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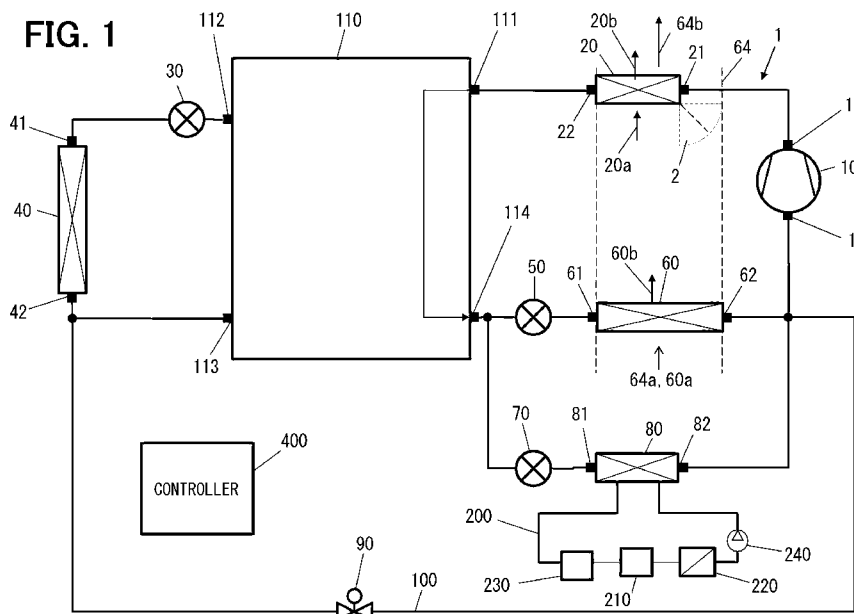
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(54) Title: METHOD FOR REGULATING A THERMAL MANAGEMENT SYSTEM FOR ELECTRIC VEHICLES AND THER-
MAL MANAGEMENT SYSTEM FOR THIS PURPOSE



(57) Abstract: A method for regulating a thermal management system and a thermal management system for this purpose are specified, which make the use of an air-side electrical heater in the HVAC duct (64) unnecessary, since the electric coolant heater (220) in the battery coolant circuit (200) is used for the cabin heating if needed. To further increase the efficiency, the electric coolant heater (220) is only activated when predetermined operating parameters of the thermal management system are met, which are defined in dependence on the respective operating mode. Heat from the coolant heater (220) and the compressor (10), ambient heat via the outdoor heat exchanger (40) and waste heat absorber (230) from the vehicle are used for the cabin heating. In the heating mode, it



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is advantageous to activate the electric coolant heater (220) only when the compressor (10) has reached a maximum speed. This maximum speed of the compressor (10) is determined by reaching the minimum suction pressure (p_s) at the compressor inlet (11), the speed limit for component protection of the compressor (10), and/or the noise/vibration behavior of the compressor (10).

Description

Title of Invention: METHOD FOR REGULATING A THERMAL MANAGEMENT SYSTEM FOR ELECTRIC VEHICLES AND THERMAL MANAGEMENT SYSTEM FOR THIS PURPOSE

Cross Reference to Related Application

[0001] This application is based on and incorporates herein by reference German Patent Application No. 102022117374.7 filed on July 12, 2022.

Technical Field

[0002] The disclosure relates to a method for regulating a thermal management system and a thermal management system for carrying out this method.

Background Art

[0003] Modern electric vehicles have a limited range, in particular at low external temperatures, at which a significant amount of the electrical energy is used for the vehicle cabin heating. To reduce the use of electrical energy for a vehicle cabin heating, heat pumps have been used in the meantime.

[0004] There are various possibilities for increasing the heating warmth, such as gas injection systems, hot gas bypass heating systems, or electrical cabin heating elements. The above-mentioned measures require additional costs and additional installation space, which is not always available. The range of an electrical vehicle sinks due to the electrical heaters.

[0005] Arranging the electric coolant heater before the chiller, so that the heat can be transferred via the refrigerant circuit to the cabin, is known from PTL 1 and PTL 2. Furthermore, regulating strategies for the use of the electric coolant heater for cabin heating and electric vehicles are known from PTL 2. In this case, the available heat of the outdoor heat exchanger is estimated beforehand by computer. If it is not sufficient to achieve the required cabin heating power and if the coolant temperature at the chiller inlet is below a specified temperature threshold value, the electric coolant heater is switched on and the heat is coupled via the chiller into the refrigerant circuit and emitted via the cabin condenser to the vehicle cabin. An individual heating operation or a combined operation is described, in which the heat from the electric coolant heater and ambient heat from the outdoor heat exchanger are coupled into the refrigerant circuit.

Citation List

Patent Literature

[0006] PTL 1: DE 102011109055 A1

PTL 2: US 11104205 B2

[0007] It is an object of the present disclosure to specify an efficient method for regulating a thermal management system for electric vehicles in various operating modes and a method for switching between the operating modes. Furthermore, it is an object of the disclosure to specify a thermal management system for electric vehicles for carrying out this method.

[0008] According to an embodiment of the present disclosure, a thermal management system for electric vehicles in various operating modes, which comprise heating, cooling, and dehumidifying of the cabin air, is regulated in a method. The thermal management system comprises a battery, an electric coolant heater, a heat pump arrangement, and a controller. The heat pump arrangement includes a compressor, a cabin condenser, an outdoor heat exchanger expansion valve, an outdoor heat exchanger, a chiller expansion valve, a chiller, a cabin evaporator expansion valve and a cabin evaporator. The compressor has a compressor inlet and a compressor outlet. The cabin condenser has a refrigerant-side condenser inlet and a refrigerant-side condenser outlet. The outdoor heat exchanger has a refrigerant-side outdoor heat exchanger inlet and a refrigerant-side outdoor heat exchanger outlet. The outdoor heat exchanger expansion valve is connected to the outdoor heat exchanger inlet. The chiller has a refrigerant-side chiller inlet and a refrigerant-side chiller outlet. The chiller expansion valve is connected to the refrigerant-side chiller inlet. The cabin evaporator has a refrigerant-side evaporator inlet and a refrigerant-side evaporator outlet. The cabin evaporator expansion valve is connected to the refrigerant-side evaporator inlet. The cabin condenser and the cabin evaporator are arranged in an HVAC duct for air as a coolant. The HVAC duct includes a duct air inlet and a duct air outlet, which opens into the vehicle cabin. The cabin condenser includes a condenser air inlet and a condenser air outlet. The cabin evaporator includes an evaporator air inlet and an evaporator air outlet. The chiller comprises a chiller coolant inlet and a chiller coolant outlet. The electric coolant heater is incorporated in a battery coolant circuit between the battery, a waste heat absorber for decoupling waste heat from the electric vehicle into the battery coolant circuit, and the chiller. In the method, the electric coolant heater is first activated when predetermined operating parameters of the thermal management system are met, which are defined in dependence on the respective operating mode.

[0009] According to another embodiment of the present disclosure, a thermal management system for electric vehicles, has a battery, an electric coolant heater, a heat pump arrangement, and a controller. The heat pump arrangement comprises a compressor, a cabin condenser, an outdoor heat exchanger expansion valve, an outdoor heat exchanger, a chiller expansion valve, a chiller, a cabin evaporator expansion valve, a

cabin evaporator and a refrigerant bypass line. The compressor has a compressor inlet and a compressor outlet. The cabin condenser has a refrigerant-side condenser inlet and a refrigerant-side condenser outlet. The outdoor heat exchanger has a refrigerant-side outdoor heat exchanger inlet and a refrigerant-side outdoor heat exchanger outlet. The external heater expansion valve is connected to the outdoor heat exchanger inlet. The chiller has a refrigerant-side chiller inlet and a refrigerant-side chiller outlet. The chiller expansion valve is connected to the refrigerant-side chiller inlet. The cabin evaporator having an evaporator inlet and an evaporator outlet. The evaporator expansion valve is connected to the evaporator inlet. The refrigerant bypass line is between the outdoor heat exchanger outlet and the compressor inlet. The refrigerant bypass line is blockable via a bypass shut-off valve. The cabin condenser and the cabin evaporator are arranged in an HVAC duct for air as a coolant. The HVAC duct includes a duct air inlet and a duct air outlet. The cabin condenser includes a condenser air inlet and a condenser air outlet. The cabin evaporator includes an evaporator air inlet and an evaporator air outlet. The chiller comprises a chiller coolant inlet and a chiller coolant outlet. The electric coolant heater is incorporated in a battery coolant circuit between the battery, a waste heat absorber for decoupling waste heat from the electric vehicle, and the chiller. The controller is designed for various operating modes, which comprise heating, cooling, and dehumidifying the cabin air, characterized in that the controller is designed to activate the electric coolant heater only when predetermined operating parameters of the thermal management system are met, which are defined in dependence on the respective operating mode.

[0010] Heat from the coolant heater and the compressor, ambient heat, and waste heat from the vehicle are used for cabin heating. An electrical heater in the HVAC duct is superfluous, since the electric coolant heater in the battery coolant circuit is used if needed for the cabin heating. To further increase the efficiency, the electric coolant heater is only activated when predetermined operating parameters of the thermal management system are met, which are defined in dependence on the respective operating mode.

[0011] In the heating mode, it is advantageous to first activate the electric coolant heater when the compressor has reached a maximum speed. This maximum speed of the compressor is determined by the controller by reaching the minimal suction pressure at the compressor inlet, the speed limit for component protection of the compressor, and/or the noise/vibration behavior of the compressor.

[0012] According to an advantageous embodiment, in the heating mode, the airflow in the duct after the cabin evaporator is allocated through the cabin condenser or past it by means of an air mix door, by which the pressure at the compressor outlet and thus the heat emission of the compressor to the refrigerant is influenced.

- [0013] It has proven to be advantageous for the regulation of the heating power of the electric coolant heater in the heating mode to be carried out using at least one of the following operating parameters of the heat pump arrangement as a control variable:
- refrigerant pressure at the compressor outlet,
 - refrigerant superheat at the refrigerant-side chiller outlet,
 - refrigerant superheat at the compressor inlet,
 - refrigerant superheat at the outdoor heat exchanger outlet,
 - air temperature at the condenser air outlet, and/or
 - air temperature at the duct air outlet.
- [0014] According to an advantageous embodiment, the heating power of the electric coolant heater is limited if the coolant temperature at the chiller inlet and thus the suction pressure at the compressor inlet would become too high to enable heat absorption from the surroundings via the outdoor heat exchanger. The efficiency is also increased or the use of electrical energy from the battery is limited in this way.
- [0015] An embodiment relates to a specific regulating strategy for the heating power of the electric coolant heater, in which the control variable for regulating the heating power of the electric coolant heater is the refrigerant pressure at the compressor outlet, and in which the control variable for the degree of opening of the chiller expansion valve is the refrigerant superheat at the refrigerant-side chiller outlet or the refrigerant superheat at the compressor inlet.
- [0016] An embodiment relates to an alternative regulating strategy for the heating power of the electric coolant heater, in which the control variable for regulating the heating power of the electric coolant heater is the refrigerant superheat at the refrigerant-side chiller outlet or the refrigerant superheat at the compressor inlet, and in which the control variable for the degree of opening of the chiller expansion valve is the refrigerant pressure at the compressor outlet.
- [0017] Due to these regulating strategies, the coolant temperature in the battery coolant circuit remains as low as possible, so that heat losses to the surroundings remain small.
- [0018] It has proven to be advantageous for the heating power of the electric coolant heater in the dehumidifying mode to be regulated using at least one of the following operating parameters of the heat pump arrangement as a control variable:
- refrigerant pressure at the compressor outlet,
 - air temperature at the condenser air outlet,
 - air temperature at the duct air outlet,
 - refrigerant superheat at the refrigerant-side chiller outlet,
 - refrigerant superheat at the compressor inlet, and/or
 - air temperature at the evaporator air outlet.
- [0019] In an advantageous embodiment, the dehumidifying takes place without heat

emission via the outdoor heat exchanger. The electric coolant heater is switched on when the compressor has reached a maximum speed or when the refrigerant superheat at the refrigerant-side chiller outlet or compressor inlet falls below a predetermined minimum value. This maximum speed of the compressor is determined by reaching the minimum suction pressure at the compressor inlet, the speed limit for component protection of the compressor, and/or the noise/vibration behavior of the compressor. The minimum suction pressure at the compressor inlet is determined by the seal concept of the heat pump arrangement and the maximum negative pressure resulting therefrom in the refrigerant circuit in comparison to the ambient pressure.

- [0020] According to one preferred embodiment, the degree of opening of the chiller expansion valve regulates the air temperature at the evaporator air outlet. A two-solution regulation problem of the compressor speed with regulation of the air temperature at the evaporator air outlet is thus avoided via the compressor speed.
- [0021] In one advantageous embodiment, the dehumidifying takes place using heat emission via the outdoor heat exchanger. The electric coolant heater is switched on when the outdoor heat exchanger expansion valve reaches a predetermined minimum opening value. This minimum opening value ensures a minimum required differential pressure at the expansion valve or valves.
- [0022] In the dehumidifying mode, it is possible to calculate the required coolant temperature at the chiller inlet with knowledge of the heat exchanger behavior, since the suction pressure level is defined by the cabin evaporator target temperature.
- [0023] According to an advantageous embodiment, icing of the cabin evaporator is also prevented by the regulation of the electric coolant heater. The coolant temperature at the chiller coolant inlet and thus the suction pressure at the compressor inlet is increased by the electric coolant heater. This has the result that the evaporation temperature in the cabin evaporator rises and icing is prevented.
- [0024] According to an advantageous embodiment, the electric coolant heater is also used when switching from one operating mode to the other in order to keep the air temperature at the duct air outlet at the desired value. More specifically, the electric coolant heater is used to keep constant the heating power of the cabin and the air temperature at the duct air outlet. Since no air-side electrical cabin heating element is provided, the compressor has to be continuously operated even during the switch between the operating modes. Due to the electric coolant heater, the absorption of heat in the refrigerant circuit at the chiller will ensure the required heating power in the cabin and the required superheat of the refrigerant at the compressor inlet. In the next step, a predetermined opening of the bypass shut-off valve enables a controlled displacement of the liquid refrigerant accumulated in the outdoor heat exchanger with refrigerant superheat ensured before the compressor.

- [0025] An advantageous embodiment relates to a specific embodiment of the switch between the operating modes, due to which the outdoor heat exchanger can be used as an evaporator. In the method, the following steps may be performed by the controller in this order. The chiller expansion valve is opened and the electric coolant heater is activated. The outdoor heat exchanger expansion valve is closed. The refrigerant-side outdoor heat exchanger outlet is connected to the compressor inlet via a bypass line having a controllable bypass shut-off valve by partially opening the controllable bypass shut-off valve to a predetermined degree of opening. The outdoor heat exchanger expansion valve is completely opened and the controllable bypass shut-off valve is completely opened when stable superheat of the refrigerant at the compressor inlet is achieved or the pressure in the outdoor heat exchanger has equalized to the suction pressure at the compressor inlet. The chiller expansion valve is closed.
- [0026] According to an advantageous embodiment, the required heating power of the electric coolant heater is estimated by computer and this value ascertained by computer is used as an initial target value for regulating the electric coolant heater. If the desired heating power is not achieved, the heat absorption by the chiller is excessively low, or if the maximum speed of the compressor is not achieved, the heat absorption by the chiller is excessively high, the initial target value is adapted in a second control loop. When the heat absorption by the chiller is lower than a first threshold or higher than a second threshold that is higher than the first threshold, the initial target value is adapted.
- [0027] Due to an advantageous embodiment, it is possible to decouple the large thermal mass of the battery, so that the heating power of the electric coolant heater is nearly entirely available for the cabin heating.
- [0028] Further details, features, and advantages of the disclosure result from the following description of a preferred embodiment of the disclosure.

Brief Description of Drawings

- [0029] The drawings described herein are for illustrative purposes only and are not intended to limit the scope of the present disclosure. Corresponding reference numerals indicate corresponding parts throughout the several views of the drawings.
- [Fig.1]FIG. 1 shows a structure of a heat pump arrangement according to a first embodiment, which is a part of a thermal management system for electric vehicles, in which a chiller, a compressor, and an electric coolant heater are used as a heat source for heating a cabin in a heating mode.
- [Fig.2]FIG. 2 shows active components in the heating mode according to FIG. 1 in a p-h diagram.
- [Fig.3]FIG. 3 shows an illustration similar to FIG. 1 according to a second em-

bodiment, in which a chiller, an outdoor heat exchanger, a compressor, and an electric coolant heater are used as a heat source for heating a cabin in a heating mode.

[Fig.4]FIG. 4 shows active components in the heating mode according to FIG. 3 in a p-h diagram.

[Fig.5]FIG. 5 shows, in combination with FIG. 1, specifically a dehumidifying mode without heat emission to the surroundings according to a third embodiment.

[Fig.6]FIG. 6 shows an illustration similar to FIG. 1 according to a fourth embodiment in the dehumidifying mode with heat emission to the surroundings via the outdoor heat exchanger, in which a chiller, a cabin evaporator, a compressor, and an electric coolant heater are used as a heat source for heating a cabin.

[Fig.7]FIG. 7 shows, in combination with FIG. 6, active components according to the fourth embodiment of the disclosure.

[Fig.8]FIG. 8 schematically shows switching from serial dehumidifying to parallel dehumidifying via intermediate modes.

[Fig.9]FIG. 9 shows decoupling of a large thermal mass of a battery by coolant bypass.

[Fig.10]FIG. 10 shows a structure of a thermal management system according to a comparative example.

Description of Embodiments

[0030] First, a comparative example shown in FIG. 10 will be described. The applicant suggests high-efficiency thermal management systems. There are various system concepts for low-pressure or high-pressure cold reservoirs (storage or collector system). In addition, different arrangements of heat exchangers are possible. One example of these thermal management systems for electric vehicles having a heat pump arrangement 1 is shown in FIG. 10. The heat pump arrangement 1 connects, via a refrigerant circuit, a compressor 10 having a compressor inlet 11 and a compressor outlet 12, a cabin condenser 20 for heating the air in a vehicle cabin having a condenser inlet 21 and a condenser outlet 22, an outdoor heat exchanger 40 for absorbing heat from or for emitting heat to the surroundings having an outdoor heat exchanger inlet 41 and an outdoor heat exchanger outlet 42, a chiller or external evaporator 80 having a refrigerant-side chiller inlet 81 and a refrigerant-side chiller outlet 82, wherein the refrigerant-side chiller inlet 81 is connected to a chiller expansion valve 70, a cabin evaporator 60 having a cabin evaporator inlet 61 and a cabin evaporator outlet 62, wherein a cabin evaporator expansion valve 50 is connected upstream of the cabin evaporator inlet 61. An air mix door 2 for temperature regulation is provided on the air side with the cabin condenser 20. An internal heat exchanger for heat exchange can optionally be arranged between the refrigerant before the entry into the cabin evaporator expansion valve 50 and the refrigerant after the

cabin evaporator outlet 62. A bypass line 100, which can be shut off via a bypass shut-off valve 90, is provided between the outdoor heat exchanger outlet 42 and the compressor inlet 11. This bypass line 100 for refrigerant is required in the heating or heat pump mode.

- [0031] The cabin condenser 20 having air mix door 2 and the cabin evaporator 60 are arranged in an HVAC duct 64 having a duct air inlet 64a and a duct air outlet 64b. To be able to adequately heat the vehicle cabin even at very low temperatures, an electrical cabin heater 300 is provided in the HVAC duct 64.
- [0032] The thermal management system or heat pump arrangement 1 furthermore comprises a battery 210 and an electric coolant heater 220, a waste heat absorber 230, and a coolant pump 240. The electric coolant heater 220, the coolant pump 240, the chiller 80, the waste heat absorber 230, and the battery 210 are connected to one another in series in a battery coolant circuit 200. Evaporation heat is supplied to the chiller 80 via the battery coolant circuit 200.
- [0033] A valve unit 110 is arranged between the outdoor heat exchanger outlet 42 and the chiller expansion valve 70, on the one hand, and the outdoor heat exchanger inlet 41 and the condenser outlet 22, on the other hand. The valve unit 110 comprises a first and a second refrigerant inlet 111, 113, and a first and a second refrigerant outlet 112, 114. A high-pressure side refrigerant reservoir can optionally be provided in the valve unit 110. Depending on the operating mode, the valve unit 110 blocks, conducts, or throttles the refrigerant flows between the refrigerant inlets 111, 113 and the refrigerant outlets 112, 114. The heat pump arrangement 1 or the thermal management system may be operated in various operating modes, such as heating, cooling, or dehumidifying mode, by means of a controller 400.
- [0034] In a heat pump or heating mode, refrigerant condensed in the cabin condenser 20 is supplied via the first refrigerant inlet 111 to the valve unit 110. Liquid refrigerant is then supplied via the second refrigerant outlet 114 to the chiller expansion valve 70 and the chiller expansion valve 70 generates a controlled expansion. The expanded refrigerant is evaporated in the chiller 80 by introduction of heat via the battery coolant circuit 200 and compressed in the compressor 10. The compressed refrigerant gas from the compressor 10 is condensed in the cabin condenser 20 while emitting heat to the air which is supplied to the vehicle cabin.
- [0035] One disadvantage of the heat pump arrangement according to FIG. 10 using currently typical refrigerants, such as R134a or R1234yf, may be that it cannot completely cover the heating demand for the vehicle cabin heating at very low temperatures, -20°C and lower. This is to be attributed to the low suction pressure of the compressor 10 at very low temperatures. If the suction pressure sinks, the density of the refrigerant is reduced and the refrigerant mass flow is thus reduced at a given maximum volumetric flow rate

of the compressor 10. The refrigerant mass flow thus decreases, and therefore the heat flow which is supplied to the vehicle cabin via the cabin condenser 20 decreases.

[0036] FIGS. 1 and 2 show a first embodiment of the disclosure. FIG. 1 shows a structure of a heat pump arrangement 1, which is a part of a thermal management system for electric vehicles, in the heating mode, wherein the chiller 80, the compressor 10, and the electric coolant heater 220 are used as a heat source for heating the cabin. The thermal management system according to FIG. 1 differs from the thermal management system according to FIG. 10 solely due to the absence of the electrical cabin heater 300 and due to the special embodiment of the controller 400, which enables the operation in the first and/or second startup phase and in the heating phase. In addition, a condenser air inlet 20a, a condenser air outlet 20b, an evaporator air inlet 60a, and an evaporator air outlet 60b are shown in the HVAC duct 64. The duct air inlet 64a corresponds here to the evaporator air inlet 60a, while the duct air outlet 64b differs from the condenser air outlet 20b due to the air mix door 2. The valve unit 110 connects the first refrigerant inlet 111 to the second refrigerant outlet 114. The cabin evaporator expansion valve 50 is closed, so that the refrigerant from the cabin condenser 20 is supplied via the chiller expansion valve 70 to the chiller 80.

[0037] FIG. 2 shows the active components in the heating mode according to FIG. 1 in the p-h diagram. The electric coolant heater 220 is first activated when the compressor 10 is operated at its maximum speed, i.e., maximum heat emission, and nonetheless the heat absorbed in the chiller 80 and the waste heat of the compressor are not sufficient for the desired heat emission by the cabin condenser 20. The control variable for regulating the heating power of the electric coolant heater 220 is the refrigerant pressure p_D at the compressor outlet 12, and the control variable for the degree of opening of the chiller expansion valve 70 is the refrigerant superheat SH_{cho} at the refrigerant-side chiller outlet 82 or the refrigerant superheat SH_{cpi} at the compressor inlet 11. Alternatively, the control variable is the refrigerant superheat SH_{cho} at the refrigerant-side chiller outlet 82 or the refrigerant superheat SH_{cpi} at the compressor inlet 11, and the control variable for the degree of opening of the chiller expansion valve 70 is the refrigerant pressure p_D at the compressor inlet 12. Due to the various regulating strategies, the coolant temperature in the battery coolant circuit 200 remains as low as possible, so that heat losses to the surroundings remain small.

[0038] FIGS. 3 and 4 show a second embodiment of the disclosure, which differs from the first embodiment solely in that in addition to the chiller 80, ambient heat is used for cabin heating via the outdoor heat exchanger 40 operating as an evaporator. The refrigerant superheat SH_{ohxo} at the outdoor heat exchanger outlet 42 is therefore additionally available as a control variable for the two regulating strategies.

[0039] The heating power of the electric coolant heater 220 is limited if the coolant tem-

perature T_{Chi} at the chiller: chiller coolant inlet 80a and thus the suction pressure (p_s) at the compressor inlet 11 were to become too large to enable a heat absorption from the surroundings via the outdoor heat exchanger 40. More specifically, the heating power of the electric coolant heater 220 is limited when the coolant temperature T_{Chi} at the chiller: chiller coolant inlet 80a and thus the suction pressure (p_s) at the compressor inlet 11 becomes higher than a predetermined threshold to enable a heat absorption from the surroundings via the outdoor heat exchanger 40. In this way as well, the efficiency is increased or the use of electrical energy from the battery is limited.

[0040] FIG. 5 shows, in combination with FIG. 1, a third embodiment of the disclosure, specifically a dehumidifying mode without heat emission to the surroundings. The compressor 10 is operated at maximum speed. The air temperature T_{aEo} at the evaporator air outlet 60b is regulated via the degree of opening of the chiller expansion valve 70. The refrigerant superheat SH_{Eo} at the evaporator outlet 62 is regulated via the degree of opening of the cabin evaporator expansion valve 50. The electric coolant heater 220 is activated when the compressor 10 has reached its maximum speed or when the refrigerant superheat (SH_{Cho} , SH_{Cpi}) at the refrigerant-side chiller outlet (82) or compressor inlet (11) falls below a predetermined minimum value. The heating power of the electric coolant heater 220 is regulated via the coolant pressure pD at the compressor outlet 12.

[0041] FIGS. 6 and 7 show a fourth embodiment of the disclosure, specifically a dehumidifying mode with heat emission to the surroundings. The speed of the compressor 10 is regulated via the air temperature T_{aEo} at the compressor air outlet 60b. The distribution of the heat emission between cabin condenser 20 and the outdoor heat exchanger 40 operating as a condenser is regulated via the outdoor heat exchanger expansion valve 30. The refrigerant superheat SH_{Eo} at the evaporator outlet 62 is regulated via the degree of opening of the cabin evaporator expansion valve 50 and the refrigerant superheat SH_{Cho} at the refrigerant-side chiller outlet 82 is regulated via the degree of opening of the chiller expansion valve 70. The electric coolant heater 220 is switched on when the desired heating power for the cabin is not sufficient and when the outdoor heat exchanger expansion valve 30 reaches a predetermined minimum opening value. The degree of opening of the chiller expansion valve 70 may be controlled by the controller 400.

[0042] In the heating modes according to FIGS. 1 to 4 without and with heat absorption via the outdoor heat exchanger 40 and in the dehumidifying mode according to FIGS. 5 and 1, dehumidifying without heat emission via the outdoor heat exchanger 40, the compressor 10 is operated at the maximum speed. When the desired heating power for the cabin is not achieved, the electric coolant heater is switched on.

[0043] In the dehumidifying modes shown in FIGS. 5 and 7, the required heating power of

the electric coolant heater 220 can be estimated by computer on the basis of the following energy balance:

Heating power of the electric coolant heater 220 =
desired heating power for the cabin - heating power of the outdoor heat exchanger 40 (omitted in FIG. 6) - waste heat power of the compressor 10 - latent component of the cabin evaporator power + heat loss power to the surroundings

[0044] The waste heat of the compressor 10 can additionally be increased in that in the heating mode, the airflow in the HVAC duct 64 from the evaporator air outlet 60b is allocated through the cabin condenser 20 or past it by means of the air mix door 2, by which the pressure pD of the compressor outlet 12 and thus the heat emission of the compressor 10 to the refrigerant is influenced. The waste heat of the compressor 10 at constant speed can thus be increased, so that the necessity of using the electric coolant heater 220 is reduced. The air mix door 2 may be controlled to be actuated by the controller 400.

[0045] FIG. 8 schematically shows switching from serial dehumidifying, in which the outdoor heat exchanger 40 is used as a condenser, to parallel dehumidifying, in which the outdoor heat exchanger 40 is used as an evaporator, via transition modes. Without air-side electrical cabin heater 300 for the vehicle cabin, it is necessary to keep the compressor 10 continuously in operation. The switching logic has to maintain the cabin comfort (heating power, dehumidifying, minor temperature variations), and prevent damage to the compressor 10 due to displacement of liquid refrigerant accumulated in the outdoor heat exchanger. This can occur above all when switching from a mode in which the outdoor heat exchanger 40 is used as a condenser and a large quantity of liquid refrigerant is stored therein to a mode in which the outdoor heat exchanger 40 is used as an evaporator. To avoid damage to the compressor 10 due to a liquid surge, the refrigerant is slowly reclaimed by controlling the degree of opening of the bypass shut-off valve 90 in the bypass line 100. The outdoor heat exchanger 40 can then be used as an evaporator. To establish whether the largest part of the refrigerant has been reclaimed and the risk of backflow of liquid refrigerant has been reduced, the refrigerant superheat SH_{OHX_0} at the outdoor heat exchanger outlet 42 can be used as a criterion. If the refrigerant superheat SH_{OHX_0} at the outdoor heat exchanger outlet 42 has stabilized, it is to be presumed that most of the liquid refrigerant has been displaced from the outdoor heat exchanger 40 into the active part of the refrigeration circuit. The bypass shut-off valve 90 can be an expansion device or a valve having an intermediate stage and small opening. To ensure the heating power of the cabin during the switching, the electric coolant heater 220 in the battery coolant circuit 200 is activated and the emitted heat is coupled via the chiller 80 into the refrigerant circuit and emitted via the cabin condenser 20 to the cabin.

- [0046] First, the chiller expansion valve 70, if closed, is opened and the electric coolant heater 220 is activated or vice versa in a first transition mode. The outdoor heat exchanger expansion valve 30 is then closed and the bypass shut-off valve 90 is opened to a certain degree of opening less than the maximum degree of opening in a second transition mode. After a certain duration or reaching stable superheat at the compressor inlet 11, the outdoor heat exchanger expansion valve 30 is opened, the bypass shut-off valve 90 is completely opened. Finally, in the target mode the chiller expansion valve 70 is closed and the outdoor heat exchanger 40 is used in the target mode as an evaporator.
- [0047] The electric coolant heater 220 is also used during the described dehumidifying modes according to FIG. 5 and FIG. 7 to prevent icing of the cabin evaporator 60. Due to the heat from the electric coolant heater 220, the coolant temperature T_{Chi} at the chiller coolant inlet 80a and thus the suction pressure (p_s) at the compressor inlet 11 is increased. This has the result that the evaporation temperature in the cabin evaporator 60 rises and icing is prevented.
- [0048] FIG. 9 shows the battery coolant circuit 200 having a coolant bypass 250 and a valve setup 260 in the form of a 3-way valve between the chiller coolant outlet 80b and a point in the battery coolant circuit 200 between the electric coolant heater 220 and the battery 210. By regulating the 3-way valve 260, the large thermal mass of the battery 210 can be more or less decoupled by the coolant bypass 250 from the battery coolant circuit 200. When a very high heating power for the cabin is required during starting of the electric vehicle at low ambient temperatures, heat of the electric coolant heater 220 can be used more or less completely for the cabin heating; unnecessary heating of the large thermal mass of the battery is avoided. The desired temperature in the cabin is thus reached faster. The 3-way valve 260 may be controlled by the controller 400.
- [0049] In the circuit diagrams according to FIGS. 1, 3, and 6, a refrigerant collector is provided on the high-pressure side of the heat pump arrangement 1 as part of the valve unit. Alternatively, the refrigerant collector can also be arranged on the low-pressure side of the heat pump arrangement 1 immediately before the compressor 10.

Claims

[Claim 1]

A method for regulating a thermal management system for electric vehicles in various operating modes, which comprise heating, cooling, and dehumidifying of cabin air blown into a vehicle cabin, wherein the thermal management system comprises a battery (210), an electric coolant heater (220), a heat pump arrangement (1), and a controller (400),
wherein the heat pump arrangement (1) includes
a compressor (10) having a compressor inlet (11) and a compressor outlet (12),
a cabin condenser (20) having a refrigerant-side condenser inlet (21) and a refrigerant-side condenser outlet (22),
an outdoor heat exchanger expansion valve (30),
an outdoor heat exchanger (40) having a refrigerant-side outdoor heat exchanger inlet (41) and a refrigerant-side outdoor heat exchanger outlet (42), wherein the outdoor heat exchanger expansion valve (30) is connected to the outdoor heat exchanger inlet (41),
a chiller (80) having a refrigerant-side chiller inlet (81) and a refrigerant-side chiller outlet (82),
a chiller expansion valve (70) connected to the refrigerant-side chiller inlet (81),
a cabin evaporator (60) having a refrigerant-side evaporator inlet (61) and a refrigerant-side evaporator outlet (62), and
a cabin evaporator expansion valve (50) connected to the refrigerant-side evaporator inlet (61),
wherein the cabin condenser (20) and the cabin evaporator (60) are arranged in an HVAC duct (64) for air as a coolant,
wherein the HVAC duct (64) includes a duct air inlet (64a) and a duct air outlet (64b), which opens into the vehicle cabin,
wherein the cabin condenser (20) includes a condenser air inlet (20a) and a condenser air outlet (20b), and
wherein the cabin evaporator (60) includes an evaporator air inlet (60a) and an evaporator air outlet (60b),
wherein the chiller (80) comprises a chiller coolant inlet (80a) and a chiller coolant outlet (80b), and wherein the electric coolant heater (220) is incorporated in a battery coolant circuit (200) between the battery (210), a waste heat absorber (230) for decoupling waste heat

from the electric vehicle into the battery coolant circuit (200), and the chiller (80), the method comprising

first activating the electric coolant heater (220) when predetermined operating parameters of the thermal management system are met, which are defined in dependence on the respective operating modes.

[Claim 2] The method as claimed in claim 1, characterized in that the activating includes, in a heating mode, first activating the electric coolant heater (220) when the compressor (10) has reached a maximum speed, and the method further comprises determining the maximum speed of the compressor (10) by reaching a minimum suction pressure (p_s) at the compressor inlet (11), a speed limit for component protection of the compressor (10), and/or a noise/vibration behavior of the compressor (10).

[Claim 3] The method as claimed in claim 1 or 2, characterized in that the method further comprises, in the heating mode, actuating an air mix door (2) such that an airflow in the HVAC duct (64) from the cabin evaporator (60) is allocated through the cabin condenser (20) or past it, wherein a pressure (p_D) at the compressor outlet (12) and thus heat emission of the compressor (10) to refrigerant is influenced.

[Claim 4] The method as claimed in claim 2 or 3, characterized in that the method further comprises regulating heating power of the electric coolant heater (220) using at least one of the following operating parameters of the heat pump arrangement (1) as a control variable:

a refrigerant pressure (p_D) at the compressor outlet (12),
 a refrigerant superheat (SH_{Cho}) at the refrigerant-side chiller outlet (82),
 a refrigerant superheat (SH_{CPI}) at the compressor inlet (11),
 a refrigerant superheat (SH_{OHXo}) at the outdoor heat exchanger outlet (42),
 an air temperature (T_{alCo}) at the condenser air outlet (20b), and/or
 an air temperature (T_{vent}) at the duct air outlet (64b).

[Claim 5] The method as claimed in claim 4, characterized in that the method further comprises, in the heating mode, limiting the heating power of the electric coolant heater (220) when a coolant temperature (T_{Chi}) at the chiller coolant inlet (80a) and thus a suction pressure (p_s) at the compressor inlet (11) becomes higher than a predetermined threshold to enable heat absorption from the surroundings via the outdoor heat exchanger (40).

[Claim 6] The method as claimed in claim 4 or 5, characterized in that, in the

heating mode, the control variable for regulating the heating power of the electric coolant heater (220) is the refrigerant pressure (pD) at the compressor outlet (12), and in that the control variable for a degree of opening of the chiller expansion valve (70) is the refrigerant superheat (SH_{Cho}) at the refrigerant-side chiller outlet (82) or the refrigerant superheat (SH_{Cpi}) at the compressor inlet (11).

[Claim 7] The method as claimed in claim 4 or 5, characterized in that, in the heating mode, the control variable for regulating the heating power of the electric coolant heater (220) is the refrigerant superheat (SH_{Cho}) at the refrigerant-side chiller outlet (82) or the refrigerant superheat (SH_{Cpi}) at the compressor inlet (11), and in that the control variable for a degree of opening of the chiller expansion valve (70) is the refrigerant pressure (pD) at the compressor outlet (12).

[Claim 8] The method as claimed in claim 1, characterized in that, in the dehumidifying mode, a control variable for regulating heating power of the electric coolant heater (220) is
 a refrigerant pressure (pD) at the compressor outlet (12),
 an air temperature (T_{aCo}) at the condenser air outlet (20b),
 an air temperature (T_{vent}) at the duct air outlet (64b),
 a refrigerant superheat (SH_{Cho}) at the refrigerant-side chiller outlet (82),
 a refrigerant superheat (SH_{Cpi}) of the compressor inlet (11), and/or
 an air temperature (T_{aEo}) at the evaporator air outlet (60b).

[Claim 9] The method as claimed in claim 8, characterized in that the activating includes deactivating the outdoor heat exchanger (40) and activating the electric coolant heater (220) when the compressor (10) has reached a maximum speed or when the refrigerant superheat (SH_{Cho} , SH_{Cpi}) at the refrigerant-side chiller outlet (82) or compressor inlet (11) falls below a predetermined minimum value.

[Claim 10] The method as claimed in claim 9, characterized in that the method comprises regulating a degree of opening of the chiller expansion valve (70) to regulate the air temperature (T_{aEo}) at the evaporator air outlet (60b).

[Claim 11] The method as claimed in claim 8, characterized in that the activating includes activating the outdoor heat exchanger (40) and activating the electric coolant heater (220) when the outdoor heat exchanger expansion valve (30) reaches a predetermined minimum opening value.

[Claim 12] The method as claimed in any one of claims 1 to 11, characterized in that the method comprising preventing icing of the cabin evaporator

- (60) by regulation of heating power of the electric coolant heater (220).
- [Claim 13] The method as claimed in any one of claims 1 to 12, characterized in that, when switching from an operating mode having the outdoor heat exchanger (40) used as a condenser to an operating mode having the outdoor heat exchanger (40) used as an evaporator, the method comprises using the electric coolant heater (220) to keep constant heating power of the cabin and an air temperature at the duct air outlet (64b), which opens into the cabin and to ensure a superheat of refrigerant at the compressor inlet (11).
- [Claim 14] The method as claimed in claim 12, characterized in that the method includes following steps:
- a) opening the chiller expansion valve (70) and activating the electric coolant heater (220);
 - b) closing the outdoor heat exchanger expansion valve (30);
 - c) connecting the refrigerant-side outdoor heat exchanger outlet (42) to the compressor inlet (11) via a bypass line (100) having a controllable bypass shut-off valve (90) by partially opening the controllable bypass shut-off valve (90) to a predetermined degree of opening;
 - d) completely opening the outdoor heat exchanger expansion valve (30) and completely opening the controllable bypass shut-off valve (90) when stable superheat of refrigerant at the compressor inlet (11) is achieved or a pressure in the outdoor heat exchanger (40) has equalized to a suction pressure (p_s) at the compressor inlet (11); and
 - e) closing the chiller expansion valve (70).
- [Claim 15] The method as claimed in any one of claims 1 to 14, characterized in that the method comprises estimating a required heating power of the electric coolant heater (220) by computer and using this value ascertained by computer as an initial target value for regulating the electric coolant heater (220), and adapting the initial target value if heat absorption in the chiller (80) is excessively low or high.
- [Claim 16] The method as claimed in any one of claims 1 to 15, characterized in that the method comprising decoupling the battery coolant circuit (200), the battery (210) and the waste heat absorber (230) from the electric coolant heater (220) and providing a coolant circuit having the chiller (80), a coolant pump (240), the electric coolant heater (220).
- [Claim 17] A thermal management system for electric vehicles, the thermal management system comprising a battery (210), an electric coolant

heater (220), a heat pump arrangement (1), and a controller (400), wherein the heat pump arrangement (1) comprises

- a compressor (10) having a compressor inlet (11) and a compressor outlet (12),
- a cabin condenser (20) having a refrigerant-side condenser inlet (21) and a refrigerant-side condenser outlet (22),
- an outdoor heat exchanger (40) having a refrigerant-side outdoor heat exchanger inlet (41) and a refrigerant-side outdoor heat exchanger outlet (42),
- an outdoor heater expansion valve (30) connected to the outdoor heat exchanger inlet (41),
- a chiller (80) having a refrigerant-side chiller inlet (81) and a refrigerant-side chiller outlet (82),
- a chiller expansion valve (70) connected to the refrigerant-side chiller inlet (81),
- a cabin evaporator (60) having an evaporator inlet (61) and an evaporator outlet (62),
- a cabin evaporator expansion valve (50) connected to the evaporator inlet, and
- a refrigerant bypass line (100) between the outdoor heat exchanger outlet (42) and the compressor inlet (11), which is blockable via a bypass shut-off valve (90),

wherein the cabin condenser (20) and the cabin evaporator (60) are arranged in an HVAC duct (64) for air as a coolant,

wherein the HVAC duct (64) includes a duct air inlet (64a) and a duct air outlet (64b),

wherein the cabin condenser (20) includes a condenser air inlet (20a) and a condenser air outlet (20b),

wherein the cabin evaporator (60) includes an evaporator air inlet (60a) and an evaporator air outlet (60b),

wherein the chiller (80) comprises a chiller coolant inlet (80a) and a chiller coolant outlet (80b),

wherein the electric coolant heater (220) is incorporated in a battery coolant circuit (200) between the battery (210), a waste heat absorber (230) for decoupling waste heat from the electric vehicle, and the chiller (80), and

wherein the controller (400) is designed for various operating modes, which comprise heating, cooling, and dehumidifying cabin air blown

into a vehicle cabin, characterized in that the controller (400) is designed to activate the electric coolant heater (220) only when predetermined operating parameters of the thermal management system are met, which are defined in dependence on the respective operating modes.

[Claim 18] The thermal management system as claimed in claim 17, characterized in that the controller (400) is designed to activate the electric coolant heater (220) only when the compressor (10) has reached its maximum speed.

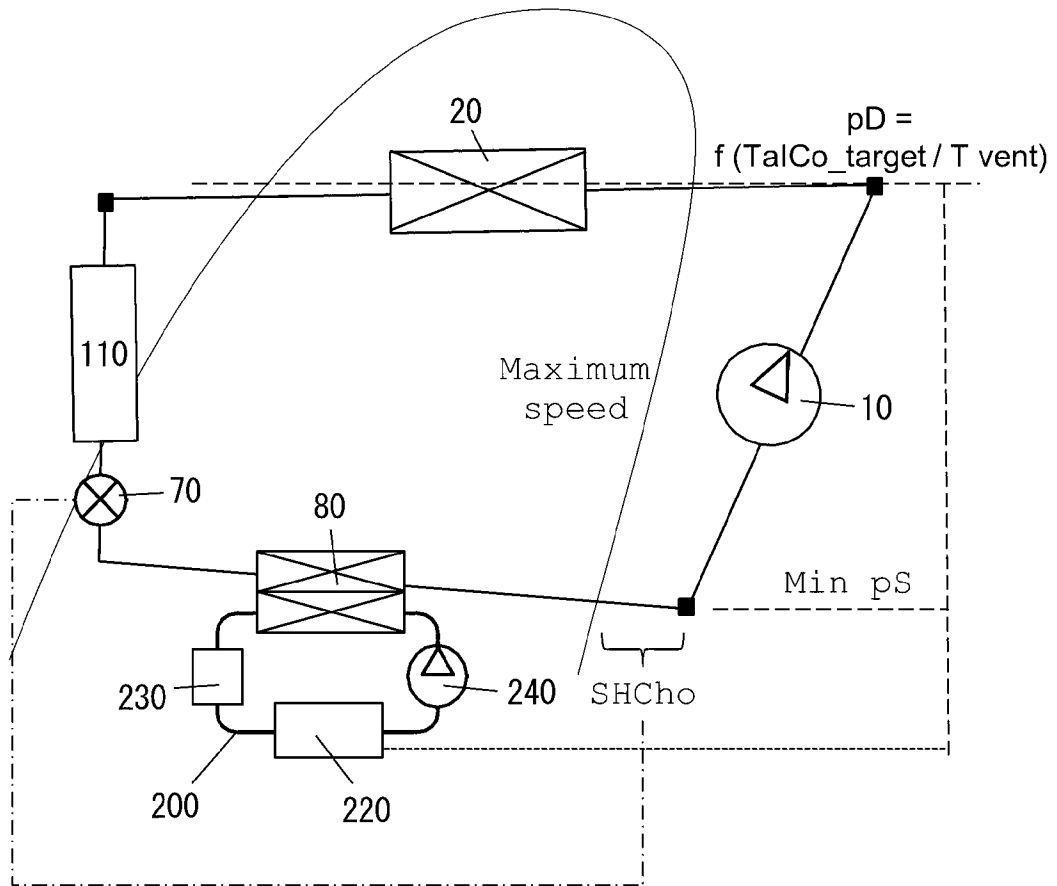
[Claim 19] The thermal management system as claimed in claim 17, characterized in that the controller (400) is designed to regulate heating power of the electric coolant heater (220) using at least one of the following operating parameters of the heat pump arrangement (1) as a control variable:

a refrigerant pressure (p_D) at the compressor outlet (12),
a refrigerant superheat (SH_{Cho}) at the refrigerant-side chiller outlet (82),
a refrigerant superheat (SH_{Cpi}) at the compressor inlet (11),
a refrigerant superheat (SH_{OHxo}) at the outdoor heat exchanger outlet (42),
an air temperature (T_{alCo}) at the condenser air outlet (20b), and/or
an air temperature (T_{vent}) at the duct air outlet (64b).

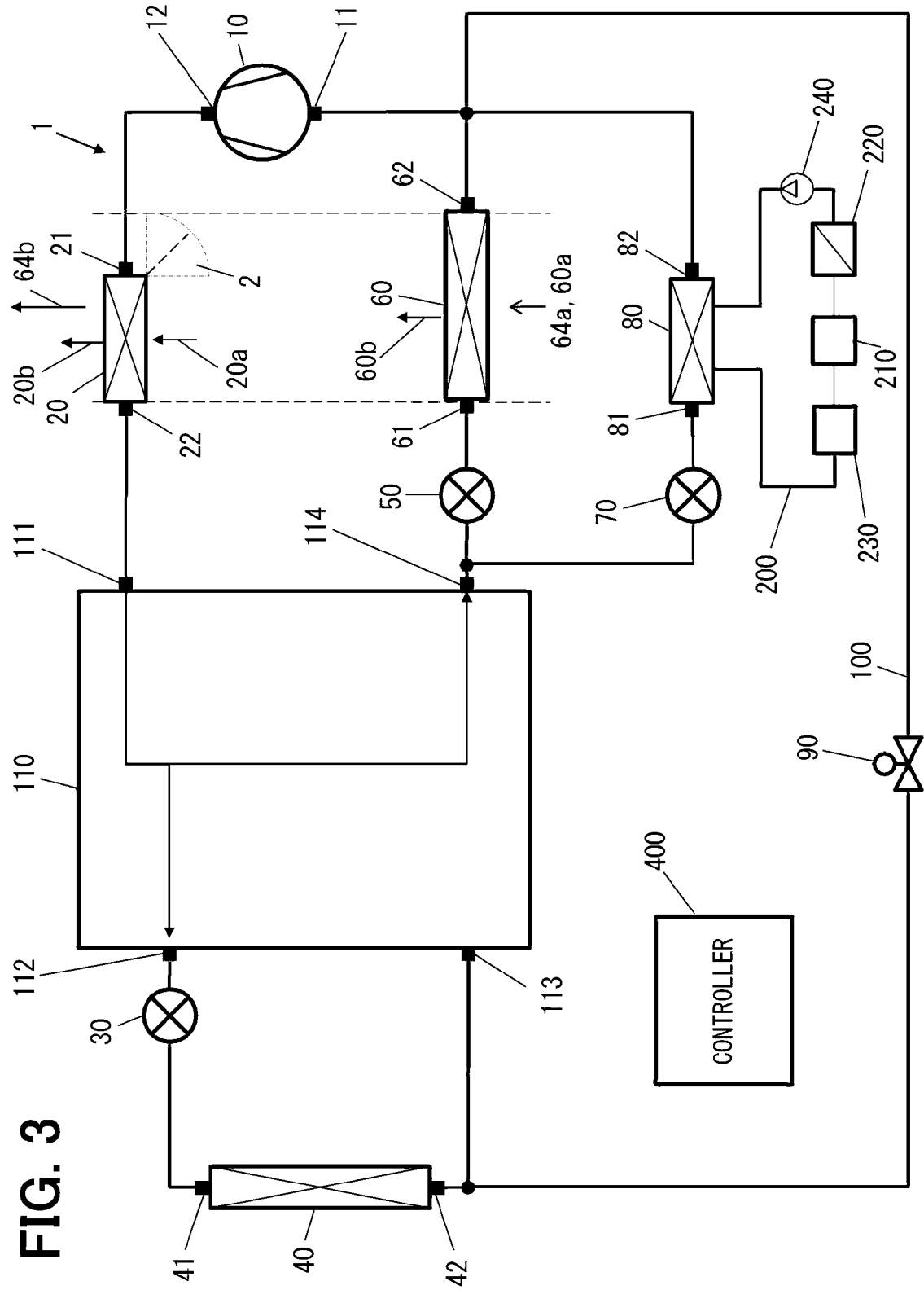
[Claim 20] The thermal management system as claimed in any one of claims 17 to 19, characterized in that the battery coolant circuit (200) includes a coolant bypass (250) having a valve setup (260) between the chiller coolant outlet (80b) and a point in the battery coolant circuit (200) between the electric coolant heater (220) and the battery (210).

[Fig. 2]

FIG. 2



[Fig. 3]



[Fig. 4]

FIG. 4

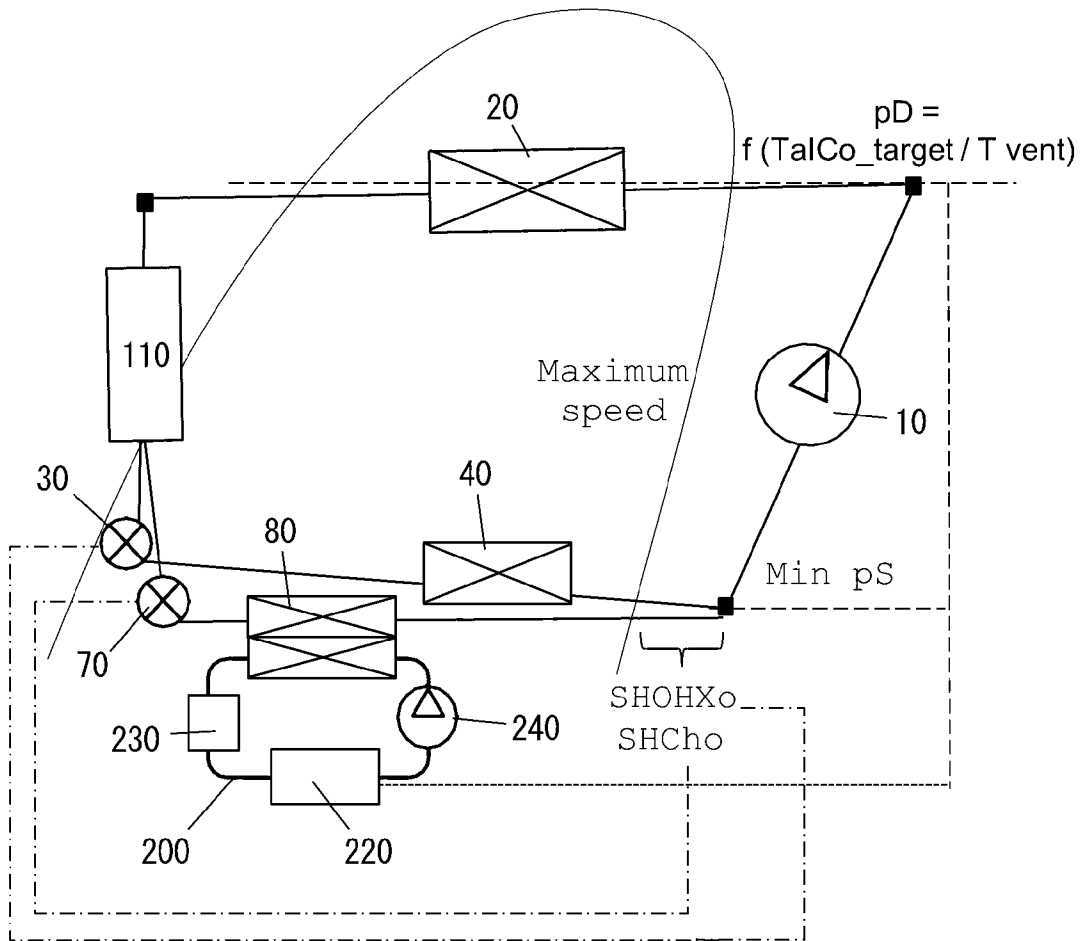
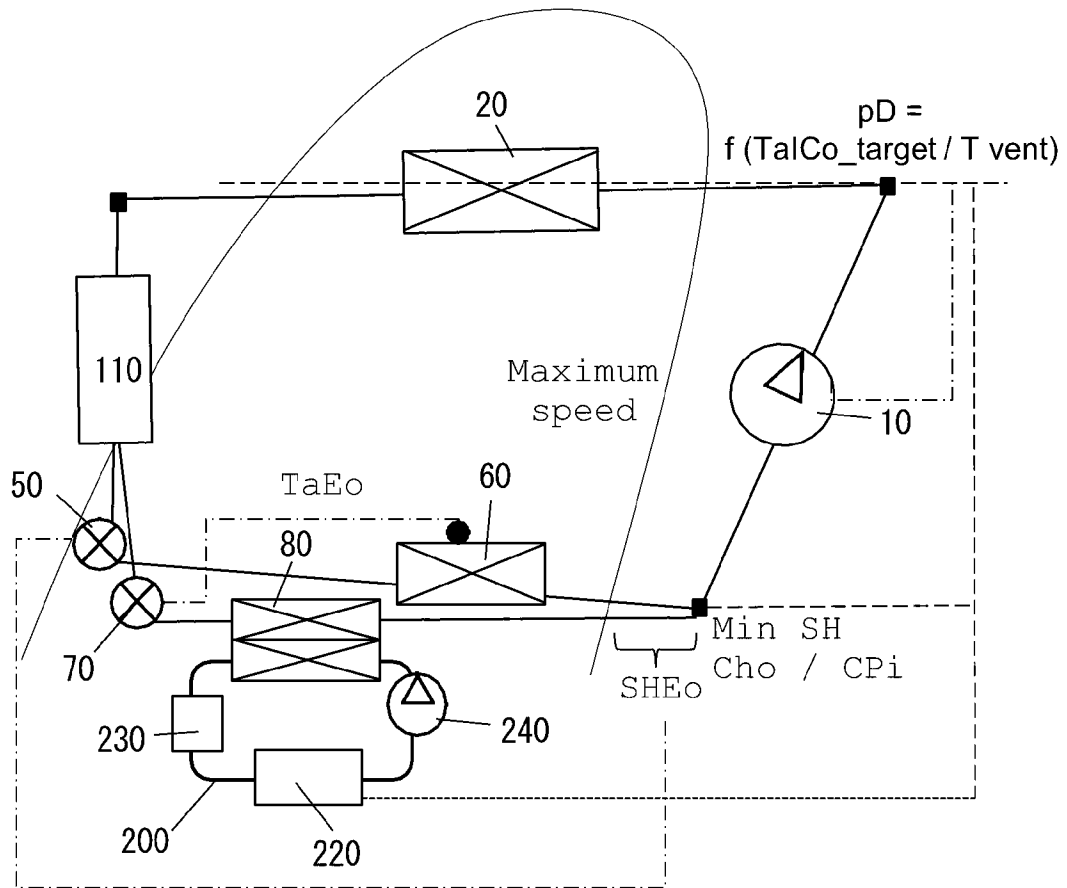
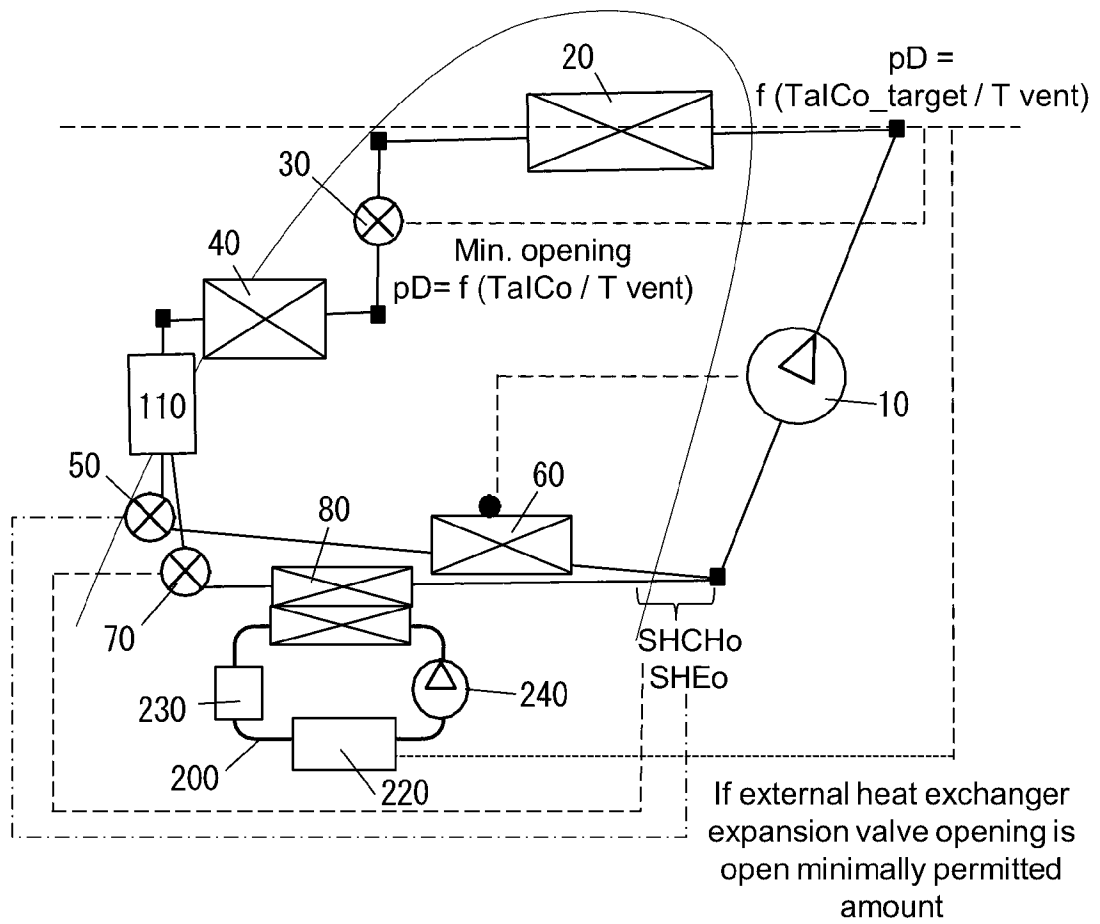


FIG. 5

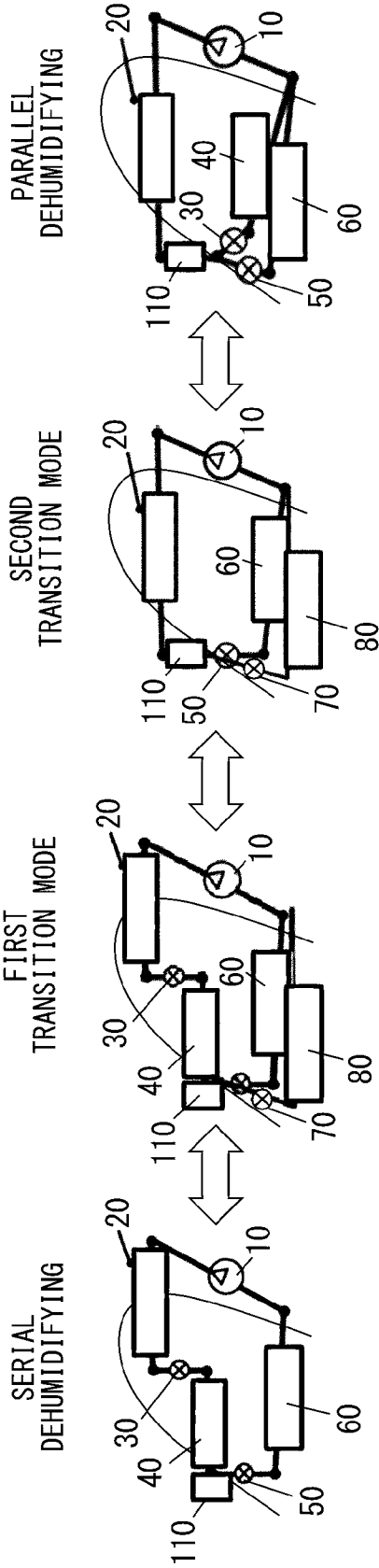


[Fig. 7]

FIG. 7

[Fig. 8]

FIG. 8



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2023/024559

A. CLASSIFICATION OF SUBJECT MATTER**B60H 1/22**(2006.01)i; **F25B 1/00**(2006.01)i

FI: B60H1/22 611Z; B60H1/22 651A; F25B1/00 361A; F25B1/00 399Y

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)

B60H1/22; F25B1/00

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

Published examined utility model applications of Japan 1922-1996
 Published unexamined utility model applications of Japan 1971-2023
 Registered utility model specifications of Japan 1996-2023
 Published registered utility model applications of Japan 1994-2023

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	US 2020/0047583 A1 (SANDEN AUTOMOTIVE CLIMATE SYSTEMS CORPORATION) 13 February 2020 (2020-02-13) paragraphs [0001]-[0151], fig. 1	1-7, 16-20
A		8-15
Y	US 2022/0010186 A1 (DENSO CORPORATION) 13 January 2022 (2022-01-13) paragraphs [0034]-[0074], fig. 1	1-7, 16-20
Y	JP 2018-12463 A (DENSO CORPORATION) 25 January 2018 (2018-01-25) paragraph [0138]	2-7, 16
Y	JP 7053906 B1 (MARELLI CORPORATION) 12 April 2022 (2022-04-12) paragraphs [0130]-[0135], [0140], fig. 10	16, 20

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

* Special categories of cited documents:

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 “Y” document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
 “&” document member of the same patent family

Date of the actual completion of the international search

29 August 2023

Date of mailing of the international search report

12 September 2023

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/JP2023/024559

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
US	2020/0047583	A1	13 February 2020	JP 2021-121542 A paragraphs [0001]-[0095], fig. 1 CN 110536808 A	
US	2022/0010186	A1	13 January 2022	WO 2020/196509 A1 paragraphs [0024]-[0065], fig. 1 CN 113748504 A	
JP	2018-12463	A	25 January 2018	(Family: none)	
JP	7053906	B1	12 April 2022	(Family: none)	