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(54) REFRIGERATION APPARATUS AND OPERATING METHOD THEREOF

(57) There is disclosed a refrigeration apparatus comprising a refrigerant circuit, the refrigerant circuit comprising a compressor comprising a compressor fan and a motor to drive the compressor fan; a condensing device disposed downstream of the compressor, the condensing device comprising a condenser and a sub-cooler; an expansion valve disposed downstream of the condensing device; an evaporator disposed between the expansion valve and the compressor; and a main refrigerant line fluidically connecting, in a loop in series: the compressor, condensing device, expansion valve and evaporator. A motor cooling line comprising a motor cooling valve fluidically connects the sub-cooler to the motor to tap refrigerant from the main refrigerant line to cool the motor and is further connected to the main refrigerant line at a return point which is upstream of the compressor fan to return refrigerant to the main refrigerant line at the compressor fan. A bypass line fluidically connects an outlet of the condenser to the expansion valve to bypass the sub-cooler, wherein the bypass line comprises a bypass valve to selectively permit refrigerant in the main refrigerant line to bypass the sub-cooler.

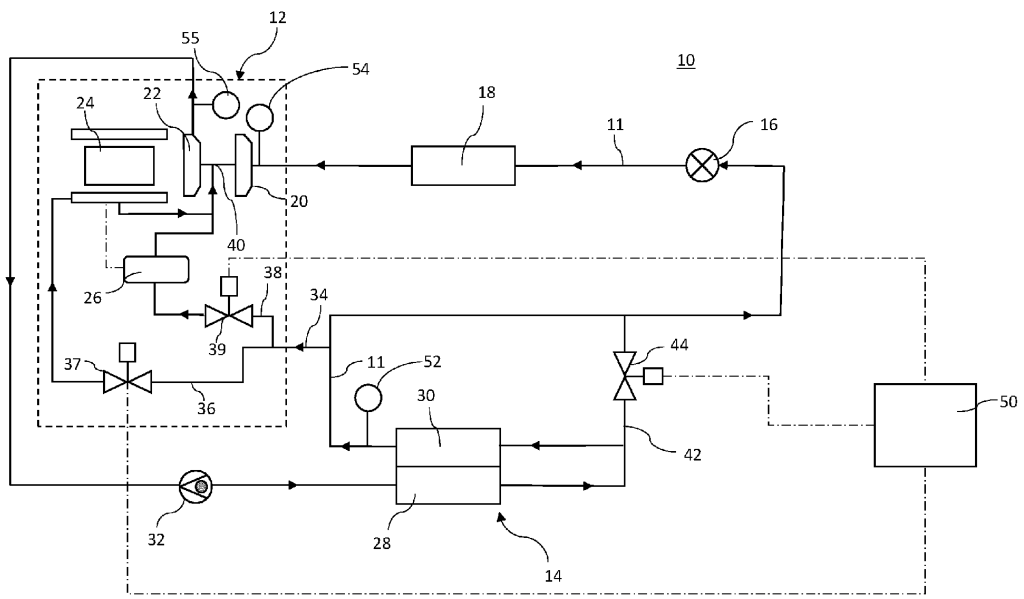

Figure 1

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Description

Field of Invention

[0001] The present invention relates to a refrigerant apparatus and a method of operating a refrigeration apparatus.

Background

[0002] Refrigeration units typically comprise a compressor, a condenser, an expansion valve and an evaporator connected in series through which refrigerant flows. Ambient air flows over the condenser to cool pressurised refrigerant in the condenser, and air or water to be cooled flows over the evaporator to transfer heat to the refrigerant in the evaporator, to thereby cool the air.

[0003] Components of the compressor get hot during use, and requiring cooling. Refrigerant from the condenser may be passively driven to the compressor and used to cool the components of the compressor. However, it is possible under certain conditions for the amount of refrigerant directed to the compressor to be insufficient to cool the components of the compressor. Previously considered methods of operating a refrigeration unit have relied on moving away from the most efficient operation in order to overcome this problem.

Summary of Invention

[0004] According to a first aspect, there is provided a refrigeration apparatus comprising a refrigerant circuit, the refrigerant circuit comprising: a compressor comprising a compressor fan and a motor to drive the compressor fan; a condensing device disposed downstream of the compressor, the condensing device comprising a condenser and a sub-cooler; an expansion valve disposed downstream of the condensing device; an evaporator disposed between the expansion valve and the compressor; a main refrigerant line fluidically connecting, in a loop in series: the compressor, condensing device, expansion valve and evaporator; and a motor cooling line comprising a motor cooling valve, the motor cooling line fluidically connecting the sub-cooler to the motor to tap refrigerant from the main refrigerant line to cool the motor, wherein the motor cooling line is further connected to the main refrigerant line at a return point which is upstream of the compressor fan to return refrigerant to the main refrigerant line at the compressor fan; wherein the refrigerant circuit further comprises a bypass line fluidically connecting an outlet of the condenser to the expansion valve to bypass the sub-cooler, wherein the bypass line comprises a bypass valve to selectively permit refrigerant in the main refrigerant line to bypass the sub-cooler.

[0005] The compressor may comprise an inverter. The sub-cooler may be connected to the inverter by an inverter cooling line comprising an inverter cooling valve, and wherein the inverter cooling line may be further connected to the main refrigerant line at the return point to direct refrigerant from the inverter to the main refrigerant line at the compressor fan.

[0006] The refrigeration apparatus may comprise a controller. The controller may be configured to control opening and closing of the bypass valve. The controller may be configured to control opening and closing of the inverter cooling valve. The controller may be configured to control opening and closing of the motor cooling valve. There may be an additional controller which is integral with the compressor, and which is configured to control the operation of the motor and the inverter, and to control opening and closing of the motor cooling valve, the inverter cooling valve, and/or the expansion valve.

[0007] The bypass valve may be a modulating valve. The controller may be configured to control the bypass valve to control the flow rate of refrigerant through the bypass valve.

[0008] The refrigeration apparatus may comprise a first pressure sensor arranged to monitor the pressure of refrigerant exiting the sub-cooler, and a second pressure sensor arranged to monitor the pressure in the main refrigerant line at the return point; wherein the controller is arranged to receive a first pressure parameter from the first pressure sensor, and a second pressure parameter from the second pressure sensor, and to control the bypass valve based on the first pressure parameter and the second pressure parameter.

[0009] The refrigerant apparatus may comprise a first pressure sensor arranged to monitor the pressure of refrigerant exiting the sub-cooler, a second pressure sensor arranged to monitor the pressure in the main refrigerant line an inlet of the compressor, and a third pressure sensor arranged to monitor the pressure in the main refrigerant line at an outlet of the compressor. The controller may be arranged to receive a first pressure parameter from the first pressure sensor, a second pressure parameter from the second pressure sensor, and a third pressure parameter from the third pressure sensor. The controller may be arranged to control the bypass valve based on the first pressure parameter, the second pressure parameter, and the third pressure parameter.

[0010] The compressor may be a two-stage compressor comprising a first stage compressor fan and a second stage compressor fan, and wherein the return point is between a first stage compressor fan and the second stage compressor fan.

[0011] According to a second aspect, there is provided a method of operating a refrigeration apparatus according to any preceding claim, the method comprising: determining whether insufficient refrigerant is being delivered from the sub-cooler to the compressor; and in response to determining that insufficient refrigerant is being delivered from the sub-cooler to the compressor, controlling the bypass valve to increase the flow rate of refrigerant through the bypass valve.

[0012] Increasing the flow of refrigerant through the bypass valve may include opening the bypass valve or incrementally increasing the size of an opening through the bypass valve.

[0013] Determining whether insufficient refrigerant is being delivered to the compressor may include: monitoring a first pressure parameter relating to the pressure of refrigerant in the main refrigerant line at an outlet of the sub-cooler; monitoring a second pressure parameter relating to the pressure in the main refrigerant line at a return point upstream of a compressor fan; and determining whether there is insufficient cooling fluid being delivered to the compressor based on the first pressure parameter and the second pressure parameter.

[0014] The second pressure parameter may relate to the pressure in the main refrigerant line at a return point between a first stage compressor fan and a second stage compressor fan of a two-stage compressor.

[0015] Determining whether there is insufficient refrigerant being delivered to the compressor may include: calculating a difference parameter relating to a difference between the first pressure parameter and the second pressure parameter; comparing the difference parameter to a first threshold; and if the difference parameter is below the first threshold, determining that there is insufficient refrigerant being delivered to the compressor.

[0016] The method may further comprise determining whether there is too much refrigerant being delivered to the compressor. The method may comprise reducing the flow of refrigerant through the bypass valve in response to determining that there is too much refrigerant being delivered to the compressor.

[0017] Reducing the flow of refrigerant through the bypass valve may include closing the bypass valve or incrementally decreasing the size of an opening through the bypass valve.

[0018] Determining whether there is too much refrigerant being delivered to the compressor may comprise: comparing the difference parameter to a second threshold; and if the difference parameter is above the second threshold, determining that there is too much refrigerant being delivered to the compressor.

[0019] The first threshold and the second threshold may be the same.

[0020] The skilled person will appreciate that except where mutually exclusive, a feature or parameter described in relation to any one of the above aspects may be applied to any other aspect. Furthermore, except where mutually exclusive, any feature or parameter described herein may be applied to any aspect and/or combined with any other feature or parameter described herein.

Brief Description of the Drawings

[0021] Embodiments will now be described, by way of example only, with reference to the accompanying Figures, in which:

Figure 1 shows a schematic representation of an example refrigeration apparatus; and

Figures 2 and 3 are flow charts showing steps of an example method of operating a refrigeration apparatus.

Detailed Description

[0022] **Figure 1** shows an example refrigeration apparatus 10 comprising a refrigerant circuit. The refrigeration circuit comprises a compressor 12, a condensing device 14, an expansion valve 16 and an evaporator 18, which are fluidically connected to one another in series and in that order by a main refrigerant line 11, where the evaporator is connected to the compressor 12 to form a circuit.

[0023] The compressor 12 in this example is a two-stage compressor comprising a first stage compressor fan 20 and a second stage compressor fan 22. In other examples, the compressor may have only one stage or the compressor may have more than two stages.

[0024] The compressor 12 comprises a motor 24 which is configured to drive the first stage compressor fan 20 and the second stage compressor fan 22. The motor 24 is connected to an inverter 26 which is configured to control the speed of the motor 24.

[0025] The condensing device 14 is disposed downstream of the compressor 12, and comprises two stages of condensing. In a first stage, the condensing device 14 comprises a condenser 28, and in a second stage, the condensing device 14 comprises a sub-cooler 30. The sub-cooler 30 is disposed downstream of the condenser 28.

[0026] The expansion valve 16 is disposed downstream of the condensing device 14, and the evaporator 18 is disposed between the expansion valve 16 and the compressor 12.

[0027] Between the compressor 12 and the condensing device 14 is disposed a check valve 32, which is configured to ensure that refrigerant flows from the compressor 12 to the condenser 28, and does not allow refrigerant to flow in an opposing direction from the condenser 28 to the compressor 12.

[0028] A cooling line 34 fluidically connects the sub-cooler 30 directly to the compressor 12 to provide sub-cooled refrigerant to the compressor 12 in order to cool the compressor 12. In this example, the cooling line 34 taps sub-cooled refrigerant from the main refrigerant line 11 connecting the sub-cooler 30 to the expansion valve 16, and directs the tapped refrigerant to the compressor 12.

[0029] Within the compressor 12, the cooling line 34 is split into a motor cooling line 36 and an inverter cooling line 38. The motor cooling line 36 fluidically connects the sub-cooler 30 to the motor 24 so that sub-cooled refrigerant is directed to the motor 24 and permitted to expand to cool the motor 24 by heat transfer. The inverter cooling line 38 fluidically connects the sub-cooler 30 to the inverter 26 so that sub-cooled refrigerant is directed to the inverter 26 and permitted to expand to cool the inverter by heat transfer.

[0030] The motor cooling line 36 comprises a motor cooling valve 37 which is configured to control the flow rate of refrigerant through the motor cooling line 36 to the motor 24. The inverter cooling line 38 comprises an inverter cooling valve 39 which is configured to control the flow rate of refrigerant through the inverter cooling line 38 to the inverter 26.

[0031] The motor cooling line 36 and the inverter cooling line 38 are further connected to the main refrigerant line 11 at a return point 40 in between the first stage compressor fan 20 and the second stage compressor fan 22, so that the tapped refrigerant in the motor cooling line 36 and the inverter cooling line 38 rejoins the main refrigerant line 11 after being used to cool the motor 24 and the inverter 26 respectively. The maximum possible refrigerant flow through the motor cooling line 36 and the inverter cooling line 38 (i.e. if the motor cooling valve 37 and the inverter cooling valve 39 are fully open) is dependent on the pressure of refrigerant in the main refrigerant line 11 at the return point 40, and the pressure of refrigerant in the main refrigerant line 11 at an outlet of the sub-cooler 30. The pressure at the return point 40 must be lower than the pressure at the outlet of the sub-cooler 30 by at least a threshold amount in order to passively drive the sub-cooled refrigerant through the motor cooling line 36 and the inverter cooling line 38 to the return point 40 (i.e. there must be a sufficiently high pressure differential to drive the refrigerant through the motor cooling line 36 and the inverter cooling line 38).

[0032] The threshold amount may be an absolute threshold, or may be dependent on the load on the compressor 12.

[0033] In an example in which the compressor is a single stage compressor comprising one compressor fan, the motor cooling line and the inverter cooling line may be connected to the main refrigerant line upstream of the compressor fan (i.e. the return point may be upstream of the compressor fan).

[0034] An outlet of the condenser 28 is also fluidically connected to the main refrigerant line 11 upstream of the expansion valve 16 by a bypass line 42. The bypass line 42 is arranged to permit at least some of the refrigerant in the main refrigerant line 11 to bypass the sub-cooler 30, so that some of the refrigerant flows directly from the condenser 28 to the main refrigerant line 11 between the sub-cooler 30 and the expansion valve 16.

[0035] The bypass line 42 comprises a bypass valve 44 which is configured to be selectively opened and closed in order to control flow of the refrigerant through the bypass line 42.

[0036] A controller 50 is connected to the bypass valve 44, the motor cooling valve 37, the inverter cooling valve 39, and the expansion valve 16. The controller 50 is configured to selectively open and close the valves to control the flow of refrigerant through the refrigerant circuit. In some examples, there may be an additional controller which is integral with the compressor, and which is configured to control the motor cooling valve, and the inverter cooling valve. The controller 50 or the additional controller may also control the operation of the inverter and the compressor in use.

[0037] The bypass valve 44, motor cooling valve 37, inverter cooling valve 39 and expansion valve 16 in this example are modulating valves, such that the controller 50 may vary the size of an opening of each valve to precisely control the flow rate of refrigerant through them. In other examples, these valves may be binary valves, which can be opened and closed selectively, but with no control of the size of the opening, and thus no direct control of the flow rate through them. In some examples, the valves may be any combination of binary and modulating valves.

[0038] The controller 50 in this example is therefore configured to control the bypass valve 44, the motor cooling valve 37, the inverter cooling valve 39 and the expansion valve 16 to precisely control the flow rate of refrigerant through the bypass line 42, the motor cooling line 36, the inverter cooling line 38 and the main refrigerant line 11 in use.

[0039] In this example, the refrigeration apparatus 10 also comprises a first pressure sensor 52 arranged to monitor the pressure of refrigerant in the main refrigerant line 11 at the outlet of the sub-cooler 30. The refrigeration apparatus 10 further comprises a second pressure sensor 54 arranged to monitor the pressure in the main refrigerant line 11 upstream (i.e. at the inlet) of the first compressor fan 20, and a third pressure sensor 55 arranged to monitor the pressure downstream (i.e. at the outlet) of the second compressor fan 22. The pressure of refrigerant at the return point 40 is calculated by the controller 50 based on the pressures monitored by the second pressure sensor 54 and the third pressure sensor 55. The pressure of refrigerant at the return point 40 (p_r) is calculated as the square root of the pressure of refrigerant at the inlet of the first compressor fan 20 (pi) times the pressure of refrigerant at the outlet of the second compressor fan (p_2) (i.e. $p_r = \sqrt{p_1 \times p_2}$).

[0040] In an example in which the compressor is a single stage compressor having one compressor fan, the second pressure sensor may be arranged to monitor the pressure in the main refrigerant line upstream of the compressor fan, and there may not be a third pressure sensor. In other examples, the sensors may be any sensor which can output a parameter which is indicative of the pressure of refrigerant, such as a temperature sensor. In yet other examples, there may be a pressure sensor arranged to monitor the pressure at the return point 40 directly.

[0041] The controller 50 is arranged to monitor a first pressure parameter received from the first pressure sensor 52, relating to the pressure of refrigerant in the main refrigerant line 11 downstream of the sub-cooler 30 or at the cooling line 34. The controller is arranged to monitor a second pressure parameter received from the second pressure sensor 54, relating to the pressure of refrigerant in the main refrigerant line 11 at the return point 40. The controller 50 is configured to control the bypass valve 44 based on the first pressure parameter and the second pressure parameter. This process will be described in more detail with reference to Figures 2 and 3 below.

[0042] The refrigerant apparatus may further comprise a temperature sensor, which is arranged to monitor the temperature of the refrigerant at the outlet of the condenser, the outlet of the sub-cooler and/or downstream of the expansion device.

[0043] The refrigeration apparatus 10 operates under normal conditions with the bypass valve 44 closed, such that all of the refrigerant is passed through the sub-cooler 30. It compresses vaporised refrigerant in the compressor 12 which pressurises the refrigerant, thereby increasing the temperature of the refrigerant. For example, the vaporised refrigerant may enter the compressor at a pressure of approximately 2.7 bar (270 kPa), and a temperature of 6°C, and may leave the compressor at a pressure of approximately 10 bar (1000 kPa), and a temperature of 50°C for an outdoor ambient temperature of 35°C. The pressure at the return point 40 is therefore calculated to be: $p_r = \sqrt{10 \times 2.7} = 5.2$ bar (520 kPa). Refrigerant leaves the compressor 12 in a vapour phase.

[0044] The refrigerant passes through the condensing device 14 in which it passes first through the condenser 28 to condense the refrigerant by heat transfer to ambient air. The refrigerant is discharged from the outlet of the condenser 28 in liquid form. The refrigerant is then passed through the sub-cooler 30 where it is further cooled. There is a pressure loss in the refrigerant across the condenser 28 and the sub-cooler 30 due to large mass flow in small channels. For example, the refrigerant may enter the condenser at 10 bar (1000 kPa) (the same pressure as the refrigerant leaving the compressor 12), and may lose 0.5 bar (50 kPa) of pressure across the condenser 28. The refrigerant may lose a further 1.5 bar (150 kPa) across the sub-cooler 30 such that it leaves the sub-cooler 30 at a pressure of 8 bar (800 kPa) which leaves a pressure differential of 2.8 bar (280 kPa) between the return point 40 and the outlet of the sub-cooler 30, which is sufficient for refrigerant flow through the motor cooling line 36 and the inverter cooling line 38 by opening the respective motor and inverter cooling valves 37 and 39.

[0045] The refrigerant then flows through the expansion valve 16 where it is allowed to expand. This decreases the pressure of the refrigerant, and therefore decreases the temperature further, such that the refrigerant is cooler than the temperature of the water or air to be cooled. For example, the pressure of the refrigerant downstream of the expansion valve 16 may be 2.7 bar (270 kPa), and the temperature of the refrigerant downstream of the expansion valve 16 may be 6°C.

[0046] An opening in the expansion valve 16 may be variable such that the pressure drop, and therefore the temperature drop of the refrigerant across the expansion valve can be varied. The size of the opening may be controlled to ensure that the temperature of the refrigerant exiting the expansion valve 16, and therefore entering the evaporator 18 is maintained constant, such that the refrigeration capacity of the refrigeration apparatus 10 is maintained constant.

[0047] The refrigerant downstream of the expansion valve 16 is then directed to the evaporator 18 where heat is exchanged between air or water to be cooled and the cooled refrigerant. The refrigerant evaporates such that it leaves the evaporator 18 in a vapour phase, and the air is cooled.

[0048] During use, the motor 24 and the inverter 26 are heated, and must be cooled. The controller 50 controls the motor cooling valve 37 and the inverter cooling valve 39 to control the flow of sub-cooled refrigerant to the motor 24 and the inverter 26 respectively.

[0049] Under operating conditions in which the ambient temperature is low (such as 0°C), the flow rate of refrigerant from the sub-cooler 30 to the compressor 12 may be insufficient to cool the motor 24 and the inverter 26, even with the motor cooling valve 37 and the inverter cooling valve 39 fully open. Under such operating conditions, the bypass valve 44 may be opened to enable a larger supply of refrigerant to the compressor, as explained below.

[0050] **Figures 2 and 3** are flow charts showing a method of operating the example refrigeration apparatus 10 to modulate the amount of refrigerant being delivered to the compressor 12 as required. This may be used when the refrigeration apparatus 10 is experiencing abnormal conditions.

[0051] Such conditions may occur, for example, when the ambient temperature is low, such as 10°C. The compressor outlet pressure may be 5.8 bar (580 kPa), the pressure of the refrigerant downstream of the expansion valve 16 may be 2.7 bar (270 kPa) and the refrigerant temperature may be 30°C at the inlet to the compressor. The pressure at the return point 40 would therefore be $\sqrt{5.8 \times 2.7} = 4$ bar (400kPa). With the same pressure drop across condenser 28 and sub-cooler 30 of total of 2 bar (200kPa) the pressure at the outlet of the sub-cooler 30 would be: 5.8 bar - 2 bar = 3.8 bar (380kPa) such that the differential pressure between the return point 40 and the outlet of the sub-cooler 30 will be -0.2 bar (-20kPa). In this case there will be no refrigerant transfer to the motor 24 and inverter 26 for cooling, even if the motor cooling valve 37 and the inverter cooling valve 39 are fully open. Under such circumstances, the low temperature of the ambient air means that there is a large pressure loss across the condenser 28 and the sub-cooler 30, such that the pressure differential between the cooling line 34 and the return point 40 is not large enough to drive enough refrigerant to the motor 24 and the inverter 26, even when the motor cooling valve 37 and the inverter cooling valve 39 are fully open. Therefore, cooling of the motor 24 and the inverter 26 may not be enough, such that these components may overheat, potentially resulting in damage or malfunction. As explained above, the pressure differential between the cooling line 34 and the return point 40 can be increased by opening the bypass valve 44. This allows refrigerant to bypass the sub-cooler 30 so that there is a smaller pressure drop between the outlet of the condenser 28 and the cooling line 34.

[0052] Figure 2 shows a method 200 of operating the refrigeration apparatus 10 to overcome such conditions.

[0053] In step 202, the method determines whether there is insufficient refrigerant being delivered from the main refrigerant line downstream of the sub-cooler 30 to the compressor 12 (e.g. insufficient to cool the motor 24 and the inverter 26).

[0054] If it is determined that there is insufficient refrigerant being delivered to the compressor 12, the method proceeds to step 204 in which the bypass valve 44 is controlled to open to increase the flow rate of refrigerant through the bypass valve 44. Increasing the flow of refrigerant through the bypass valve 44 decreases the flow of refrigerant through the sub-cooler 30, such that the pressure of the refrigerant in the main refrigerant line 11 between the sub-cooler 30 and the expansion valve 16 increases. This is because less of the refrigerant is experiencing a pressure loss across the sub-cooler 30.

[0055] Increasing the pressure of the refrigerant in the main refrigerant line 11 at the cooling line 34 means that the pressure differential between the cooling line 34 and the return point 40 increases, so that more refrigerant is driven through the motor cooling line 36 and the inverter cooling line 38.

[0056] In this example, the bypass valve 44 is a modulating valve and in step 204 the bypass valve 44 is incrementally opened, and the method returns to step 202 to determine whether there is still insufficient refrigerant being delivered to the compressor 12. This generates a negative feedback loop. In other examples, the bypass valve may be controlled to open by a specific amount dependent on the degree of insufficient supply of refrigerant to the compressor 12.

[0057] If there is sufficient refrigerant being supplied to the compressor 12, then the method determines whether there is too much refrigerant being delivered to the compressor in step 206. If there is not too much refrigerant being delivered, and the refrigerant delivered is not insufficient, then the level of refrigerant being delivered is at a desired set-point. The method then proceeds to step 208 in which no changes are made to the bypass valve 44, and the method returns to step 202.

[0058] If it is determined that there is too much refrigerant being delivered to the compressor 12, the method proceeds to step 210 to decrease the flow rate of refrigerant through the bypass valve 44 (e.g. by reducing the size of an opening in the bypass valve 44, or by closing the bypass valve 44). If the bypass valve 44 is already closed, the refrigeration apparatus 10 can return to normal operation, in which the bypass valve 44 is closed. The method then returns to step 202.

[0059] **Figure 3** shows an example method, in detail, of determining whether there is insufficient, too much or just enough refrigerant being delivered to the compressor 12. This is determined by monitoring the pressure differential from the cooling line 34 to the return point 40. The pressure differential will ideally fall within a set-range or at a set-point, where it will be determined that there is just enough refrigerant being delivered to the compressor 12. The set-range may be an absolute range of acceptable pressure differentials, or it may vary and be calculated based on the loading on the compressor 12.

[0060] In the method described below, the controller 50 is configured to maintain the pressure differential within a set-range which is defined between a lower threshold and an upper threshold.

[0061] In an example in which the threshold is dependent on the load on the compressor 12, the controller 50 may determine the thresholds in real time by monitoring the compressor loading and looking up a corresponding thresholds from a look-up table. In other examples, the thresholds may be calculated using a formula based on the compressor loading. For example the minimum threshold pressure at 30% compressor loading may be 0.2 bar (20kPa) while at 100% compressor load it could be as much as 1 bar (100kPa) times more.

[0062] In step 220, the method includes monitoring a first pressure parameter relating to the pressure of refrigerant in the main refrigerant line 11 at the outlet of the sub-cooler 30. This may be monitored with the first pressure sensor 52.

[0063] In step 222, the method includes monitoring a second pressure parameter relating to the pressure of refrigerant in the main refrigerant line 11 at the return point 40 (i.e. between the first stage compressor fan 20 and the second stage compressor fan 22). This may be monitored with the second pressure sensor 54. In an example where the compressor is a single stage compressor having only one compressor fan, the second pressure parameter may relate to the pressure of refrigerant in the main refrigerant line upstream of the compressor fan.

[0064] The method determines whether there is insufficient, just enough, or too much refrigerant being delivered to the compressor 12 in steps 224-234, based on the first pressure parameter and the second pressure parameter.

[0065] In step 224, the method includes calculating a difference parameter relating to the difference between the first pressure parameter and the second pressure parameter. This will indicate the pressure differential of refrigerant between the outlet of the sub-cooler 30 (i.e. the cooling line 34) and the return point 40 of the compressor.

[0066] In step 226, the difference parameter is compared to the lower threshold, and it is determined whether the difference parameter is below the lower threshold. If the difference parameter is below the lower threshold, then it is determined in step 228 that the pressure differential between the sub-cooler 30 and the return point 40 is not high enough, such that there is insufficient refrigerant being delivered to the compressor 12 to cool it. If the difference parameter is not below the lower threshold (i.e. it is above the lower threshold), the method proceeds to step 230.

[0067] In step 230, the difference parameter is compared to the second, upper threshold, and it is determined whether the difference parameter is above the upper threshold. If the difference parameter is above the upper threshold, it is determined in step 232 that there is too much refrigerant being delivered to the compressor 12. If the difference parameter is below or equal to the upper threshold, the difference parameter must be within the set-range, such that it is determined in step 234 that there is just enough refrigerant being delivered to the compressor 12.

[0068] In an example in which the ideal pressure differential is a set-point rather than a set-range, the upper threshold and the lower threshold may be the same, such that it is only determined that there is enough refrigerant being delivered to the compressor when the difference parameter is equal to the threshold or set-point. In such an example, if the difference parameter is above the threshold, it is determined that there is too much refrigerant being delivered to the compressor, and if the difference parameter is below the threshold, it is determined that there is not enough refrigerant being delivered to the compressor.

[0069] In this example, the controller 50 implementing the method controls the bypass valve 44 to incrementally increase or decrease a flow rate through the bypass valve 44, in a negative feedback loop so that the cooling of the compressor 12 is maintained at the desired point.

[0070] Although it has been described that determining whether there is insufficient or too much refrigerant delivered to the compressor is based on the monitored pressure at the outlet of the sub-cooler 30 and the return point 40, this could be determined by other means, such as by monitoring the flow rate of fluid through the cooling line, the motor cooling line and/or the inverter cooling line, or by monitoring the temperature of the motor 24 and the inverter 26 to infer that there is insufficient refrigerant if the motor temperature is raised above a threshold.

[0071] It will be understood that the invention is not limited to the embodiments above-described and various modifications and improvements can be made without departing from the concepts described herein. Except where mutually exclusive, any of the features may be employed separately or in combination with any other features and the disclosure extends to and includes all combinations and sub-combinations of one or more features described herein.

Claims

1. A refrigeration apparatus comprising a refrigerant circuit, the refrigerant circuit comprising:

a compressor comprising a compressor fan and a motor to drive the compressor fan;
a condensing device disposed downstream of the compressor, the condensing device comprising a condenser and a sub-cooler;
an expansion valve disposed downstream of the condensing device;
an evaporator disposed between the expansion valve and the compressor;
a main refrigerant line fluidically connecting, in a loop in series: the compressor, condensing device, expansion valve and evaporator; and
a motor cooling line comprising a motor cooling valve, the motor cooling line fluidically connecting the sub-cooler to the motor to tap refrigerant from the main refrigerant line to cool the motor, wherein the motor cooling line is further connected to the main refrigerant line at a return point which is upstream of the compressor fan to return refrigerant to the main refrigerant line at the compressor fan;
wherein the refrigerant circuit further comprises a bypass line fluidically connecting an outlet of the condenser to the expansion valve to bypass the sub-cooler, wherein the bypass line comprises a bypass valve to selectively permit refrigerant in the main refrigerant line to bypass the sub-cooler.

2. A refrigeration apparatus according to any preceding claim, wherein the compressor comprises an inverter, and wherein the sub-cooler is connected to the inverter by an inverter cooling line comprising an inverter cooling valve, and wherein the inverter cooling line is further connected to the main refrigerant line at the return point to direct refrigerant from the inverter to the main refrigerant line at the compressor fan.

3. A refrigeration apparatus according to claim 1 or 2, comprising a controller configured to control opening and closing of the bypass valve.

4. A refrigeration apparatus according to claim 2 and 3 wherein the controller is configured to control opening and closing of the inverter cooling valve.

5. A refrigeration apparatus according to claim 3 or 4, wherein the bypass valve is a modulating valve, and wherein the controller is configured to control the bypass valve to control the flow rate of refrigerant through the bypass valve.

6. A refrigeration apparatus according to any of claims 3-5, comprising a first pressure sensor arranged to monitor the pressure of refrigerant exiting the sub-cooler, and a second pressure sensor arranged to monitor the pressure in the main refrigerant line at the return point;
wherein the controller is arranged to receive a first pressure parameter from the first pressure sensor, and a second pressure parameter from the second pressure sensor, and to control the bypass valve based on the first pressure parameter and the second pressure parameter.

7. A refrigeration apparatus according to claims 3-5, comprising a first pressure sensor arranged to monitor the pressure of refrigerant exiting the sub-cooler, a second pressure sensor arranged to monitor the pressure in the main refrigerant line an inlet of the compressor, and a third pressure sensor arranged to monitor the pressure in the main refrigerant line at an outlet of the compressor;
wherein the controller is arranged to receive a first pressure parameter from the first pressure sensor, a second pressure parameter from the second pressure sensor, and a third pressure parameter from the third pressure sensor, and wherein the controller is arranged to control the bypass valve based on the first pressure parameter, the second pressure parameter, and the third pressure parameter.

8. A refrigeration apparatus according to any preceding claim, wherein the compressor is a two-stage compressor comprising a first stage compressor fan and a second stage compressor fan, and wherein the return point is between a first stage compressor fan and the second stage compressor fan.

9. A refrigeration apparatus according to any of claims 3-8, wherein the controller is configured to control opening and closing of the motor cooling valve.

10. A method of operating a refrigeration apparatus according to any preceding claim, the method comprising:

determining whether insufficient refrigerant is being delivered from the sub-cooler to the compressor; and
in response to determining that insufficient refrigerant is being delivered from the sub-cooler to the compressor, controlling the bypass valve to increase the flow rate of refrigerant through the bypass valve.

11. A method according to claim 10, wherein determining whether insufficient refrigerant is being delivered to the compressor includes:

monitoring a first pressure parameter relating to the pressure of refrigerant in the main refrigerant line at an outlet of the sub-cooler;
monitoring a second pressure parameter relating to the pressure in the main refrigerant line at a return point upstream of a compressor fan; and
determining whether there is insufficient cooling fluid being delivered to the compressor based on the first pressure parameter and the second pressure parameter.

12. A method according to claim 11, wherein the second pressure parameter relates to the pressure in the main refrigerant line at a return point between a first stage compressor fan and a second stage compressor fan of a two-stage compressor.

13. A method according to claim 11 or 12, wherein determining whether there is insufficient refrigerant being delivered to the compressor includes:

calculating a difference parameter relating to a difference between the first pressure parameter and the second pressure parameter;
comparing the difference parameter to a first threshold; and
if the difference parameter is below the first threshold, determining that there is insufficient refrigerant being delivered to the compressor.

14. A method according to any of claims 10-13, wherein the method further comprises determining whether there is too much refrigerant being delivered to the compressor, and in response to determining that there is too much refrigerant being delivered to the compressor, reducing the flow of refrigerant through the bypass valve.

15. A method according to claim 14, wherein determining whether there is too much refrigerant being delivered to the compressor comprises:

comparing the difference parameter to a second threshold; and
if the difference parameter is above the second threshold, determining that there is too much refrigerant being delivered to the compressor.

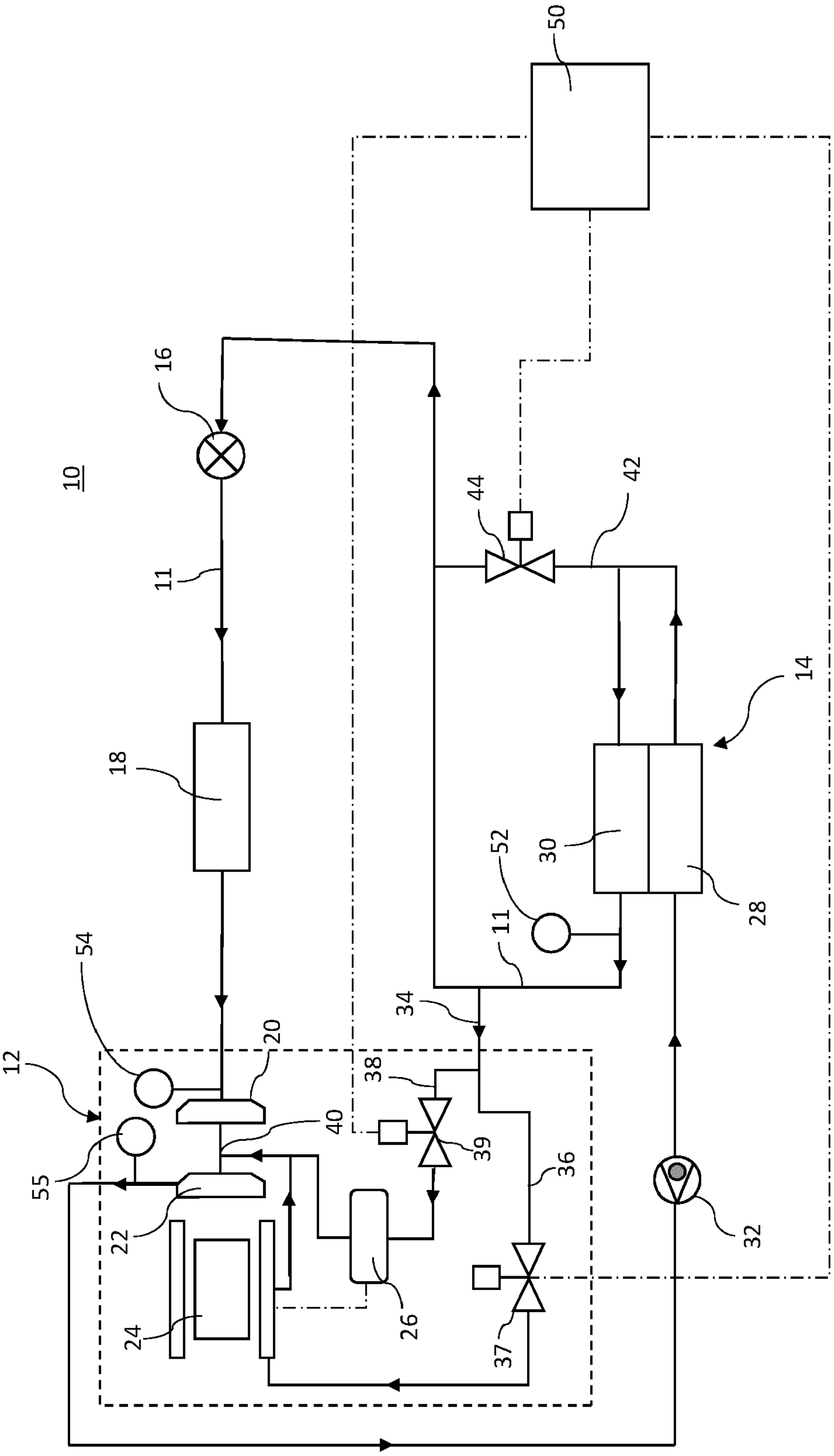
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Figure 1

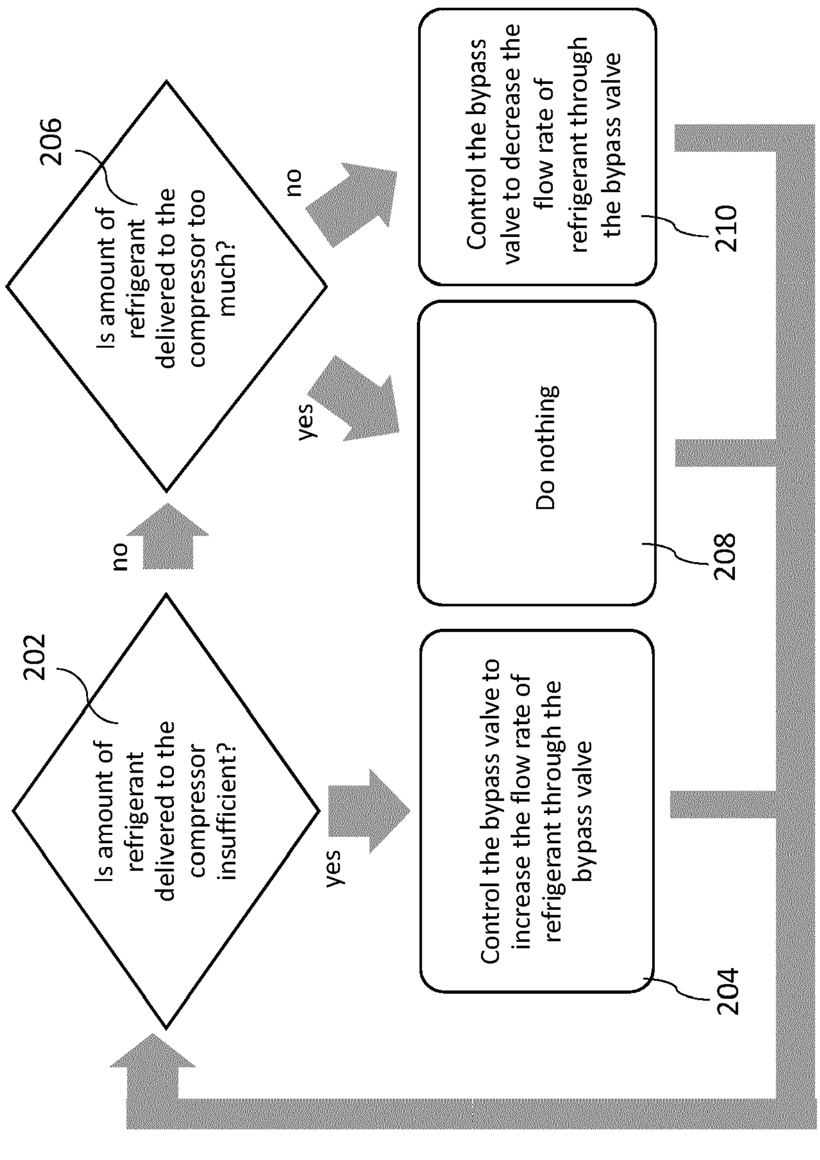
202
Is amount of refrigerant delivered to the compressor insufficient?
yes
no
Control the bypass valve to increase the flow rate of refrigerant through the bypass valve
204
206
Is amount of refrigerant delivered to the compressor too much?
yes
no
Do nothing
208
Control the bypass valve to decrease the flow rate of refrigerant through the bypass valve
210

Figure 2

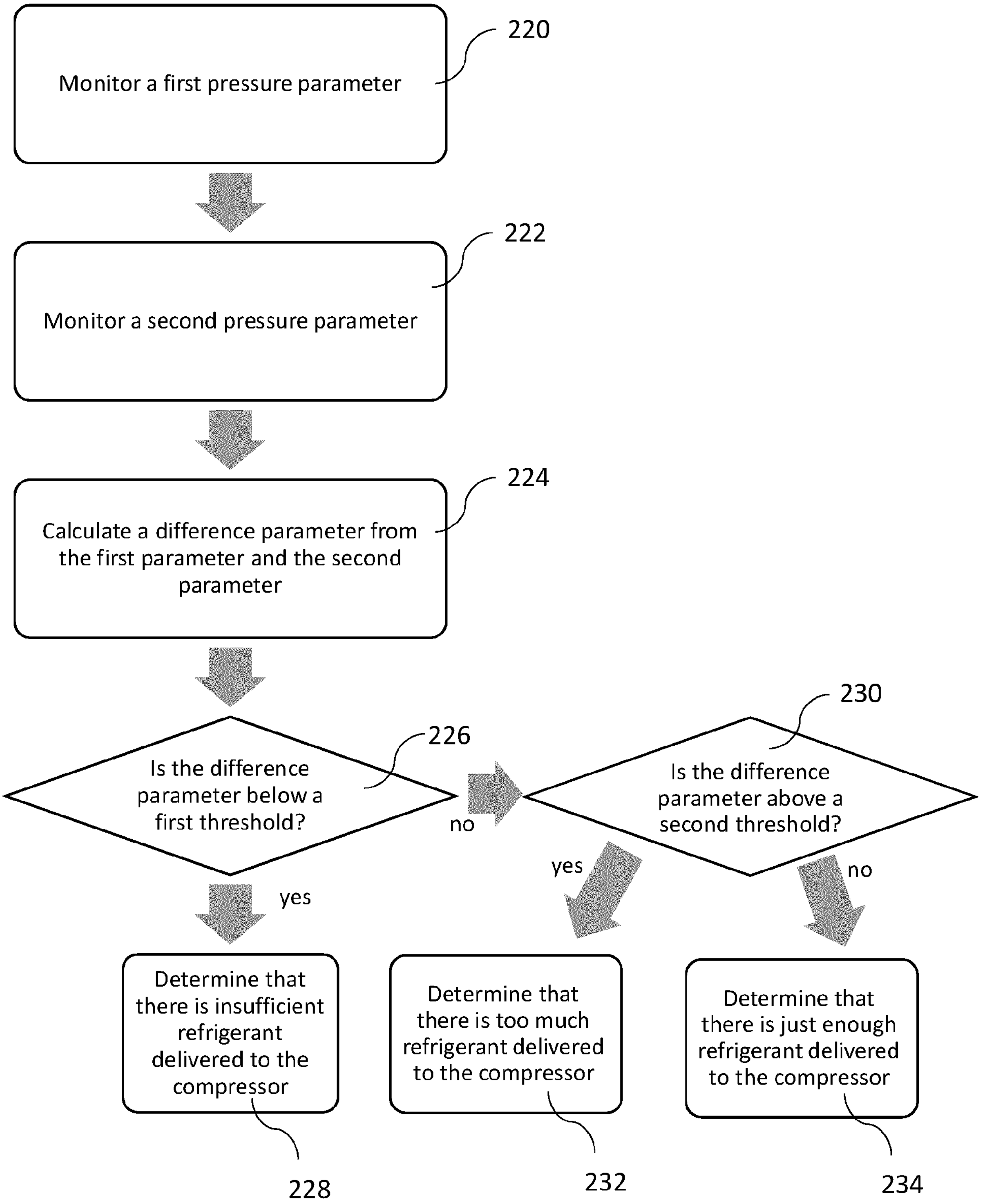
Monitor a first pressure parameter
220
Monitor a second pressure parameter
222
Calculate a difference parameter from the first parameter and the second parameter
224
Is the difference parameter below a first threshold?
226
no
yes
Is the difference parameter above a second threshold?
230
yes
no
Determine that there is insufficient refrigerant delivered to the compressor
228
Determine that there is too much refrigerant delivered to the compressor
232
Determine that there is just enough refrigerant delivered to the compressor
234

Figure 3

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EUROPEAN SEARCH REPORT

Application Number
EP 20 16 2093

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The present search report has been drawn up for all claims

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Place of search	Date of completion of the search	Examiner
Munich	7 September 2020	Lepers, Joachim

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