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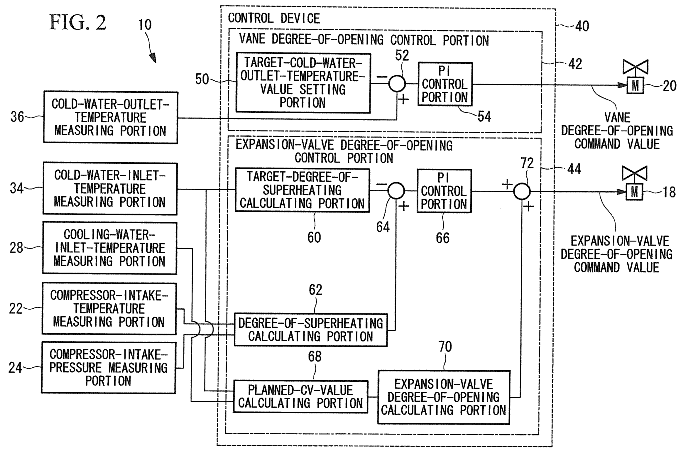
(54) **EXPANSION VALVE CONTROL DEVICE, HEAT SOURCE MACHINE, AND EXPANSION VALVE CONTROL METHOD**

(57) The purpose of the invention is to set the opening degree of an expansion valve to an appropriate opening degree, irrespective of a load on a heat source machine and external conditions. An expansion valve control device (40) controls the opening degree of an expansion valve (18) of a turbo refrigerating machine comprising: a compressor for compressing a refrigerant; a condenser for condensing the compressed refrigerant with cooling water; an evaporator for evaporating the condensed refrigerant and performing heat-exchange between the refrigerant and cold water; and an expansion valve for expanding the refrigerant in the liquid phase stored in the condenser. The expansion valve control device (40) calculates an opening degree of the expansion valve (18) on the basis of the difference between a target overheating degree and a measured overheating degree of the refrigerant taken into the turbo compressor, calculates an opening degree of the expansion valve (18) on the basis of a planned CV value, which is an estimated value of the flow rate of the refrigerant caused to pass through the expansion valve (18), and calculates an expansion valve opening degree command value from the two calculated opening degrees of the expansion valve (18).

FIG. 2



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Description

{Technical Field}

[0001] The present invention relates to an expansion-valve control device, a heat-source unit, and an expansion-valve control method.

{Background Art}

[0002] A heat-source unit, for example, a refrigerator, is provided with an expansion valve for expanding a high-temperature, high-pressure refrigerant that has been condensed at a condenser after being compressed at a compressor in order to make it low-temperature, low pressure refrigerant. To realize highly efficient and stable operation of the refrigerator, the expansion valve needs to be held at an appropriate degree-of-opening in accordance with the load and external conditions.

[0003] Deviation from the appropriate degree-of-opening of the expansion valve causes problems such as those described below.

[0004] If the degree-of-opening of the expansion valve is too large, the flow volume of the refrigerant becomes excessive, and thus, it is possible that the coefficient of performance (COP (coefficient of performance)) deteriorates as a result of the motive power of the refrigerator becoming excessive, that so-called liquid back occurs, in which the compressor draws in liquid-phase refrigerant, and that gas bypass occurs, in which a portion of the refrigerant flows into an evaporator in the gas phase without being turned into the liquid phase in a condenser due to insufficient supercooling at the condenser.

[0005] On the other hand, if the degree-of-opening of the expansion valve is too small, pressure difference between the condenser and the evaporator becomes excessive, and thus, it is possible that the COP deteriorates as a result of the motive power of the refrigerator becoming excessive.

[0006] Thus, for the purpose of improving the refrigeration efficiency of a turbo refrigerator, Patent Literature 1 discloses a technique in which a turbo refrigerator is provided with a control device that controls the degree-of-opening of an expansion valve so that the degree of intake superheating achieves a predetermined target degree of superheating, and the control device changes the target degree of superheating so as to be decreased when the intake flow volume of refrigerant steam for a turbo compressor is changed so as to be increased and changes the target degree of superheating so as to be increased when the intake flow volume of the refrigerant steam therefor is changed so as to be decreased.

[0007] In addition, Patent Literature 2 discloses a technique in which a control portion in an air conditioner has, for individual times in the day, a predicted degree-of-opening that is calculated from set conditions set in accordance with the load connected to a condenser, a current degree-of-opening that is calculated from current conditions, and a command degree-of-opening that is calculated based on both the predicted degree-of-opening and the current degree-of-opening and that is given to an expansion valve, and, when the predicted degree-of-opening changes suddenly or stepwise during the heat-pump operation, the control portion gives a degree-of-opening that is smaller than the predicted degree-of-opening to the expansion valve as a command degree-of-opening.

{Citation List}

{Patent Literature}

[0008]

{PTL 1} Japanese Unexamined Patent Application, Publication No. 2010-8013

{PTL 2} Japanese Unexamined Patent Application, Publication No. 2006-284034

{Summary of Invention}

{Technical Problem}

[0009] In the technique disclosed in Patent Literature 1, the degree of superheating for the refrigerant to be taken into the compressor is calculated from the temperature and pressure of the refrigerant to be taken into the compressor, the target degree of superheating is calculated from a set value of the degree-of-opening of a vane that controls the outlet temperature of cold water, and the expansion valve is feedback-controlled so that the degree of superheating achieves the target degree of superheating. Accordingly, because the technique disclosed in Patent Literature 1 controls the expansion valve solely by the feedback control that utilizes only the output information of the refrigerator, such as the outlet temperature of cold water, the temperature and pressure of the refrigerant, and so forth, tracking performance thereof has been insufficient with respect to fluctuations in the load on the refrigerator, such as the inlet temperature of cold water, the flow volume of cold water, and so forth, and external conditions, such as the inlet temperature of cooling water, the flow volume of cooling water, and so forth.

[0010] In addition, with the technique disclosed in Patent Literature 2, if there are deviations between the specification of actual machinery and parameters set in advance, such as a calculation formula, set conditions, and so forth, for calculating the degree-of-opening, the expansion valve cannot be held at an appropriate degree-of-opening, and thus, the deterioration of the COP cannot be avoided.

[0011] The present invention has been conceived in light of the above-described circumstances, and an object thereof is to provide an expansion-valve control device, a heat-source unit, and an expansion-valve control method with which the degree-of-opening of an expansion valve can be set to an appropriate degree-of-opening regardless of a load and external conditions for a heat-source unit.

{Solution to Problem}

[0012] In order to solve the above-described problems, an expansion-valve control device, a heat-source unit, and an expansion-valve control method according to the present invention employ the following solutions.

[0013] Specifically, an expansion-valve control device according to a first aspect of the present invention is an expansion-valve control device that, in a heat-source unit including a compressor that compresses a refrigerant, a condenser that condenses a compressed refrigerant by means of a heat-source medium, an evaporator that evaporates a condensed refrigerant and also performs heat exchange between this refrigerant and a heating medium, and an expansion valve that causes a liquid-phase refrigerant retained in the condenser to expand, controls a degree-of-opening of the expansion valve, the expansion-valve control device including a first calculating portion that calculates a degree-of-opening of the expansion valve based on the difference between a target value of a degree of superheating for the refrigerant to be taken into the compressor and a measured value of the degree of superheating; a second calculating portion that calculates a degree-of-opening of the expansion valve based on an estimated value of a flow volume of the refrigerant that is allowed to pass through the expansion valve; and a command-value calculating portion that calculates a command value for controlling the degree-of-opening of the expansion valve from the degree-of-opening of the expansion valve calculated by the first calculating portion and the degree-of-opening of the expansion valve calculated by the second calculating portion.

[0014] With the first aspect described above, the expansion-valve control device controls the degree-of-opening of the expansion valve in the heat-source unit that is provided with the compressor that compresses the refrigerant, the condenser that condenses the compressed refrigerant by means of the heat-source medium, the evaporator that evaporates the condensed refrigerant and also performs heat exchange between this refrigerant and the heating medium, and the expansion valve that causes the liquid-phase refrigerant retained in the condenser to expand.

[0015] Also, the degree-of-opening of the expansion valve is calculated by the first calculating portion based on the difference between the target value of the degree of superheating of the refrigerant that is taken into the compressor and the measured value of the degree of superheating. In addition, the degree-of-opening of the expansion valve is calculated by the second calculating portion based on the estimated value of the flow volume of the refrigerant that is allowed to pass through the expansion valve.

[0016] Specifically, with the present invention, the first calculating portion performs feedback control for the degree-of-opening of the expansion valve based on the degree of superheating which tends to change in accordance with the load and external conditions for the heat-source unit, and the second calculating portion performs feedforward control for the degree-of-opening of the expansion valve based on the estimated value of flow volume of the refrigerant which tends to change in accordance with the load and external conditions for the heat-source unit.

[0017] Furthermore, the command-value calculating portion calculates the command value for controlling the degree-of-opening of the expansion valve from the degree-of-opening of the expansion valve calculated by the first calculating portion and the degree-of-opening of the expansion valve calculated by the second calculating portion.

[0018] In this way, with the first aspect described above, because the degree-of-opening of the expansion valve is controlled by means of feedback control, which maintains the stability thereof, and also by using, in combination therewith, feedforward control in which the input information for the heat-source unit is utilized, the degree-of-opening of the expansion valve can be set to an appropriate degree-of-opening regardless of the load and external conditions for the heat-source unit.

[0019] In addition, in the expansion-valve control device of the first aspect described above, the target value of the degree of superheating may be calculated based on the temperature of the heating medium that flows into the evaporator.

[0020] The temperature of the heating medium that flows into the evaporator is related to the load on the heat-source unit. Accordingly, with the first aspect described above, because the target value of the degree of superheating is calculated based on the temperature of the heating medium that flows into the evaporator, effective feedback control can be performed to control the degree-of-opening of the expansion valve.

[0021] In addition, in the expansion-valve control device of the first aspect described above, the target value of the degree of superheating may be calculated so as to take a greater value with a decrease in the temperature of the heating medium that flows into the evaporator.

[0022] If the degree of superheating is low, the possibility of the compressor drawing in the liquid-phase refrigerant increases; however, if the temperature difference between the heating medium and the refrigerant that flow into the evaporator is small, it is difficult to increase the degree of superheating. Thus, with the first aspect described above, because the target value of the degree of superheating is calculated so as to take a greater value with a decrease in the temperature of the heating medium that flows into the evaporator, it is possible to prevent the liquid-phase refrigerant from being drawn into the compressor (liquid back).

[0023] In addition, in the expansion-valve control device of the first aspect described above, the flow volume may be calculated based on at least one of the temperature of the heating medium that flows into the evaporator and the temperature of the heat-source medium that flows into the condenser.

[0024] The flow volume of the refrigerant that is allowed to pass through the expansion valve changes depending on the load and external conditions for the heat-source unit, that is, the temperature of the heating medium that flows into the evaporator and the temperature of the heat-source medium that flows into the condenser. Accordingly, with the first aspect described above, because this flow volume is calculated based on at least one of the temperature of the heating medium that flows into the evaporator and the temperature of the heat-source medium that flows into the condenser, effective feedforward control can be performed to control the degree-of-opening of the expansion valve.

[0025] In addition, in the expansion-valve control device of the first aspect described above, the flow volume may be calculated so as to take a smaller value with a decrease in the temperature of the heating medium that flows into the evaporator and so as to take a greater value with a decrease in the temperature of the heat-source medium that flows into the condenser.

[0026] The case in which the temperature of the heating medium that flows into the evaporator is decreased is a case in which the load on the heat-source unit is decreased, and thus, the flow volume of the refrigerant can be decreased. In addition, the flow volume of the refrigerant needs to be increased by increasing the degree-of-opening of the expansion valve, because the internal pressure of the condenser is decreased when the temperature of the heat-source medium that flows into the condenser is decreased, which decreases the pressure on the upstream side of the expansion valve, thus decreasing the degree of supercooling (increasing the specific volume).

[0027] Accordingly, with the first aspect described above, because the flow volume of the refrigerant that is allowed to pass through the expansion valve is calculated so as to take a smaller value with a decrease in the temperature of the heating medium that flows into the evaporator and so as to take a greater value with a decrease in the temperature of the heat-source medium that flows into the condenser, it is possible to increase the precision of the feedforward control for the degree-of-opening of the expansion valve.

[0028] In addition, in the expansion-valve control device of the first aspect described above, the heat-source unit may be provided with a bypass pipe that forms a bypass path between a refrigerant intake port of the compressor and a refrigerant exhaust port of the compressor; and the measured value of the degree of superheating may be calculated based on the temperature of the heating medium that has flowed out from the evaporator and the pressure of the refrigerant to be compressed at the compressor.

[0029] With the first aspect described above, by providing the heat-source unit with the bypass pipe that forms a bypass path between the refrigerant intake port of the compressor and the refrigerant exhaust port of the compressor, the refrigerant in which the gas-phase refrigerant at the outlet of the compressor and the gas-phase refrigerant at the outlet of the evaporator are mixed is taken into the compressor. Because of this, if the temperature of the refrigerant to be compressed at the compressor is used to measure the degree of superheating, the temperature of the above-described mixed refrigerant, that is, a temperature differing from the temperature of the refrigerant at the outlet of the evaporator, would be used, and thus, the degree of superheating would not be measured correctly.

[0030] Thus, with the first aspect described above, the temperature of the refrigerant at the outlet of the evaporator and the temperature of the heating medium that has flowed out of the evaporator are assumed to be equivalent, and the measured value of the degree of superheating is calculated based on the temperature of the heating medium that has flowed out of the evaporator and the pressure of the refrigerant to be compressed at the compressor; therefore, even though the heat-source unit is provided with the bypass pipe, the degree of superheating can be measured with high precision.

[0031] On the other hand, a heat-source unit according to a second aspect of the present invention is provided with a compressor that compresses a refrigerant; a condenser that condenses a compressed refrigerant by means of a heat-source medium; an evaporator that evaporates a condensed refrigerant and also performs heat exchange between this refrigerant and a heating medium; an expansion valve that causes a liquid-phase refrigerant retained in the condenser to expand; and the above-described expansion-valve control device.

[0032] Furthermore, an expansion-valve control method according to a third aspect of the present invention is an expansion-valve control method of controlling, in a heat-source unit including a compressor that compresses a refrigerant, a condenser that condenses a compressed refrigerant by means of a heat-source medium, an evaporator that evaporates a condensed refrigerant and also performs heat exchange between this refrigerant and a heating medium, and an expansion valve that causes a liquid-phase refrigerant retained in the condenser to expand, a degree-of-opening of the expansion valve, the expansion-valve control method including a first step of calculating a degree-of-opening of the expansion valve based on the difference between a target value of a degree of superheating for the refrigerant to be taken into the compressor and a measured value of the degree of superheating; a second step of calculating a degree-of-opening of the expansion valve based on an estimated value of a flow volume of the refrigerant that is allowed to pass through the expansion valve; and a third step of calculating a command value for controlling the degree-of-opening of the expansion valve from the degree-of-opening of the expansion valve calculated in the first step and the degree-of-opening of the expansion valve calculated in the second step.

{Advantageous Effects of Invention}

[0033] The present invention affords an excellent advantage in that the degree-of-opening of an expansion valve can be set to an appropriate degree-of-opening regardless of the load and external conditions for a heat-source unit.

{Brief Description of Drawings}

[0034]

{Fig. 1} Fig. 1 is a configuration diagram of a turbo refrigerator according to a first embodiment of the present invention.
{Fig. 2} Fig. 2 is a block diagram showing the configurations of a vane degree-of-opening control portion and an expansion-valve degree-of-opening control portion according to the first embodiment of the present invention.
{Fig. 3} Fig. 3 is a graph showing the relationship between planned CV values and cold-water inlet temperature and also cooling-water inlet temperature according to the first embodiment of the present invention.
{Fig. 4} Fig. 4 is a graph showing the relationship between CV values and the degree-of-opening of an expansion valve according to the first embodiment of the present invention.
{Fig. 5} Fig. 5 is a configuration diagram of a turbo refrigerator according to a second embodiment of the present invention.
{Fig. 6} Fig. 6 is a block diagram showing the configurations of a vane degree-of-opening control portion and an expansion-valve degree-of-opening control portion according to the second embodiment of the present invention.

{Description of Embodiments}

[0035] Embodiments of an expansion-valve control device, a heat-source unit, and an expansion-valve control method according to the present invention will be described with reference to the drawings.

{First Embodiment}

[0036] A first embodiment of the present invention will be described below.
[0037] Fig. 1 shows the configuration of a turbo refrigerator 10, which is an example of a heat-source unit according to the first embodiment.
[0038] The turbo refrigerator 10 is provided with a turbo compressor 12 that compresses refrigerant; a condenser 14 that, by means of cooling water serving as heat-source medium, condenses gas-phase refrigerant (gaseous refrigerant) compressed at the turbo compressor 12 into liquid-phase refrigerant (liquid refrigerant; an evaporator 16 that evaporates the refrigerant condensed at the condenser 14 and also performs heat exchange between this refrigerant and cold water serving as heating medium; and an expansion valve 18 that causes the liquid refrigerant retained in the condenser 14 to expand.
[0039] The turbo compressor 12 is, as an example, a centrifugal two-stage compressor, and is driven by an electric motor. At a refrigerant intake port of the turbo compressor 12, a compressor inlet vane 20 (IGV) that controls the flow volume of the refrigerant to be taken thereinto is provided, thus enabling capacity control for the turbo compressor 12. In addition, the refrigerant intake port of the turbo compressor 12 is provided with a compressor-intake-temperature measuring portion 22 that measures the temperature of refrigerant to be compressed (hereinafter, referred to as "compressor-intake temperature") and a compressor-intake-pressure measuring portion 24 that measures the pressure of the refrigerant to be compressed (hereinafter, referred to as "compressor-intake pressure").
[0040] A cooling heat-transmitting pipe 26 in which the cooling water flows is inserted into the condenser 14. The temperature of the cooling water that flows into the condenser 14 (hereinafter, referred to as "cooling-water inlet temperature") is measured by a cooling-water-inlet-temperature measuring portion 28, and the temperature of the cooling water that flows out of the condenser 14 (hereinafter, referred to as "cooling-water outlet temperature ") is measured by a cooling-water-outlet-temperature measuring portion 30. Note that the cooling water that has flowed out of the condenser 14 is guided to the condenser 14 again after externally exhausting the heat thereof at a cooling tower (not shown).
[0041] A cold-water heat-transmitting pipe 32 for cooling, by means of the refrigerant, the cold water to be supplied to an external load is inserted into the evaporator 16. Note that the temperature of the cold water that flows into the evaporator 16 (hereinafter referred to as "cold-water inlet temperature") is measured by a cold-water-inlet-temperature measuring portion 34 and the temperature of the cold water that flows out of the evaporator 16 (hereinafter, referred to as "cold-water outlet temperature") is measured by a cold-water-outlet-temperature measuring portion 36.
[0042] In addition, the turbo compressor 12 is provided with a control device 40 that performs overall control of the turbo compressor 12. The control device 40 is provided with a vane degree-of-opening control portion 42 that controls the degree-of-opening of the compressor inlet vane 20 and an expansion-valve degree-of-opening control portion 44 that controls the degree-of-opening of the expansion valve 18.
[0043] The vane degree-of-opening control portion 42

according to the first embodiment calculates a command value for controlling the degree-of-opening of the compressor inlet vane 20 (hereinafter, referred to as "vane degree-of-opening command value") by means of feedback control based on the cold-water outlet temperature.

[0044] The expansion-valve degree-of-opening control portion 44 according to the first embodiment calculates the degree-of-opening of the expansion valve 18 based on the difference between a target value of the degree of superheating for the refrigerant that is taken into the turbo compressor 12 and the measured value of the degree of superheating thereof, and calculates the degree-of-opening of the expansion valve 18 based on a planned CV value, which is an estimated value of the flow volume of the refrigerant that is allowed to pass through the expansion valve 18. Then, the expansion-valve degree-of-opening control portion 44 calculates a command value for controlling the degree-of-opening of the expansion valve 18 (hereinafter, referred to as "expansion-valve degree-of-opening command value") from the above-described two types of degree-of-opening calculated for the expansion valve 18.

[0045] Specifically, the expansion-valve degree-of-opening control portion 44 according to the first embodiment performs feedback control for the degree-of-opening of the expansion valve 18 based on the degree of superheating which tends to change in accordance with the load and external conditions for the turbo refrigerator 10, and performs feedforward control therefor based on the planned CV value, that is, an estimated value of the flow volume of the refrigerant which tends to change in accordance with the load and external conditions for the turbo refrigerator 10.

[0046] Fig. 2 is a block diagram showing the configurations of the vane degree-of-opening control portion 42 and the expansion-valve degree-of-opening control portion 44 according to the first embodiment.

[0047] The vane degree-of-opening control portion 42 is provided with a target-cold-water-outlet-temperature-value setting portion 50, a subtraction portion 52, and a PI control portion 54.

[0048] The target-cold-water-outlet-temperature-value setting portion 50 sets a target value for the cold-water outlet temperature, and outputs the set target value to the subtraction portion 52. Note that the target value for the cold-water outlet temperature is input by, for example, an operator of the turbo refrigerator 10 via an operation input portion (not shown), and the input target value serves as a set value.

[0049] The subtraction portion 52 receives an input of the cold-water outlet temperature measured by the cold-water-outlet-temperature measuring portion 36, subtracts the target value for the cold-water outlet temperature from this cold-water outlet temperature, and outputs the subtraction result to the PI control portion 54.

[0050] The PI control portion 54 calculates a vane degree-of-opening command value based on the subtraction result input from the subtraction portion 52, and outputs it to the compressor inlet vane 20. Upon receiving an input of the vane degree-of-opening command value, the compressor inlet vane 20 changes the degree-of-opening thereof in accordance with the vane degree-of-opening command value.

[0051] In this way, the vane degree-of-opening control portion 42 calculates the vane degree-of-opening command value by means of feedback control based on the cold-water outlet temperature.

[0052] On the other hand, the expansion-valve degree-of-opening control portion 44 according to the first embodiment is provided with a target-degree-of-superheating calculating portion 60, the degree-of-superheating calculating portion 62, a subtraction portion 64, a PI control portion 66, a planned-CV-value calculating portion 68, an expansion-valve degree-of-opening calculating portion 70, and an addition portion 72.

[0053] The target-degree-of-superheating calculating portion 60 calculates a target value of the degree of superheating (hereinafter, referred to as "target degree of superheating") based on the cold-water inlet temperature measured by the cold-water-inlet-temperature measuring portion 34.

[0054] More specifically, the target-degree-of-superheating calculating portion 60 calculates the target degree of superheating so as to take a greater value with a decrease in the cold-water inlet temperature. The reason for this will be described below.

[0055] It is desirable that the turbo refrigerator 10 be operated so that the degree of superheating at the outlet of the evaporator 16 becomes 0 (zero) in order to maximize the COP. However, if the degree of superheating becomes 0, the possibility of liquid back occurring increases, and, if the liquid back occurs, motive power of the turbo compressor 12 increases, which makes it likely that an overload trip occurs in the turbo refrigerator 10.

[0056] In order to prevent the liquid back, a sufficient degree of superheating needs to be ensured to obtain tolerance against saturation of the refrigerant; however, if the temperature difference between the cold water and the refrigerant that flow into the evaporator 16 is small, it is difficult to increase the degree of superheating. Thus, the target-degree-of-superheating calculating portion 60 calculates the target degree of superheating so as to take a greater value with a decrease in the temperature of cold water that flows into the evaporator 16.

[0057] Note that the target-degree-of-superheating calculating portion 60 stores, in advance, table information or function information that indicates the relationship between the target degree of superheating and the cold-water inlet temperature in accordance with the characteristics of the turbo refrigerator 10, and calculates the target degree of superheating based on the table information or the function information.

[0058] The degree-of-superheating calculating portion 62 calculates a measured value of the degree of superheating (hereinafter, referred to as "measured degree of superheating") based on the compressor intake temperature (the temperature of the refrigerant at the outlet of the evaporator 16) measured by the compressor-intake-temperature measuring portion 22 and the compressor intake pressure measured by the compressor-intake-pressure measuring portion 24.

[0059] Note that the degree-of-superheating calculating portion 62 stores, in advance, physical-property information, for example, a p-h diagram (Mollier diagram) or the like, and calculates the measured degree of superheating from the information about the compressor intake temperature and the compressor intake pressure, as well as the stored physical property information.

[0060] The subtraction portion 64 receives inputs of the target degree of superheating calculated by the target-degree-of-superheating calculating portion 60 and the measured degree of superheating calculated by the degree-of-superheating calculating portion 62, subtracts the target degree of superheating from the measured degree of superheating, and outputs the subtraction result to the PI control portion 66.

[0061] The PI control portion 66 calculates the degree-of-opening of the expansion valve 18 based on the subtraction result input from the subtraction portion 64, and outputs it to the addition portion 72.

[0062] In this way, the expansion-valve degree-of-opening control portion 44 according to the first embodiment performs feedback control for the degree-of-opening of the expansion valve 18 based on the degree of superheating by means of the target-degree-of-superheating calculating portion 60, the degree-of-superheating calculating portion 62, the subtraction portion 64, and the PI control portion 66.

[0063] On the other hand, the planned-CV-value calculating portion 68 calculates the planned CV value based on the cold-water inlet temperature measured by the cold-water-inlet-temperature measuring portion 34 and the cooling-water inlet temperature measured by the cooling-water-inlet-temperature measuring portion 28.

[0064] Fig. 3 is a graph showing the relationship between the planned CV value and the cold-water inlet temperature and also the cooling-water inlet temperature according to the first embodiment.

[0065] Note that, as shown in Fig. 3, the planned-CV-value calculating portion 68 according to the first embodiment calculates the planned CV value so as to take a smaller value with a decrease in the cold-water inlet temperature and so as to take a greater value with a decrease in the cooling-water inlet temperature.

[0066] The reason for decreasing the planned CV value with a decrease in the cold-water inlet temperature is that the flow volume of cold water can be decreased, because the case in which the cold-water inlet temperature is decreased is a case in which the load on the turbo refrigerator 10 is decreased. On the other hand, the reason for increasing the planned CV value with a decrease in the cooling-water inlet temperature is to increase the flow volume of the refrigerant by increasing the degree-of-opening of the expansion valve 18, because the internal pressure of the condenser 14 is decreased when the cooling-water inlet temperature is decreased, which decreases the pressure on the upstream side of the expansion valve 18, thus decreasing the degree of supercooling (increasing the specific volume).

[0067] Note that the planned-CV-value calculating portion 68 stores, in advance, information that indicates the relationship between the planned CV value and the cold-water inlet temperature and also the cooling-water inlet temperature, such as the one shown in Fig. 3, and calculates the planned CV value based on that information.

[0068] The expansion-valve degree-of-opening calculating portion 70 calculates the degree-of-opening of the expansion valve 18 based on the planned CV value calculated by the planned-CV-value calculating portion 68. Fig. 4 is a graph showing the relationship between the CV value and the degree-of-opening of the expansion valve 18 according to the first embodiment, which shows that the degree-of-opening of the expansion valve 18 increases with an increase in the CV value.

[0069] Note that the expansion-valve degree-of-opening calculating portion 70 stores, in advance, information that indicates the CV value and the degree-of-opening of the expansion valve 18, such as the one shown in Fig. 4, and calculates the degree-of-opening of the expansion valve 18 based on that information.

[0070] In this way, the expansion-valve degree-of-opening control portion 44 according to the first embodiment performs feedforward control for the degree-of-opening of the expansion valve 18 based on the estimated value of the flow volume of the refrigerant by means of the planned-CV-value calculating portion 68 and the expansion-valve degree-of-opening calculating portion 70.

[0071] Then, as an expansion-valve degree-of-opening command value, the addition portion 72 calculates the sum of the degree-of-opening of the expansion valve 18 input from the PI control portion 66 and the degree-of-opening of the expansion valve 18 input from the expansion-valve degree-of-opening calculating portion 70, and outputs it to the expansion valve 18. Upon receiving an input of the expansion-valve degree-of-opening command value, the expansion valve 18 changes the degree-of-opening thereof in accordance with the expansion-valve degree-of-opening command value.

[0072] As has been described above, the turbo refrigerator 10 according to the first embodiment calculates the degree-of-opening of the expansion valve 18 based on the difference between the target degree of superheating and the measured degree of superheating, calculates the degree-of-opening of the expansion valve 18 based on the planned CV value, and calculates the expansion-valve degree-of-opening command value from the above-described two types of degree-of-opening calculated for the expansion valve 18.

[0073] In this way, with the turbo refrigerator 10 according to the first embodiment, because the degree-of-opening of the expansion valve 18 is controlled by means of feedback control, which maintains the stability thereof, and also by using, in combination therewith, feedforward control in which the input information for the turbo refrigerator 10 is utilized, the degree-of-opening of the expansion valve 18 can be set to an appropriate degree-of-opening regardless of the load and external conditions for the turbo refrigerator 10.

[0074] In addition, because the turbo refrigerator 10 according to the first embodiment calculates the target degree of superheating based on the cold-water inlet temperature, which is related to the load on the turbo refrigerator 10, effective feedback control can be performed to control the degree-of-opening of the expansion valve 18.

[0075] In addition, because the turbo refrigerator 10 according to the first embodiment calculates the target degree of superheating so as to take a greater value with a decrease in the cold-water inlet temperature, it is possible to prevent the liquid-phase refrigerant from being drawn into the turbo compressor 12 (liquid back).

[0076] In addition, because the turbo refrigerator 10 according to the first embodiment calculates the planned CV value based on the cold-water inlet temperature and the cooling-water inlet temperature, effective feedforward control can be performed to control the degree-of-opening of the expansion valve 18 in accordance with the load and external conditions.

[0077] In addition, because the turbo refrigerator 10 according to the first embodiment calculates the planned CV value so as to take a smaller value with a decrease in the cold-water inlet temperature and so as to take a greater value with a decrease in the cooling-water inlet temperature, it is possible to increase the precision of the feedforward control for the degree-of-opening of the expansion valve 18.

{Second Embodiment}

[0078] A second embodiment of the present invention will be described below.

[0079] Fig. 5 shows the configuration of a turbo refrigerator 10 according to the second embodiment. Note that components in Fig. 5 that are the same as those in Fig. 1 are given the same reference signs as in Fig. 1, and descriptions thereof will be omitted.

[0080] The turbo refrigerator 10 according to the second embodiment is provided with a hot-gas bypass pipe 80 that forms a bypass path between a refrigerant intake port of the turbo compressor 12 and a refrigerant exhaust port of the turbo compressor 12 (between a gas-phase portion in the condenser 14 and a gas-phase portion in the evaporator 16). Also, the hot-gas bypass pipe 80 is provided with a hot-gas bypass valve 82 for controlling the flow volume of the refrigerant that flows in the hot-gas bypass pipe 80.

[0081] With the turbo refrigerator 10 according to the second embodiment, by adjusting the flow volume of bypassed hot gas by means of the hot-gas bypass valve 82, it is possible to perform capacity control of an extremely small region that cannot be sufficiently controlled with the compressor inlet vane 20.

[0082] By providing the hot-gas bypass pipe 80 in the turbo refrigerator 10, refrigerant in which the gas-phase refrigerant at the outlet of the turbo compressor 12 and the gas-phase refrigerant at the outlet of the evaporator 16 are mixed is taken into the turbo compressor 12. Because of this, if the temperature of the refrigerant to be compressed at the turbo compressor 12 is used to measure the degree of superheating, the temperature of the above-described mixed refrigerant, that is, a temperature differing from the temperature of the refrigerant at the outlet of the evaporator 16, would be used, and thus, the degree of superheating would not be measured correctly.

[0083] Thus, with the turbo refrigerator 10 according to the second embodiment, the temperature of the refrigerant at the outlet of the evaporator 16 and the cold-water outlet temperature are assumed to be equivalent, and the measured degree of superheating is calculated based on the cold-water outlet temperature and the compressor intake pressure.

[0084] Fig. 6 shows the configurations of a vane degree-of-opening control portion 42 and an expansion-valve degree-of-opening control portion 44 according to the second embodiment. Note that components in Fig. 6 that are the same as those in Fig. 2 are given the same reference signs as in Fig. 2, and descriptions thereof will be omitted.

[0085] The expansion-valve degree-of-opening control portion 44 according to the second embodiment is provided with a compressor-intake-saturation-temperature calculating portion 84 instead of the degree-of-superheating calculating portion 62 provided in the expansion-valve degree-of-opening control portion 44 according to the first embodiment.

[0086] The compressor-intake-saturation-temperature calculating portion 84 calculates the saturation temperature of the refrigerant to be taken into the compressor (hereinafter, referred to as "compressor-intake saturation temperature") based on the compressor intake pressure measured by the compressor-intake-pressure measuring portion 30.

[0087] The compressor-intake-saturation-temperature calculating portion 84 stores, in advance, physical-property information that indicates the relationship between the pressure and saturation temperature of the refrigerant, and calculates the compressor-intake saturation temperature based on the compressor intake pressure and that physical-property information.

[0088] Furthermore, the expansion-valve degree-of-opening control portion 44 according to the second embodiment is provided with a subtraction portion 86.

[0089] The subtraction portion 86 receives inputs of the compressor-intake saturation temperature calculated by the compressor-intake-saturation-temperature calculating portion 84 and the cold-water outlet temperature measured by the cold-water-outlet-temperature measuring portion 36, and calculates the measured degree of superheating by subtracting the compressor-intake saturation temperature from the cold-water outlet temperature.

[0090] The subtraction portion 64 receives inputs of the target degree of superheating calculated by the target-degree-of-superheating calculating portion 60 and the measured degree of superheating calculated by the subtraction portion 86, subtracts the target degree of superheating from the measured degree of superheating, and outputs the subtraction result to the PI control portion 66.

[0091] As has been described above, because the turbo refrigerator 10 according to the second embodiment calculates the measured degree of superheating based on the cold-water outlet temperature and the compressor intake pressure, even though the hot-gas bypass pipe 80 is provided, the degree of superheating can be measured with high precision.

[0092] Although the present invention has been described as above by means of the individual embodiments described above, the technical scope of the present invention is not limited to the range described in the individual embodiments described above. Various alterations or improvements can be incorporated into the individual embodiments described above within a range that does not depart from the spirit of the invention, and the technical scope of the present invention also encompasses forms into which such alterations or improvements are incorporated.

[0093] For example, although the forms in which the planned CV value is calculated by using the cold-water inlet temperature and the cooling-water inlet temperature have been described in the individual embodiments described above, the present invention is not limited thereto, and a form in which the planned CV value is calculated by using only one of the cold-water inlet temperature and the cooling-water inlet temperature may be employed.

[0094] In addition, although the forms in which the heat-source medium that flows inside the cooling heat-transmitting pipe 26 inserted into the condenser 14 is assumed to be cooling water have been described in the individual embodiments described above, the present invention is not limited thereto, and a form in which the heat-source medium is assumed to be gas (external air) and the condenser is assumed to be an air heat exchanger may be employed. In the case of this form, a measuring portion that measures the gas (external air) serving as the heat-source medium is provided instead of the cooling-water-inlet-temperature measuring portion 28, and the thus-measured gas temperature is used instead of the cooling-water inlet temperature used in the individual embodiments described above.

[0095] In addition, although the cases in which the present invention is employed in the turbo refrigerator 10 that performs refrigeration operation have been described in the individual embodiments described above, without limitation thereto, the present invention may be employed in a heat-pump turbo refrigerator that is also capable of heat-pump operation.

[0096] In addition, although the forms in which a centrifugal compressor is employed in the turbo refrigerator 10 have been described in the individual embodiments described above, the present invention is not limited thereto, and other compression systems can also be employed, and, for example, a screw heat pump employing a screw compressor may be employed.

{Reference Signs List}

[0097]

10	turbo refrigerator
12	turbo compressor
14	condenser
16	evaporator
18	expansion valve
28	cooling-water-inlet-temperature measuring portion
34	cold-water-inlet-temperature measuring portion
36	cold-water-outlet-temperature measuring portion
40	control device
44	expansion-valve degree-of-opening control portion
80	hot-gas bypass pipe

Claims

1. An expansion-valve control device that, in a heat-source unit including a compressor that compresses a refrigerant; a condenser that condenses a compressed refrigerant by means of a heat-source medium; an evaporator that evaporates a condensed refrigerant and also performs heat exchange between the refrigerant and a heating medium; and an expansion valve that causes a liquid-phase refrigerant retained in the condenser to expand, controls a degree-of-opening of the expansion valve, the expansion-valve control device comprising:

    a first calculating portion that calculates a degree-of-opening of the expansion valve based on the difference between a target value of a degree of superheating for the refrigerant to be taken into the compressor and a measured value of the degree of superheating;
    a second calculating portion that calculates a degree-of-opening of the expansion valve based on an estimated value of a flow volume of the refrigerant that is allowed to pass through the expansion valve; and
    a command-value calculating portion that calculates a command value for controlling the degree-of-opening of the expansion valve from the degree-of-opening of the expansion valve cal-

culated by the first calculating portion and the degree-of-opening of the expansion valve calculated by the second calculating portion.

2. An expansion-valve control device according to Claim 1, wherein the target value of the degree of superheating is calculated based on the temperature of the heating medium that flows into the evaporator.

3. An expansion-valve control device according to Claim 2, wherein the target value of the degree of superheating is calculated so as to take a greater value with a decrease in the temperature of the heating medium that flows into the evaporator.

4. An expansion-valve control device according to any one of Claims 1 to 3, wherein the flow volume is calculated based on at least one of the temperature of the heating medium that flows into the evaporator and the temperature of the heat-source medium that flows into the condenser.

5. An expansion-valve control device according to Claim 4, wherein the flow volume is calculated so as to take a smaller value with a decrease in the temperature of the heating medium that flows into the evaporator and so as to take a greater value with a decrease in the temperature of the heat-source medium that flows into the condenser.

6. An expansion-valve control device according to any one of Claims 1 to 5,
wherein the heat-source unit is provided with a bypass pipe that forms a bypass path between a refrigerant intake port of the compressor and a refrigerant exhaust port of the compressor; and
wherein the measured value of the degree of superheating is calculated based on the temperature of the heating medium that has flowed out from the evaporator and the pressure of the refrigerant to be compressed at the compressor.

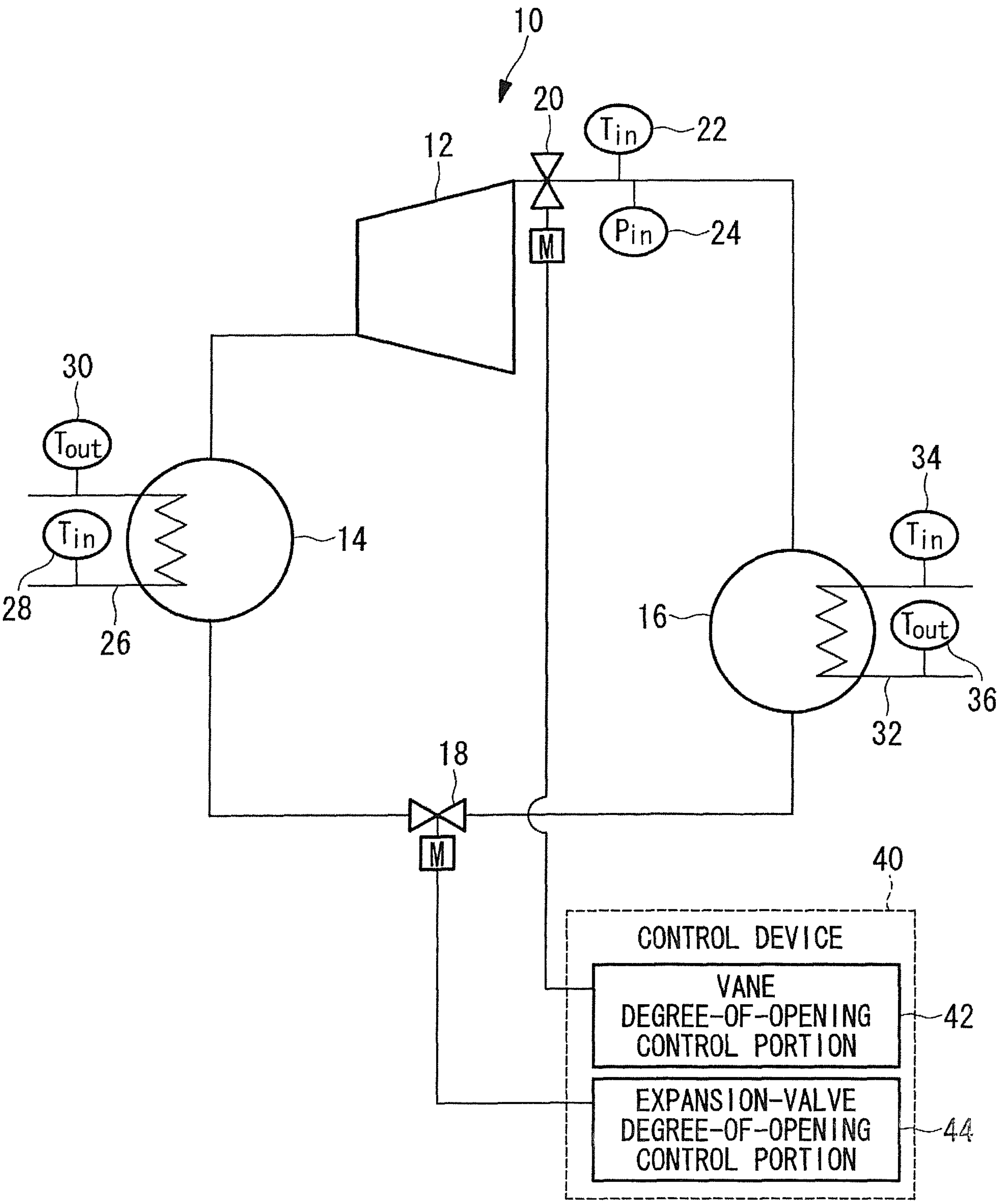
7. A heat-source unit comprising:

a compressor that compresses a refrigerant;
a condenser that condenses a compressed refrigerant by means of a heat-source medium;
an evaporator that evaporates a condensed refrigerant and also performs heat exchange between the refrigerant and a heating medium;
an expansion valve that causes a liquid-phase refrigerant retained in the condenser to expand; and
an expansion-valve control device according to any one of Claims 1 to 6.

8. An expansion-valve control method of controlling, in a heat-source unit including a compressor that compresses a refrigerant; a condenser that condenses a compressed refrigerant by means of a heat-source medium; an evaporator that evaporates a condensed refrigerant and also performs heat exchange between this refrigerant and a heating medium; and an expansion valve that causes a liquid-phase refrigerant retained in the condenser to expand, a degree-of-opening of the expansion valve, the expansion-valve control method comprising:

a first step of calculating a degree-of-opening of the expansion valve based on the difference between a target value of a degree of superheating for the refrigerant to be taken into the compressor and a measured value of the degree of superheating;
a second step of calculating a degree-of-opening of the expansion valve based on an estimated value of a flow volume of the refrigerant that is allowed to pass through the expansion valve; and
a third step of calculating a command value for controlling the degree-of-opening of the expansion valve from the degree-of-opening of the expansion valve calculated in the first step and the degree-of-opening of the expansion valve calculated in the second step.

FIG. 1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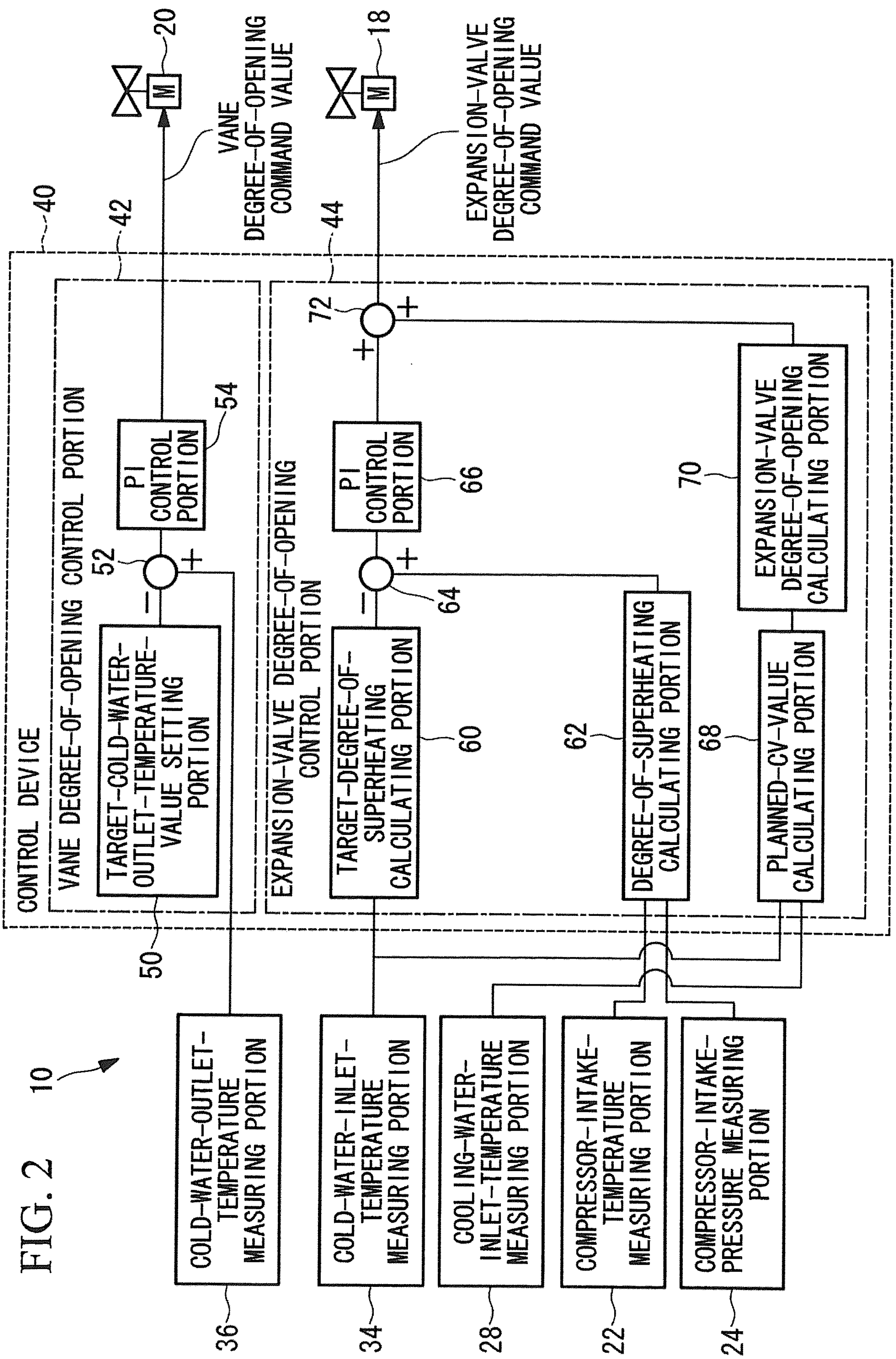
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PI CONTROL PORTION
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TARGET-DEGREE-OF-SUPERHEATING CALCULATING PORTION
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64
PI CONTROL PORTION
66
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EXPANSION-VALVE DEGREE-OF-OPENING COMMAND VALUE
M
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DEGREE-OF-SUPERHEATING CALCULATING PORTION
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PLANNED-CV-VALUE CALCULATING PORTION
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EXPANSION-VALVE DEGREE-OF-OPENING CALCULATING PORTION
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COLD-WATER-OUTLET-TEMPERATURE MEASURING PORTION
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COLD-WATER-INLET-TEMPERATURE MEASURING PORTION
34
COOLING-WATER-INLET-TEMPERATURE MEASURING PORTION
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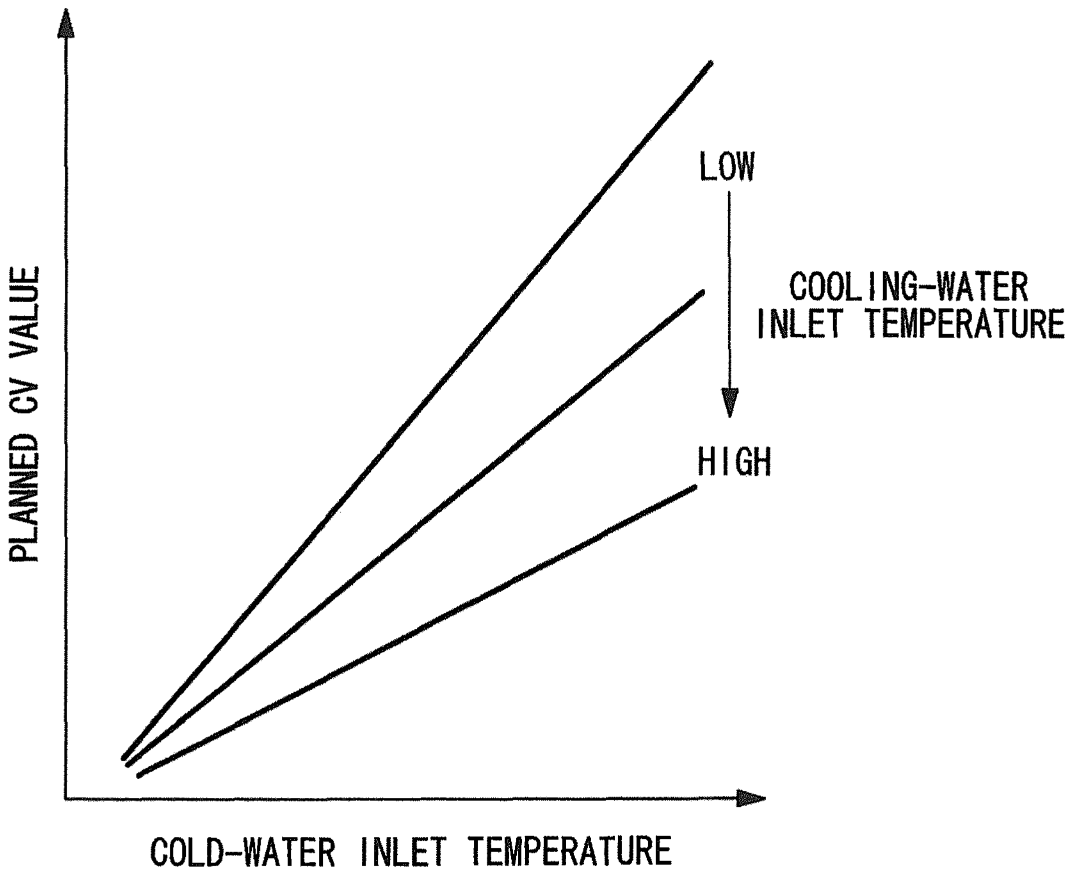
COMPRESSOR-INTAKE-TEMPERATURE MEASURING PORTION
22
COMPRESSOR-INTAKE-PRESSURE MEASURING PORTION
24

FIG. 2

FIG. 3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HIGH
COLD-WATER INLET TEMPERATURE

FIG. 4

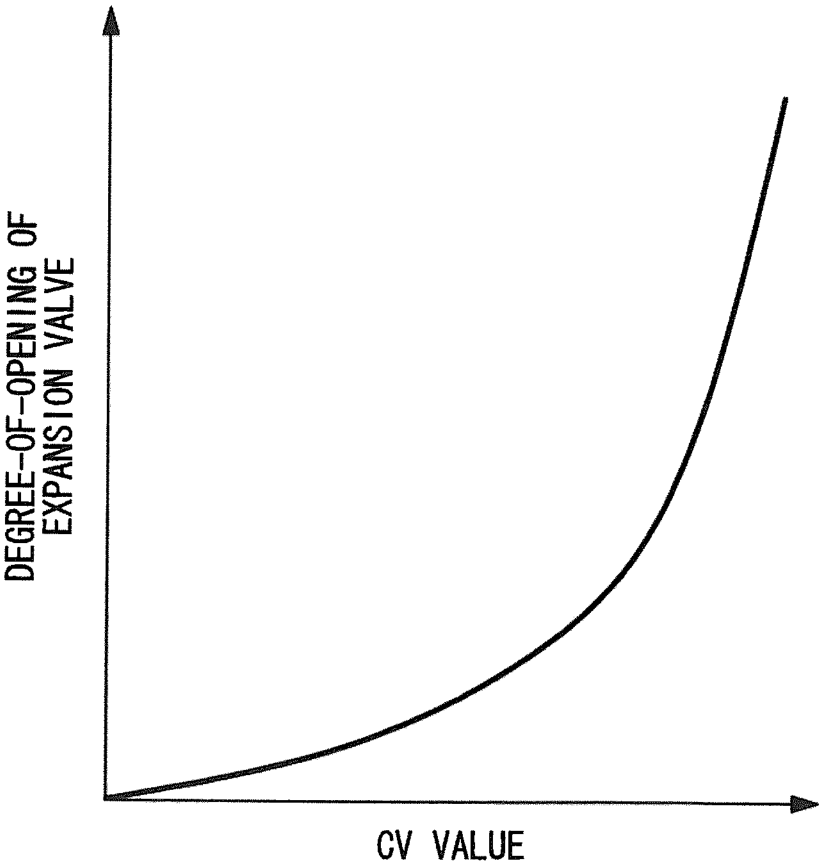
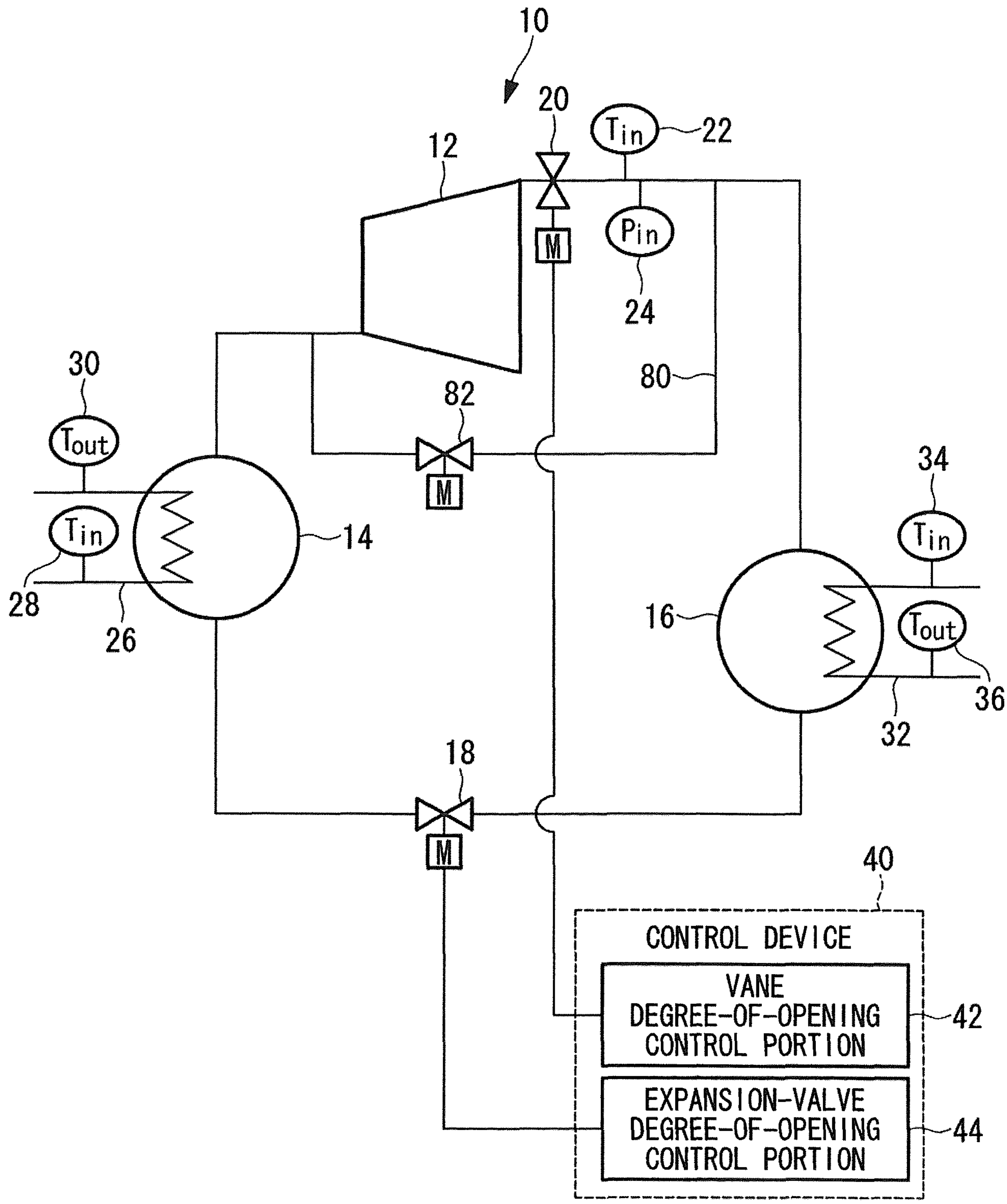


FIG. 5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CONTROL DEVICE
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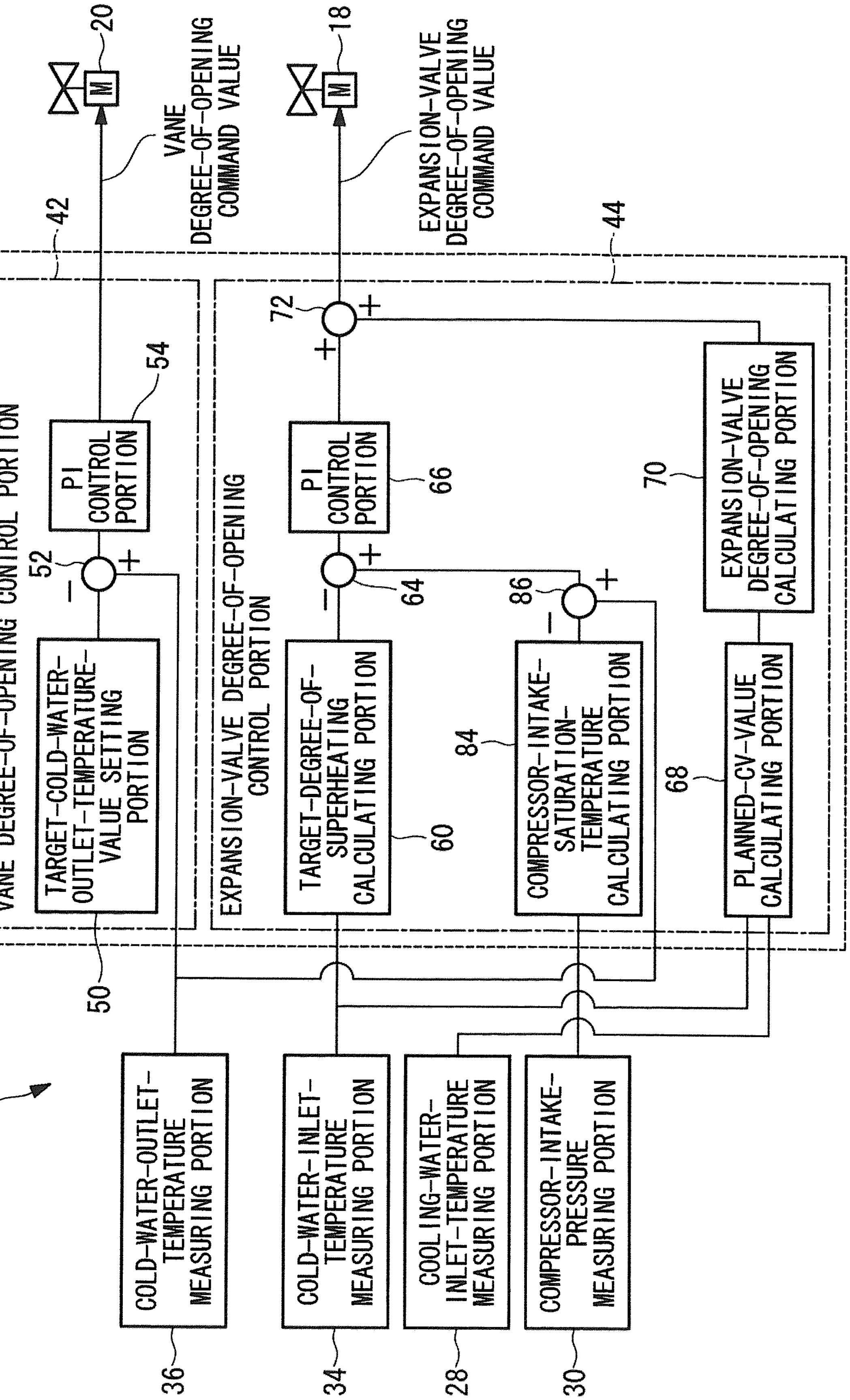
EXPANSION-VALVE DEGREE-OF-OPENING CONTROL PORTION
44

FIG. 6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PI CONTROL PORTION
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VANE DEGREE-OF-OPENING COMMAND VALUE
EXPANSION-VALVE DEGREE-OF-OPENING CONTROL PORTION
44
TARGET-DEGREE-OF-SUPERHEATING CALCULATING PORTION
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PI CONTROL PORTION
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EXPANSION-VALVE DEGREE-OF-OPENING COMMAND VALUE
COMPRESSOR-INTAKE-SATURATION-TEMPERATURE CALCULATING PORTION
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PLANNED-CV-VALUE CALCULATING PORTION
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EXPANSION-VALVE DEGREE-OF-OPENING CALCULATING PORTION
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COLD-WATER-INLET-TEMPERATURE MEASURING PORTION
34
COOLING-WATER-INLET-TEMPERATURE MEASURING PORTION
28
COMPRESSOR-INTAKE-PRESSURE MEASURING PORTION
30

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2012/056764

A. CLASSIFICATION OF SUBJECT MATTER
F25B1/00(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F25B1/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2012
Kokai Jitsuyo Shinan Koho	1971-2012	Toroku Jitsuyo Shinan Koho	1994-2012

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y A	JP 2010-54094 A (Mitsubishi Heavy Industries, Ltd.), 11 March 2010 (11.03.2010), paragraphs [0018] to [0025], [0046], [0047]; fig. 1 (Family: none)	1-4,7,8 5,6
Y A	JP 2005-315559 A (Daikin Industries, Ltd.), 10 November 2005 (10.11.2005), paragraphs [0200] to [0204]; fig. 36 & US 2007/0180851 A1 & EP 1739366 A1 & WO 2005/098320 A1 & KR 10-2006-0132916 A & CN 1926387 A & AU 2005230498 A	1-4,7,8 5,6

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

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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
27 April, 2012 (27.04.12)	15 May, 2012 (15.05.12)

Name and mailing address of the ISA/	Authorized officer
Japanese Patent Office	
Facsimile No.	Telephone No.

Form PCT/ISA/210 (second sheet) (July 2009)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2012/056764

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 3-271656 A (Zexel Corp.), 03 December 1991 (03.12.1991), page 5, upper left column, lines 2 to 9 (Family: none)	6
A	JP 2001-248919 A (Daikin Industries, Ltd.), 14 September 2001 (14.09.2001), paragraph [0035] (Family: none)	6
A	JP 2007-248001 A (Mitsubishi Electric Corp.), 27 September 2007 (27.09.2007), paragraph [0095] (Family: none)	6

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- JP 2010008013 A **[0008]**
- JP 2006284034 A **[0008]**