0046]

In the feedback control, the main expansion valve opening-degree calculation unit 53 calculates an opening degree command OP\_FB such that a temperature difference  $\Delta T_{swo}$  between the heat source water outlet temperature Tsw0 in the evaporator 7 and an evaporation temperature ET which is converted from the evaporation pressure Ps coincides with a target value  $\Delta T_{swo}^*$  (Step SB4). For example, the opening degree command OP\_FB in the feedback control is calculated by performing PID control with respect to a difference between the temperature difference  $\Delta T_{swo}$  and the target value  $\Delta T_{swo}^*$ .

[0047]

In this way, if the opening degree command OP\_FF by the feedforward control and the opening degree command OP\_FB by the feedback control are calculated, these commands are added together, whereby a final opening degree command  $OP = OP\_FF + OP\_FB$  is calculated (Step SB5).

Then, the degree of opening of the main expansion valve 5 is controlled based on the opening degree command OP.

[0048]

The auxiliary expansion valve opening-degree calculation unit 54 calculates a feedforward opening degree command by performing feedforward control by using the current flow rate  $G_{eva}$  of the main expansion valve 5 and the current flow rate  $G_{eco}$  of the auxiliary expansion valve 9 calculated by the current-flow-rate calculation unit 51, and the setting flow rate  $G_{eva}^*$  of the main expansion valve 5 and the setting flow rate  $G_{eco}^*$  of the auxiliary expansion valve 9 set by the setting-flow-rate calculation unit 52, calculates a feedback opening degree command by performing feedback control by using the main expansion valve inlet temperature  $T_{ecoh}$ , and adds these commands together, thereby generating an opening degree command  $O_{Peco}$  of the auxiliary expansion valve.

Fig. 5 is a flowchart showing the processing which is executed by the auxiliary expansion valve opening-degree calculation unit 54.

First, in the feedforward control, the auxiliary expansion valve opening-degree calculation unit 54 calculates a current opening degree  $C_{veco}$  of the auxiliary expansion valve 9 by using the current flow rate  $G_{eco}$  of the auxiliary expansion valve 9, differential pressure  $\Delta P1 (= P_d - P_m)$  between the condensation pressure  $P_d$  and the intermediate pressure  $P_m$ , and the like as parameters (Step SC1). Next, the auxiliary expansion valve opening-degree

calculation unit 54 calculates a setting opening degree  $C_{veco}^*$  of the auxiliary expansion valve 9 by using the setting flow rate  $G_{eco}^*$  of the auxiliary expansion valve 9, the differential pressure  $\Delta P_1$ , and the like as parameters (Step SC2).

Then, the auxiliary expansion valve opening-degree calculation unit 54 calculates a command value  $O_{Peco\_FF}$  in the feedforward control by prorating the current opening degree  $C_{veco}$  and the setting opening degree  $C_{veco}^*$  of the auxiliary expansion valve 9 (Step SC3).

[0049]

In the feedback control, the auxiliary expansion valve opening-degree calculation unit 54 sets a main expansion valve inlet temperature target value  $T_{ecohset}$  ( $=\Delta T_2 + MT$ ) by adding an economizer outlet temperature difference  $\Delta T_2$  set in advance to an auxiliary expansion valve inlet temperature  $MT$  (Step SC4). Next, the auxiliary expansion valve opening-degree calculation unit 54 calculates an opening degree command  $O_{Peco\_FB}$  which conforms the current main expansion valve inlet temperature  $T_{ecoh}$  to a main expansion valve inlet temperature target value  $T_{ecoh}^*$  (Step SC5). For example, the opening degree command  $O_{Peco\_FB}$  in the feedback control is calculated by performing PID control with respect to a difference between the current main expansion

valve inlet temperature  $T_{coh}$  and the main expansion valve inlet temperature target value  $T_{coh}^*$ .

[0050]

In this way, if the command value  $OPeco\_FF$  by the feedforward control and the command value  $OPeco\_FB$  by the feedback control are calculated, these command values are added together, whereby a final opening degree command  $OPeco = OPeco\_FF + OPeco\_FB$  is calculated (Step SC6). Then, the degree of opening of the auxiliary expansion valve 9 is controlled based on the opening degree command  $OPeco$ .

[0051]

Next, an operation of the control device 30 will be described with reference to Fig. 6.

Fig. 6 is a diagram for describing the control of the control device 30 according to this embodiment.

In Fig. 6, before a variation occurs in the hot-water inlet temperature  $T_{hwi}$  at time  $t_1$ , the hot-water inlet temperature  $T_{hwi}$  shows a stable numerical value, and therefore, the temperature difference  $|\Delta CT|$  which is calculated by the temperature-difference calculation unit 42 of the temperature correction unit 31 becomes a value close to zero. For this reason, in the determination unit 43, a determination that the temperature difference  $|\Delta CT|$  is less than the threshold value is made, and the temperature correction by the correction unit 44 is not

performed.

[0052]

In contrast, if the hot-water inlet temperature  $Th_{wi}$  is rapidly lowered at time  $t_1$ , the condensation pressure  $P_d$  is rapidly lowered accordingly, and the condensation temperature which is acquired by the condensation-temperature acquisition unit 41 is lowered. As a result, the absolute value  $|\Delta CT|$  of the temperature difference which is calculated in the temperature-difference calculation unit 42 becomes a relatively large value. As a result, in the determination unit 43, a determination that the temperature difference  $|\Delta CT|$  is greater than or equal to the threshold value is made, and the temperature correction by the correction unit 44 is performed. In this way,  $\Delta CT$  (a negative value) is added to each of the hot-water inlet temperature  $Th_{wi}$  measured by the temperature sensor 12 and the hot-water outlet temperature  $Th_{wo}$  measured by the temperature sensor 13, and the flow rate calculation or the opening-degree calculation using the hot-water inlet temperature  $Th_{wi}$  and the hot-water outlet temperature  $Th_{wo}$  corrected so as to drop is performed in the expansion-valve control unit 32. In this way, for example, with respect to the auxiliary expansion valve 9, it is controlled in a direction in which the valve opening degree is reduced (a period of time  $t_1$  to  $t_2$

of Fig. 6). In the opening degree control of the auxiliary expansion valve of the related art, the valve opening degree is calculated by using the temperatures measured by the temperature sensors 12 and 13, that is, temperatures with measurement delay, and therefore, even though the hot-water inlet temperature  $Th_{wi}$  is actually lowered, control is performed in a direction of opening the auxiliary expansion valve 9, and this becomes a cause of liquid suction of the compressor 2.

[0053]

As described above, in the turbo refrigerator, and the control device and the control method for the turbo refrigerator according to this embodiment, the condensation temperature is acquired based on the condensation pressure, and in a case where the absolute value  $|\Delta CT|$  of the temperature difference between a current condensation temperature and a condensation temperature at a certain amount of time earlier is greater than or equal to a predetermined threshold value, the temperature difference  $\Delta CT$  is added to each of the hot-water inlet temperature  $Th_{wi}$  and the hot-water outlet temperature  $Th_{wo}$  measured by the temperature sensors 12 and 13, whereby the temperatures are corrected, and therefore, it is possible to reduce control delay of the expansion valve due to measurement delay in the temperature sensors 12 and 13.

In this way, it becomes possible to avoid liquid refrigerant suction of the compressor 2.

[0054]

In this embodiment, by correcting the hot-water inlet temperature  $Th_{wi}$  and the hot-water outlet temperature  $Th_{wo}$ , the expansion valve is prevented from being opened too much. However, for example, by adopting a technique of reducing a change rate of the degree of opening of the auxiliary expansion valve 9 to a value less than or equal to a rating which is determined by the specifications, it is also possible to avoid liquid refrigerant suction of the compressor.

[0055]

[Second Embodiment]

Hereinafter, a turbo refrigerator, and a control device and a control method for the turbo refrigerator according to a second embodiment of the present invention will be described with reference to the drawings.

In the first embodiment described above, the hot-water inlet temperature  $Th_{wi}$  and the hot-water outlet temperature  $Th_{wo}$  are corrected. However, in this embodiment, in addition to this, alternatively, instead of this, the evaporation temperature  $ET$  in the evaporator 7, in other words, the evaporation pressure  $P_s$  is corrected. In this way, further improvement of the accuracy of

expansion-valve control is attained.

[0056]

In the first embodiment, if the hot-water inlet temperature  $T_{hwi}$  changes, the influence thereof relatively appears early in the condensation pressure  $P_d$ , and therefore, the temperature correction is performed by using the condensation temperature  $CT$  converted from the condensation pressure  $P_d$ . However, with regard to the evaporator 7, it is revealed by experiment that in a case where the heat source water inlet temperature  $T_{swi}$  is lowered, the influence thereof does not appear early in the evaporation pressure  $P_s$ . An example of temporal transitions of the heat source water inlet temperature  $T_{swi}$  measured by the temperature sensor 17, the heat source water outlet temperature  $T_{swo}$  measured by the temperature sensor 18, the evaporation temperature  $ET$  converted from the evaporation pressure  $P_s$ , and the compressor discharge temperature is shown in Fig. 7.

[0057]

As shown in Fig. 7, it can be seen that a change in the evaporation temperature  $ET$  converted from the evaporation pressure  $P_s$  is slower than a change in the heat source water inlet temperature  $T_{swi}$  or the heat source water outlet temperature  $T_{swo}$ . For this reason, in the evaporator 7, it is not possible to adopt the same

technique as that in the evaporator 3 described above, such as correcting the heat source water inlet temperature  $T_{si}$  and the heat source water outlet temperature  $T_{sw}$  by using the evaporation pressure  $P_s$ .

Here, by analyzing Fig. 7, it can be seen that at the time of stability, a ratio  $K$  between a difference  $\Delta T_e$  between the heat source water inlet temperature  $T_{sw}$  and the evaporation temperature  $ET$  (the converted value of the evaporation pressure  $P_s$ ) and a difference  $\Delta T_s$  between the heat source water inlet temperature  $T_{sw}$  and heat source water outlet temperature  $T_{sw}$  is constant. That is, it can be seen that the following expression is established.

[0058]

$$K = \Delta T_e / \Delta T_s = (T_{sw} - ET) / (T_{sw} - T_{sw}) = \text{constant} \quad (6)$$

[0059]

Therefore, in this embodiment, the value of the ratio  $K$  at the time of stability is set as a target ratio  $K^*$ , and a change in the heat source water inlet temperature  $T_{sw}$  is promptly reflected in the expansion-valve control by correcting the evaporation temperature  $ET$  such that the ratio  $K$  always becomes the target ratio  $K^*$ .

[0060]

Fig. 8 is a functional block diagram of a control device 35 according to this embodiment. As shown in Fig. 8, the control device 35 is further provided with an

evaporation temperature correction unit 33, in addition to the configurations of the control device 30 shown in Fig. 2.

The evaporation temperature correction unit 33 holds the value of the ratio  $K$  at the time of stability as the target ratio  $K^*$  and corrects the evaporation temperature such that the ratio  $K$  becomes the target ratio  $K^*$ . That is, the evaporation temperature  $ET$  is calculated by assigning the heat source water inlet temperature  $T_{swi}$ , the heat source water outlet temperature  $T_{swo}$ , and the target ratio  $K^*$  held in advance to the following expression (7) derived from the above expression (6).

[0061]

$$ET = T_{swi} - (T_{swi} - T_{swo})K^* \quad (7)$$

[0062]

Then, the evaporation temperature  $ET$  is converted into the evaporation pressure  $P_s$ , and the evaporation pressure  $P_s$  is used for the expansion-valve control. That is, the main expansion valve opening-degree calculation unit 53 and the auxiliary expansion valve opening-degree calculation unit 54 calculate the main expansion valve opening degree command  $OP$  and the auxiliary expansion valve opening degree command  $OP_{eco}$  by using the evaporation pressure  $P_s$  based on the evaporation temperature  $ET$  calculated by the evaporation temperature

correction unit 33.

Here, for example, in a case where the heat source water inlet temperature  $T_{swi}$  is lowered, whereby the evaporation temperature  $ET$  is lowered, the evaporation pressure  $P_s$  is also reduced. In the feedforward control of the opening degree command of the main expansion valve 5 (Steps SB1 to SB3 of Fig. 4), if the evaporation pressure  $P_s$  is reduced, the differential pressure across the main expansion valve,  $\Delta P_2 = P_d - P_s$ , becomes a large value. As a result, the current flow rate  $C_{veva}$  and the setting flow rate  $C_{eva}^*$  of the main expansion valve are reduced, and the opening degree command  $OP_{FF}$  of the feedforward control of the main expansion valve is reduced.

In the feedback control (Step SB4 of Fig. 4), the opening degree command  $OP_{FB}$  such as conforming a temperature difference  $\Delta T_{swo}$  between the heat source water outlet temperature  $T_{swo}$  in the evaporator 7 and the evaporation temperature  $ET$  to a target value  $\Delta T_{swo}^*$  is calculated. Here, with respect to the temperature difference  $\Delta T_{swo}$ , it can be said that it is substantially constant even if the heat source water inlet temperature  $T_{swi}$  varies (refer to Fig. 7), and therefore, the main expansion valve 5 does not act in an opening direction. From the above, by reflecting the evaporation temperature  $ET$  by the evaporation temperature correction unit 33 in

the valve opening degree control of the main expansion valve 5, it is possible to prevent the main expansion valve 5 from being opened too much, and thus it becomes possible to avoid the liquid refrigerant suction of the compressor 2.

[0063]

In the embodiments described above, the control devices 30 and 35 which are applied to the turbo refrigerator 1 having the configuration shown in Fig. 1 have been described. However, the turbo refrigerator 1 to which the control device according to the present invention is applied is not limited to that having the configuration shown in Fig. 1. The control device according to the present invention can also be applied to, for example, a turbo refrigerator which does not have configurations related to the economizer 4, specifically, a turbo refrigerator having a configuration in which the economizer 4, the auxiliary expansion valve 9, the gas circuit 10, the temperature sensor 16, and the pressure sensor 21 in Fig. 1 are omitted. In this case, it is favorable if in the opening degree control of the main expansion valve 5, the above calculation is performed with a flow rate flowing to the auxiliary expansion valve 9 as zero.

The present invention is not limited to only the

above-described embodiments, and various modifications can be made within a scope which does not depart from the gist of the invention.

#### Reference Signs List

[0064]

- 1: turbo refrigerator
- 2: compressor
- 3: condenser
- 5: main expansion valve
- 7: evaporator
- 8: refrigerant main circuit
- 9: auxiliary expansion valve
- 12 to 14, 16 to 18: temperature sensor
- 20 to 22: pressure sensor
- 30: control device
- 31: temperature correction unit
- 32: expansion-valve control unit
- 33: evaporation temperature correction unit
- 41: condensation-temperature acquisition unit
- 42: temperature-difference calculation unit
- 43: determination unit
- 44: correction unit
- 51: current-flow-rate calculation unit
- 52: setting-flow-rate calculation unit
- 53: main expansion valve opening-degree calculation

unit

54: auxiliary expansion valve opening-degree  
calculation unit

## Claims

### [Claim 1]

A control device for a turbo refrigerator, which is applied to a turbo refrigerator which includes a main circuit of a refrigeration cycle, in which a compressor, a condenser, an expansion valve, and an evaporator are sequentially connected and a refrigerant circulates, first temperature measurement means for measuring an inlet temperature of a heat transfer medium which flows into the condenser, second temperature measurement means for measuring an outlet temperature of the heat transfer medium which flows out from the condenser, and pressure measurement means for measuring a condensation pressure,

the control device comprising:

temperature correction means for correcting a heat transfer medium inlet temperature and a heat transfer medium outlet temperature measured by the first temperature measurement means and the second temperature measurement means; and

expansion-valve control means for performing opening degree control of the expansion valve by using the heat transfer medium inlet temperature and the heat transfer medium outlet temperature corrected by the temperature correction means,

wherein the temperature correction means includes  
condensation-temperature acquisition means for  
acquiring a condensation temperature from a condensation  
pressure which is acquired by the pressure measurement  
means,

temperature-difference calculation means for  
calculating a temperature difference by subtracting a  
condensation temperature at a certain period of time  
earlier from a current condensation temperature,

determination means for determining whether or not  
an absolute value of the temperature difference is greater  
than or equal to a threshold value set in advance, and

correction means for adding the temperature  
difference to the respective temperatures measured by the  
first temperature measurement means and the second  
temperature measurement means in a case where the absolute  
value of the temperature difference is greater than or  
equal to the threshold value.

[Claim 2]

The control device for a turbo refrigerator  
according to Claim 1, wherein the certain period of time  
is set to a period in which a refrigerant cycles through  
the main circuit once.

[Claim 3]

The control device for a turbo refrigerator according to Claim 1 or 2, wherein the turbo refrigerator includes

a heat exchanger which is provided between the condenser and the expansion valve and performs heat exchange between a liquid refrigerant flowing through the main circuit and a refrigerant which is diverted from the main circuit and decompressed by an auxiliary expansion valve to supercool the liquid refrigerant flowing through the main circuit, and

a gas circuit which returns the refrigerant that has been subjected to heat exchange with the liquid refrigerant flowing through the main circuit in the heat exchanger to the compressor, and

the expansion-valve control means performs opening degree control of the auxiliary expansion valve by using the heat transfer medium inlet temperature and the heat transfer medium outlet temperature corrected by the temperature correction means.

[Claim 4]

A control device for a turbo refrigerator, which is applied to a turbo refrigerator which includes a main circuit of a refrigeration cycle, in which a compressor, a

condenser, an expansion valve, and an evaporator are sequentially connected and a refrigerant circulates, heat source water inlet temperature measurement means for measuring an inlet temperature of heat source water which flows into the evaporator, and heat source water outlet temperature measurement means for measuring an outlet temperature of the heat source water which flows out from the evaporator,

the control device comprising:

evaporation temperature correction means for calculating an evaporation temperature such that a ratio of a value obtained by subtracting the evaporation temperature from the heat source water inlet temperature to a value obtained by subtracting the heat source water inlet temperature from the heat source water outlet temperature coincides with a target ratio at the time of stability; and

expansion-valve control means for performing opening degree control of the expansion valve by using an evaporation pressure obtained from the evaporation temperature corrected by the evaporation temperature correction means.

[Claim 5]

A turbo refrigerator comprising:

the control device according to any one of Claims 1 to 4.

[Claim 6]

A control method for a turbo refrigerator, which is applied to a turbo refrigerator which includes a main circuit of a refrigeration cycle, in which a compressor, a condenser, an expansion valve, and an evaporator are sequentially connected and a refrigerant circulates, first temperature measurement means for measuring an inlet temperature of a heat transfer medium which flows into the condenser, second temperature measurement means for measuring an outlet temperature of the heat transfer medium which flows out from the condenser, and pressure measurement means for measuring a condensation pressure,

the control method comprising:

a temperature correction step of correcting temperatures measured by the first temperature measurement means and the second temperature measurement means; and

an expansion-valve control step of performing opening degree control of the expansion valve by using a heat transfer medium inlet temperature and a heat transfer medium outlet temperature corrected in the temperature correction step,

wherein the temperature correction step includes

a condensation-temperature acquisition step of acquiring a condensation temperature from a condensation pressure which is acquired by the pressure measurement means,

a temperature-difference calculation step of calculating a temperature difference by subtracting a condensation temperature at a certain period of time earlier from a current condensation temperature,

a determination step of determining whether or not an absolute value of the temperature difference is greater than or equal to a threshold value set in advance, and

a temperature correction step of adding the temperature difference to the respective temperatures measured by the first temperature measurement means and the second temperature measurement means in a case where the absolute value of the temperature difference is greater than or equal to the threshold value.

[Claim 7]

A control method for a turbo refrigerator, which is applied to a turbo refrigerator which includes a main circuit of a refrigeration cycle, in which a compressor, a condenser, an expansion valve, and an evaporator are sequentially connected and a refrigerant circulates, heat source water inlet temperature measurement means for

measuring an inlet temperature of heat source water which flows into the evaporator, and heat source water outlet temperature measurement means for measuring an outlet temperature of the heat source water which flows out from the evaporator,

the control method comprising:

an evaporation temperature correction step of calculating an evaporation temperature such that a ratio of a value obtained by subtracting the evaporation temperature from the heat source water inlet temperature to a value obtained by subtracting the heat source water inlet temperature from the heat source water outlet temperature coincides with a target ratio at the time of stability; and

an expansion-valve control step of performing opening degree control of the expansion valve by using an evaporation pressure obtained from the evaporation temperature corrected in the evaporation temperature correction step.