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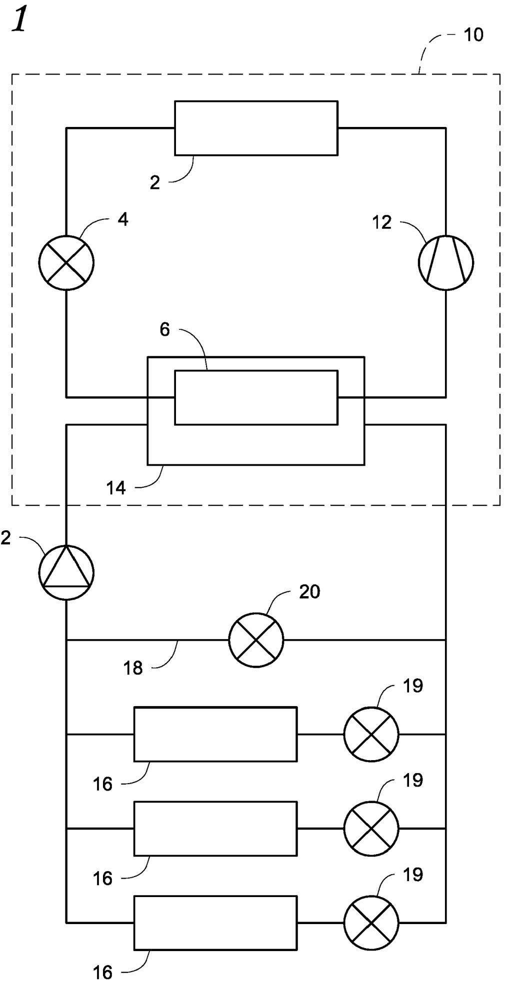
(54) COMPRESSOR CYCLING CONTROL FOR VARIABLE FLOW SYSTEMS

(57) Systems and methods for preventing excessive restarting of compressors (12) in variable primary flow systems operating at low loads, with system embodiments including temperature sensors both upstream and downstream from a heat exchanger (14), using the sensor downstream from the heat exchanger to determine when to stop a compressor and the sensor upstream from the heat exchanger to determine when to start the compressor. Methods may include a delay period between restarting operations of the compressor, or use a soft loading period in which the compressor is operated at a low level to reduce the frequency of starts and stops.

Fig. 1



EP 3 421 904 A1

Description

Field

[0001] This invention relates to control systems and methods of controlling the cycling of chillers and/or heaters in variable flow heating and cooling systems such as variable primary flow systems, decoupled systems, and primary/secondary/tertiary systems.

Background

[0002] Variable flow (VF) systems cycle fluid through heating or cooling systems, varying the flow rate through the cooling coils, compared to constant-flow systems where the entire design flow is directed through cooling coils circuit with the amount required for heating or cooling flowing through the coils while the remainder of the design flow is diverted around the coils through a bypass. At low loads, the pump circulating chilled or heated fluid through the system reduces flow rates, reducing the power required by the pump and circulating less fluid, for example water, through the system.

[0003] In cooling systems, for example when a compressor in a cooler has a minimum threshold load that is greater than the cooling load required by the cooling system, fluid temperature can drop through the circuit conveying the fluid from the chiller to the heat exchangers used in the cooling system as the compressor in the chiller removes more heat from the system than is added in the heat exchangers. The excessive cooling can cause problems, particularly freezing of the fluid. Freezing of the fluid in a heating or cooling system can have catastrophic effects on the system and necessitate significant repairs or replacement.

[0004] Controls in constant flow systems use the leaving fluid temperature from the cooler heat exchanger and differentials from the active setpoint to determine when to cycle the compressor on or off. When these control systems and control methods are applied to VF systems, there can be rapid cycling on and off of the compressor at low loads due to the thermodynamic properties of VF systems and in particular the low flow in VF systems at low loads, which allows the fluid to warm or cool rapidly and thus quickly move between the temperature differentials to start or stop the compressor. This repeated, rapid on-off cycling causes energy inefficiency and excessive system wear, for example compressor wear.

Summary

[0005] Variable flow (VF) systems and compressor controls for variable flow systems that reduce excessive starting and stopping operations during low-load cooling operations. Starting and stopping the compressor may be based on at least one operational parameter of the VF system. In an embodiment, a delay period may be introduced between compressor starting operations. In an embodiment, a soft loading period controls restarting operations by defining a period during which the compressor is operated at a particular capacity. In an embodiment, the one or more temperature measurements used as the operational parameter to determine whether a stopping threshold has been satisfied and the one or more temperature measurements used as the operational parameter to determine when a starting threshold has been satisfied are each taken from different locations within the system.

[0006] Variable flow HVACR system embodiments include a pump, a chiller which includes a heat exchanger and a compressor, one or more sensors measuring one or more operational parameters, for example a first temperature sensor located upstream of a heat exchanger with respect to a fluid flow through the heat exchanger and a second temperature sensor located downstream of the heat exchanger with respect to the fluid flow, a third temperature sensor located downstream of the cooling coils but upstream of the bypass segment with respect to the fluid flow, and/or a fourth temperature sensor located upstream of the cooling coils but downstream of the bypass segment with respect to the fluid flow, a bypass segment, one or more cooling coils, and a controller that determines, based on operational parameters such as temperature readings and other starting conditions such as a delay period and/or a defined soft loading period, when to start and stop the compressor. In an embodiment, the selected delay period and/or the soft loading period may be determined based on the number of restarting operations of the compressor in a preselected time period. In an embodiment, the temperature sensors are located within the chiller or in the VF system.

[0007] Method embodiments controlling the starting and stopping of a compressor in a chiller include measuring one or more operational parameters, for example a first temperature through a first temperature sensor, comparing the first temperature to a starting threshold temperature, determining, based on a starting condition and/or a temperature at the previous stopping of the compressor, a compressor start procedure, and operating the compressor according to the determined compressor start procedure. In an embodiment, the one or more operational parameters further include a second temperature at a second temperature sensor, comparing the second temperature to a stopping threshold, and stopping the compressor when the second temperature is less than the stopping threshold. In an embodiment, the starting condition may comprise a delay period between restarting operations. In an embodiment, the starting condition may comprise a soft loading period which defines a period following the restart during which to operate the compressor at a defined capacity or a controlled rate of loading.

[0008] Control system embodiments for compressors in variable primary flow systems include a controller with a memory storing starting and stopping threshold temperatures and a processor determining, based on the threshold values, readings from one or more sensors measuring one or more operational parameters such as temperature sensors, and starting conditions such as one or more delay periods and/or one or more soft loading periods, whether to start or stop the compressor. In an embodiment, a sensor measuring an operational parameter used to determine satisfaction of a starting threshold may be a temperature sensor located upstream from a heat exchanger of the chiller or downstream from the heating or cooling coils. In an embodiment, a sensor measuring an operational parameter used to determine satisfaction of a stopping threshold may be a temperature sensor located downstream from the heat exchanger. In an embodiment, the memory stores starting conditions governing the starting and stopping of the compressor, such as delay periods setting a minimum time between restarting operations, or soft loading periods which limit the capacity or the rate of loading at which a compressor is operated following a restart.

Drawings

[0009]

Figure 1 is a schematic diagram of an embodiment of an HVACR system.

Figure 2 is a schematic diagram of an embodiment of a variable primary flow (VPF) system.

Figure 3 is a schematic diagram of an embodiment of a primary/secondary (P/S) system

Figure 4 is a flow diagram for a method embodiment controlling a compressor in a VF system.

Figure 5 is a system diagram of a control system embodiment.

Detailed Description

[0010] Heating and cooling systems with variable flow (VF) adjust the flow rates based on system load. At low load, this results in low flow rates. Control logic exists to prevent chiller compressors from violating certain key temperatures, such as preventing water from freezing in chilled-water systems. At low system loads in VF systems, the combination of reduced fluid flow and the control logic for stopping and starting the compressor can result in rapid cycling of the compressor, causing excessive wear and energy inefficiency. The control logic can be enhanced using measurements of water temperature leaving the heat exchanger, and setting starting conditions for the compressor such as determining soft loading for the compressor on startup based on successive compressor cycle events or setting minimum delay periods between cycling the compressor off and then on.

[0011] Figures 1 and 2 show schematics of HVACR system embodiments. Components common between the embodiments are identified with like reference numbers. Figure 1 shows a variable primary flow (VPF) HVACR system. Figure 2 shows a primary/secondary (P/S) HVACR system. In both systems shown in Figures 1 and 2, chiller 10 contains a first fluid circuit which includes compressor 12, condenser 2, expansion device 4 and evaporator 6, and a heat exchanger 14 where the evaporator 6 of the first fluid circuit absorbs heat from the second fluid circuit. The first fluid circuit may be a refrigerant circuit. The first fluid circuit can generally be applied in a variety of systems used to control an environmental condition (e.g., temperature, humidity, air quality, or the like) in a space (generally referred to as a conditioned space), for example in an embodiment to control water temperature leaving chiller 10. Examples of such systems include, but are not limited to, HVACR systems, for example, a water chiller. The second fluid circuit may convey a chilled process fluid, such as water, to terminal units including cooling coils 16. Cooling coils 16 are used at the terminal unit to cool air, heating the process fluid before the process fluid returns to the chiller 10. Flow into each cooling coil 16 may be controlled by coil valves 19. Flow out of the cooling coils 16 and the bypass 18 may be circulated through the system by pump 22. In the embodiment shown in Figure 2, a second pump 15 may be located between where the bypass 18 splits off from the circuit and the coil valves 19 and cooling coils 16.

[0012] The compressor 12, condenser 2, expansion device 4, and evaporator 6 are fluidly connected to form the first fluid circuit. In an embodiment, the first fluid circuit can be configured to be a cooling system (e.g., an HVACR system such as a water chiller) capable of operating in a cooling mode. In an embodiment, the first fluid circuit can be configured to be a heat pump system that can operate in both a cooling mode and a heating/defrost mode.

[0013] The first fluid circuit can operate according to generally known principles. The first fluid circuit can be configured to heat or cool a liquid process fluid (e.g., a heat transfer fluid or medium such as, but not limited to, water, glycol, or the like), in which case the first fluid circuit may be representative of a liquid chiller system. The first fluid circuit can alternatively be configured to heat or cool a gaseous process fluid (e.g., a heat transfer medium or fluid such as, but not limited to, air or the like), in which case the first fluid circuit may be generally representative of an air conditioner or heat pump.

[0014] In operation, the compressor 12 compresses a working fluid (e.g., a heat transfer fluid such as a refrigerant or the like) from a relatively lower pressure gas to a relatively higher-pressure gas. The relatively higher-pressure gas is also at a relatively higher temperature, which is discharged from the compressor 12 and flows through the condenser 2. In an embodiment, the condenser 2 can include a condenser portion and a subcooler portion that are fluidly connected. The working fluid flows through the condenser 2 and rejects heat to a fluid (e.g., air or the like), thereby cooling the working fluid. The cooled working fluid, which is now in a liquid form, flows to the expansion device 4. In an embodiment in which the condenser 2 includes a subcooler portion, the liquid working fluid can flow through the subcooler portion prior to flowing to the expansion device 4. In the subcooler portion, the working fluid may be further subcooled. The expansion device 4 reduces the pressure of the working fluid. As a result, a portion of the working fluid is converted to a gaseous form. The working fluid, which is now in a mixed liquid and gaseous form flows to the evaporator 6. The working fluid flows through the evaporator 6 and absorbs heat from a process fluid (e.g., water, glycol, air, or the like) heating the working fluid, and converting it to a gaseous form and cooling the process fluid in the second fluid circuit. The gaseous working fluid then returns to the compressor 12. The above-described process continues while the refrigerant circuit is operating, for example, in a cooling mode (e.g., while the compressor 12 is enabled).

[0015] Figure 3 is an embodiment of a variable primary flow (VPF) heating and cooling system as an example of the HVACR system embodiment shown in Figure 1. In this system, a chiller 10, which includes a compressor 12 and a heat exchanger 14, removes heat from a process fluid travelling through a cooling circuit which includes one or more cooling coils 16 and a bypass segment 18, with a bypass valve 20. The cooling circuit may be defined by the fluid pathway leaving the heat exchanger 14, traveling through the bypass segment 18 or a cooling coil 16 and returning to the heat exchanger 14. A variable-rate pump 22 drives the process fluid flow through the heat exchanger 14 and the cooling circuit. Sensors may measure operational parameters of the VPF system, for example a first temperature sensor 24, a second temperature sensor 26, a third temperature sensor 30 and/or a fourth temperature sensor 32 may be located along the cooling circuit. The compressor may have a control unit 28 to start and stop the compressor in response to system conditions and to adapt to changes in system load.

[0016] Compressor 12 may be, for example, a centrifugal compressor as shown in Figure 2, a screw compressor or a scroll compressor, which is used in chiller 10 to cool a fluid provided to heat exchanger 14. The chiller 10 may have a particular load, defined by the flow rate of a process fluid, such as water, through the chiller 10 and a differential between the entering temperature and a set point temperature to which the process fluid is cooled in operation of the chiller 10. The set point temperature may be a static constant or a dynamic value. Dynamic values may vary during operations, for example by being computed based on current conditions. In an embodiment, the dynamic value may be determined based on one or more of system load, entering water temperature, outdoor air temperature, or other operating conditions. Compressor 12 and heat exchanger 14 of the chiller 10 control the cooling provided by the chiller 10, as compressor 12 cools a working fluid which absorbs heat from the process fluid in the heat exchanger 14. The compressor 12 has a designed maximum load. The compressor 12 also has a minimum load that must be maintained when keeping the compressor 12 in operation. The minimum load may, in some embodiments, depend on the time since the compressor 12 was last started, with the minimum being higher at or for a period following the starting of the compressor 12. The compressor 12 may be operated at capacities between the minimum load and the maximum load. The minimum load that must be maintained may be expressed as a percentage of the maximum designed load for the compressor, such as 10% or 25% of the maximum load for the compressor 12. The utilization of the compressor 12 at any particular point in time may also be defined by such a percentage. In an embodiment, the compressor 12 may require operation above its minimum load for a period on start-up; the required load and time to maintain that load is based on and known from the particular chiller 10 design used in a given embodiment.

[0017] Control unit 28 is a controller which at least controls the stopping and starting of the compressor 12. The control unit 28 may interface with one or more sensors measuring operational parameters of the chiller 10, such as compressor run times, temperatures within the chiller 10, and operational parameters VF system such as temperatures at different locations within the VF system In an embodiment, the sensors measuring operational parameters may be temperature sensors 24, 26, 30 and 32. Control unit 28 may include a memory storing information relating to temperature set points to determine stopping and starting of the compressor 12. The control unit 28 may additionally control the particular utilization of the compressor 12 based on operational parameters including, for example, temperatures from sensors 24, 26, 30 and/or 32, the required load to maintain desired operating temperatures, and/or constraints on compressor operations such as design limits. In an embodiment, the control unit 28 may set starting conditions for the compressor 12, such as soft loading, during which the compressor 12 operates at a selected capacity or a restricted rate of loading for a predetermined time on start-up, with that selected capacity typically being a low level of capacity, for example the minimum capacity at which the compressor can be operated on startup. The selected capacity or reduced rate of loading may be a static constant or a dynamic value. Dynamic values may vary during operations, for example by being computed based on current conditions. In an embodiment, the dynamic value may be determined based on temperature readings from sensors 24, 26, 30 and/or 32, rates of changes observed in those temperature readings, and/or a number of times compressor 12 has been cycled on and off during a predetermined time period. In an embodiment, the starting condition determined by the compressor control may be a delay period in which the compressor 12 is prevented from restarting, based on a duration of time since the previous stopping or starting operation performed at the compressor 12. The delay period may be a static constant or a dynamic value which is incremented with successive starting operations. For example, the delay period may be selected based on the number of restarts during a selected time period. For example, the delay period may be incremented with each restart and having the delay period value reduce over time, then using the delay period value at a restart operation to set the delay period until another restart operation may be performed for the compressor 12.

[0018] Chiller 10 also includes heat exchanger 14, which uses the working fluid, such as a refrigerant, cooled by compressor 12 to remove heat from the process fluid used in the cooling circuit. The process fluid may be, for example, water. Heat exchanger 14 may be, for example, a shell and tube heat exchanger.

[0019] The cooling circuit includes a bypass segment 18, the flow through which may be controlled by a bypass valve 20. In an embodiment, the bypass segment 18 branches off from the cooling circuit close to the outlet of heat exchanger 14 and joining the rest of the cooling circuit close to the pump 22. In this embodiment, the bypass segment 18 is in parallel with the cooling coils 16 with respect to the cooling circuit, and branches off upstream of the cooling coils 16 with respect to the direction of fluid flow through the cooling circuit. In this embodiment, the bypass segment rejoins the cooling circuit downstream of the cooling coils 16 with respect to the direction of fluid flow. In these embodiments, the bypass segment 18 may be located in the chiller plant along with the chiller 10. In an embodiment, the bypass segment 18 and bypass valve 20 may be located elsewhere within the cooling circuit, with at least some of the cooling coils 16 and their associated valves branching from the cooling circuit upstream of the bypass segment 18 with respect to the direction of fluid flow through the cooling circuit, and joining the cooling circuit downstream of the bypass segment 18 with respect to the direction of fluid flow. This increases the volume of fluid from the bypass segment 18 and fluid heated in the cooling coils 16 that have mixed before the fluid reaches the pump 22 and the inlet to the heat exchanger 14.

[0020] Cooling coils 16 are one or more heat exchangers located along the cooling circuit, which transfer heat from the location to the fluid traveling through the cooling circuit, for example to cool air which is distributed in different locations within a building. The cooling coils 16 may be located, for example, in terminal units in a building HVACR system. The cooling coils 16 may have a valve 19 controlling the flow of fluid through that particular cooling coil. Where there are multiple cooling coils, they may be in parallel with one another in the cooling circuit. As fluid travels through a cooling coil 16, it is heated, leaving the cooling coil at a higher temperature than it entered. When the cooling coils 16 transfer less heat to the process fluid in the cooling circuit than is removed from the process fluid by the chiller 10, the temperature of the process fluid drops below design parameters, which can cause problems such as freezing, which may catastrophically damage the cooling system. In VF systems, the flow through the cooling circuit may be restricted during these low load conditions. The low flow in the VF system at low loads may increase the magnitude of temperature changes for the fluid in the chiller 10 and in the cooling coils 16.

[0021] In an embodiment, pump 22 is located downstream of all cooling coils 16 and the bypass segment 18 and upstream of heat exchanger 14 with respect to the direction of fluid flow in the cooling circuit. In an embodiment, pump 22 may be located downstream of the heat exchanger 14 and upstream from the bypass 18 and cooling coils 16 with respect to the direction of fluid flow in the system. In an embodiment, pump 22 is a variable-output pump which drives fluid flow through the heat exchanger and the cooling circuit. At low cooling system loads, the pump 22 drives a lower flow than it does at higher cooling system loads.

[0022] Operational parameters of the system may be monitored by one or more sensors. In the embodiment shown in Figure 3, the operational parameter is temperature, measured by temperature sensors 24, 26, 30 and/or 32. Temperature sensors 24, 26, 30 and/or 32 may be placed at locations along the cooling circuit, for example the inlet and outlet of the heat exchanger 14 and in the supply and return from the cooling coils 16. The temperature sensors 24, 26, 30 and/or 32 may be connected to the control unit 28 and optionally to other control and monitoring devices for the VF system. Additional sensors measuring one or more operational parameters may additionally be included at the inlet or outlet of the pump 22, or along the cooling circuit following where the bypass segment 18 joins the cooling circuit. The location of at least one of the temperature sensors may be based on where the bypass segment 18 joins the remainder of the cooling circuit, such that the temperature sensor is located at a point where the process fluid from the bypass segment 18 and process fluid from the cooling circuit has mixed.

[0023] Figure 4 is a flowchart of a method embodiment for controlling a variable primary flow heating and cooling system. Operational parameters are measured, for example by temperature sensors, during systems operations 50. The operational parameters are used to determine when a stopping threshold has been reached 52, at which point the compressor is switched off 54. While the compressor is off, at least one operational parameter is monitored 56, and the operational parameter changes as heat is introduced into the system in the cooling coils 16 while the compressor is not in operation. The operational parameter monitored in step 56 is compared to a starting threshold in step 58. If the starting threshold is satisfied, it may be determined whether a delay period prevents restarting the compressor 60, or if the compressor may be restarted. Additionally or alternatively, a soft loading period may be determined for the restarting operation 62. The compressor is restarted according to the delay period and/or the soft loading in step 64.

[0024] Operational parameters are measured in step 50. The operational parameters may be, for example, temperature measurements taken at one or more points within the variable flow chiller system. During compressor operations for the embodiment shown in Figure 3, the operational parameter may be, for example, a temperature measured at an outlet of heat exchanger 14 by temperature sensor 26, a temperature measured at the inlet of heat exchanger 14 by temperature sensor 24, a temperature measured within the cooling circuit by temperature sensor 30, and/or a temperature measured within the cooling circuit by temperature sensor 32. In the embodiment of Figure 3, the temperature sensors may be located at the outlet of heat exchanger 14, at the inlet of heat exchanger 14, at the inlet or outlet of the pump 22, in the cooling circuit following the bypass 18 but prior to the cooling coils 16, or following the cooling coils 16 but prior to the bypass 18 rejoining the cooling circuit, or along the cooling circuit where pipes serving the cooling coils 16 and the bypass segment 18 have all rejoined one another. The temperature sensors report this temperature data to a processor or to a memory in the control unit 28.

[0025] Operational parameters are compared to a stopping threshold in step 52. This comparison may be continuous or occur at discrete sampling times. The operational parameters are those recorded during step 50, for example, temperature measurements. In the embodiment shown in Figure 3, a temperature measurement used for comparison to the stopping threshold may be, for example, the temperature measurement from a second temperature sensor 26 located at the outlet of the heat exchanger 14. The stopping threshold may be a stopping set point temperature, which may be based, for example, on the design output temperature of the chiller minus a differential-to-stop value, for example 3-5 degrees Fahrenheit. If the comparison between the stopping set point temperature and the measured temperature shows that the measured temperature is below the stopping set point temperature, the compressor 12 may be switched off or otherwise deactivated in step 54, stopping it from further removing heat from the system.

[0026] Following a shutoff of the compressor 12 in step 54, system operational parameters are monitored in step 56. The operational parameters may be, for example, temperatures within the cooling circuit. For example, when the compressor is shut off, the monitored operational parameter may be a temperature measured at an inlet of heat exchanger 14 by temperature sensor 24 or a temperature measured prior to a bypass 18 but following the cooling coils 16 by temperature sensor 30. In an embodiment, the operational parameter monitored in step 56 may be a different operational parameter than the one measured in step 50. In an embodiment, the operational parameter measured in step 50 may be the same operational parameter monitored in step 56. In an embodiment, the operational parameter monitored in step 56 when the compressor is shut off may differ from the operational parameter measured during compressor operations in step 50. For example, the operational parameter in step 50 may be a first temperature from a first location in the cooling circuit while the operational parameter in step 56 may be a second temperature from a second location in the cooling circuit.

[0027] In step 58, the operational parameters monitored in step 56 are compared to a starting threshold. For example, a temperature monitored during step 56 may be compared to a starting threshold temperature in step 58. This comparison maybe continuous or occur at discrete sampling times. The operational parameter compared to the starting threshold may be, for example, the temperature recorded by temperature sensor 24 which may be located at an inlet of the heat exchanger 14, or temperature readings from an inlet or outlet of the pump 22, or in the cooling circuit upstream of the pump 22 and bypass segment 18 downstream from where pipes from each of the cooling coils 16 rejoin one another. The temperature reading is compared to a starting threshold temperature, which may be determined based on, for example, a differential-to-start value plus a typical operating temperature for fluid entering the chiller 10 or the design temperature leaving the chiller plus the differential-to-start value for the chiller 10. In an embodiment, the differential-to-start value may be a static constant or a dynamic value. Dynamic values may vary during operations, for example by being computed based on current conditions. In an embodiment, the differential-to-start value may be based on the design delta-t of the chiller 10. In an embodiment, the differential-to-start value may be based on a temperature in the cooling circuit upstream of pump 22 and bypass 18 but downstream of all the cooling coils 16, for example measured by temperature sensor 30. In an embodiment, the differential-to-start value may be based on a minimum capacity of the compressor 12. For example, where the chiller has a smaller delta-t rating at lower loads, the differential-to-start may be 3 to 5 degrees Fahrenheit, whereas a chiller where the delta-t rating is higher at lower loads may have a differential-to-start value of 7 to 10 degrees Fahrenheit. If the measured temperature from step 56 exceeds the starting threshold temperature, the compressor may, in an embodiment be restarted. In an embodiment, step 60 may then be performed to determine whether the compressor may be restarted.

[0028] When the temperature comparison meets the requirements to restart the compressor 12, starting conditions for the compressor may be determined. In step 60, it may be determined whether a delay period should prevent restarting of the compressor 12, or require the restarting of the compressor 12 to occur at a specific time. This may be determined based on, for example, referencing a timer of when the last restart operation occurred, comparing a current time to the time of previous restarts, comparing a current time to a time of the most recent stopping of the compressor 12, comparing a current time to a time stored in memory identifying when the compressor may be next restarted, or other determinations that there is not a lockout period associated with restarting the compressor that is currently affecting whether the compressor may be restarted. The delay period may be, for example, a static constant between each compressor stopping and starting operation, or a static constant between a compressor starting operation and the next subsequent compressor starting observation, or a dynamic value. Dynamic values may vary during operations, for example by being computed based on current conditions. In an embodiment, the dynamic value may be selected based on the number of recent restarts, for example with a first constant selected for a first restart within a given time period such as at or about 5 or 10 minutes, then a second, larger constant for a longer delay period such as at or about 10 or 15 minutes following a second restart within the longer time period and continuing with escalating delay times for each subsequent restart within the given time period. In an embodiment, the delay period may be a value which includes a constant value, and then has an incrementing value added with each restart operation, and the delay period decays towards the constant value over time between restart operations. In an embodiment, the delay period may be a dynamic value determined based on design conditions for operation of the system and a comparison of the design conditions with one or more measured temperatures within the system at the time of compressor shutdown. In an embodiment, there may be a maximum value for the delay period, for example a maximum delay period of at or about 30 minutes. In an embodiment, step 60 may be skipped.

[0029] If the compressor may be restarted based on the operational parameter, starting conditions may be determined by setting soft loading in step 62. In an embodiment, setting soft loading in step 62 may be skipped. The soft loading period may be a constant value or a dynamic value. Dynamic values may vary during operations, for example by being computed based on current conditions. Where the soft loading period is a dynamic value, the soft loading period may be determined based on a number of restarts occurring within a predefined time period. In an embodiment, the soft loading period may be a dynamic value determined based on design conditions for operation of the system and a comparison of the design conditions with one or more measured temperatures within the system at the time of compressor shutdown. Soft loading may be, for example, a soft loading period which governs compressor operations in a period following restart. In an embodiment, during the soft loading period, the compressor may be set to operate at a particular capacity, typically in the lower portion of the range of permissible compressor operations on startup, such as 10% to 30% of maximum capacity. In an embodiment, during the soft loading period, the compressor may ramp in capacity from a minimum value to a predetermined value, for example from 10% to 30% of maximum capacity. The period for this soft loading on start-up may be determined, for example, setting the period of soft loading based on a constant associated with a number of restarts during a given time period, for example with a first constant selected for a first restart within a given time period such as at or about 10 to 15 minutes, then a second, larger constant such as at or about 15 or 20 minutes for the soft loading period following a second restart within the given time period and continuing with escalating soft loading periods for each subsequent restart within the given time period. In an embodiment, the soft loading period may increment only up to a maximum value, for example at or about 30 minutes. In step 64, the compressor is restarted. In an embodiment, the compressor may be operated according to the soft loading period determined in step 62 following restarting.

[0030] Figure 5 is a system diagram of a control system embodiment which directs operations in a variable flow heating and cooling system such as that shown in Figures 1 and 2. In the control system, a first temperature sensor 24 measures a temperature for process fluid entering the heat exchanger 14 of a chiller 10 including a compressor 12. A second temperature sensor 26 is located near the outlet of the heat exchanger 14, measuring a temperature for the process fluid leaving the heat exchanger. In an embodiment, the first temperature sensor 24 may be located at an inlet to the chiller 10, at an inlet or outlet of the pump 22, or along the cooling circuit at a point downstream from where the bypass segment 18 and pipes serving each cooling coil 16 rejoin one another.

[0031] The first temperature sensor 24 and the second temperature sensor 26 are connected to control unit 28. The control unit 28 includes a processor 80, a memory 82, and connection to the compressor 12 through which the control unit 28 may at least control the stopping and starting of the compressor 12. In an embodiment, the control unit 28 may direct compressor operations such as setting the capacity at which to operate the compressor 12. In an embodiment, the compressor controls may also be connected to the pump 22 and dictate the flow rate provided by the pump 22. In an embodiment, the control unit 28 may be linked to additional compressor controls besides start-stop to additionally control, for example, bypass flow rate through bypass valve 20, the compressor load, and/or the flow rate of pump 22.

[0032] While the compressor is running, the processor 80 uses operational parameters, for example data from the temperature sensors 24 or 26, and data from the memory 82 to determine whether conditions require the compressor be stopped. The processor may do this, for example, by receiving a temperature reading, for example from a first temperature sensor located at an outlet of the chiller 10, and comparing that received temperature value to a stopping set point temperature. The stopping set point temperature may be based, for example, on the design output temperature of the chiller minus a differential-to-stop value, for example 3-10 degrees Fahrenheit. The stopping set point temperature may be predetermined and directly stored in memory 82 or computed from stored values for the design output temperature and the differential-to-stop value. In an embodiment, the stopping set point may be computed based on system limits such as the properties of the fluid used, for example a stopping set point temperature based at least in part on the freezing temperature of water when that is the fluid used in the cooling circuit.

[0033] While the compressor 12 is stopped, the processor 80 uses data from the temperature sensors 24 or 26 and data from the memory 82 to determine whether the operational parameters require the compressor 12 be restarted. If the compressor 12 is restarted, the processor 80 may be used to determine starting conditions such as soft loading and/or delay periods. The processor 80 determines whether the compressor 12 needs to be restarted based on a temperature measurement taken at first temperature sensor 24, located for example at the inlet of the pump 22 or the inlet of the heat exchanger 14, and compares the temperature value to a starting set point temperature. The starting set point temperature may be determined based on, for example, a differential-to-start value plus a typical operating temperature for fluid entering the chiller 10 or the design temperature leaving the chiller plus a design delta-t value for the chiller. The differential-to-start value may be selected based on characteristics of the cooling system such as required compressor loads during startup operations, flow volumes at low loads, and chiller behavior in low-load operations. For example, where the chiller removes less heat from the system at lower loads, the differential-to-start may be 3 to 5 degrees Fahrenheit, whereas a chiller that removes more heat from the system at lower loads may have a differential-to-start value of 7 to 10 degrees Fahrenheit. In an embodiment, the starting set point may be dynamically computed based on operational characteristics of the variable flow system such as the rate of temperature pulldown, which may be based on temperature data from temperature sensors 24, 26, 30 and/or 32 and/or the number of compressor stop and start operations over a period of time.

[0034] The processor 80 may increment values such as delay periods between restarts of the compressor or adjust the soft loading for a restarting operation, for example incrementing the values during a restarting operation for a compressor or on completion of the restarting of the compressor; these changes may be communicated to and stored in the memory 82 for retrieval during subsequent operations. In an embodiment, the occurrence and time of a restarting operation may be logged and stored in memory 82 for at least a defined period of time over which restarting operations are tracked and counted, such as an hour, day, or up to the operating life of the chiller 10.

Aspects:

[0035] It is to be appreciated that any of aspects 1-9 may be combined with any of aspects 10-17 or 18-20, and that any of aspects 10-17 may be combined with aspects 18-20.

Aspect 1. A variable flow system comprising:

- a pump,
- a chiller including a compressor and a heat exchanger,
- at least one sensor measuring one or more operational parameters of the variable primary flow system,
- one or more cooling coils, and
- a processor, connected to the at least one sensor and the compressor, the processor:
  - determines, based on at least one of the operational parameters, whether a stopping threshold satisfied;
  - commands the compressor to stop when the stopping threshold is satisfied;
  - determines, based on at least one of the operational parameters, whether a starting threshold is satisfied;
  - determines a starting condition for the compressor;
  - operates the compressor, based on the starting condition and the satisfaction of the starting threshold.

Aspect 2. The variable flow system according to aspect 1, wherein the operational parameters comprises at least one of:

- a temperature measurement from a temperature sensor located upstream of the heat exchanger with respect to a fluid flow through the heat exchanger;
- a temperature measurement from a temperature sensor downstream of the heat exchanger with respect to the fluid flow through the heat exchanger;
- a temperature measurement from a temperature sensor downstream of a bypass and upstream of the one or more cooling coils with respect to a fluid flow through the variable flow system; and
- a temperature measurement from a temperature sensor upstream of a bypass pipe by downstream of the one or more cooling coils with respect to the fluid flow through the variable flow system.

Aspect 3. The variable flow system according to any of aspects 1-2, wherein the processor sets a delay period preventing starting of the compressor for a period of time following the starting of the compressor.

Aspect 4. The variable flow system according to aspect 3, wherein the delay period is a dynamic value based on the number of compressor starts within a predetermined time period.

Aspect 5. The variable flow system according to any of aspects 1-4, wherein the starting condition for the compressor comprises a soft loading period.

Aspect 6. The variable flow system according to aspect 5, wherein the soft loading period and/or rate of loading is determined based on the number of starting operations of the compressor in a selected time period.

Aspect 7. The variable flow system according to any of aspects 5-6, wherein the soft loading period and/or rate of loading is determined based on variable flow system design conditions and a temperature measurement.

Aspect 8. The variable flow system according to any of aspects 1-7, wherein the starting condition for the compressor is a soft loading rate of loading.

Aspect 9. The variable flow system according to aspect 8, wherein the soft loading rate of loading is determined based on the number of starting operations of the compressor in a selected time period.

Aspect 10. The variable flow system according to any of aspects 8-9, wherein the soft loading rate of loading is determined based on variable flow system design conditions and a temperature measurement.

Aspect 11. A method for controlling a compressor in a variable flow system, comprising:

measuring one or more operational parameters of the variable flow system;
comparing the at least one of the operational parameters to a starting threshold;
determining, based on a starting condition, a compressor start procedure;
operating the compressor according to the determined compressor start procedure.

Aspect 12. The method according to aspect 11, wherein the operational parameters comprise a first temperature measured by a temperature sensor that is located upstream from a heat exchanger connected to the compressor with respect to the direction of fluid flow in the variable flow system.

Aspect 13. The method according to any of aspects 11-12, further comprising:

comparing at least one of the operational parameters to a stopping threshold; and
stopping the compressor based on the comparison of the at least one of the operational parameters and the stopping threshold.

Aspect 14. The method according to aspect 13, wherein the operational parameters comprise a temperature measured by a temperature sensor that is located downstream from a heat exchanger connected to the compressor with respect to the direction of fluid flow in the variable flow system.

Aspect 15. The method according to any of aspects 10-14, wherein the starting condition is a delay period between starting operations for the compressor and the determined start procedure is a time at which to start the compressor.

Aspect 16. The method according to any of aspects 10-15, wherein the starting condition is a soft loading period for the compressor and the determined start procedure is a compressor capacity and a period of time to operate at the compressor capacity.

Aspect 17. The method according to any of aspects 10-16, further comprising determining a starting condition based on a number of compressor starting operations within a predetermined period of time.

Aspect 18. The control system according to any of aspects 10-17, further comprising determining a starting condition based on variable flow system design conditions and a temperature measurement.

Aspect 19. A control system for a compressor, comprising:

at least one sensor measuring one or more operational parameters,
a memory, storing a starting threshold temperature and a stopping threshold temperature;
a processor, connected to the at least one sensor and the compressor, the processor:
determines, based on at least one of the operational parameters, whether a stopping threshold satisfied;
commands the compressor to stop when the stopping threshold is satisfied;
determines, based on at least one of the operational parameters, whether a starting threshold is satisfied;
determines a starting condition for the compressor; and
operates the compressor, based on the starting condition and the satisfaction of the starting threshold.

Aspect 20. The control system according to aspect 19, wherein the operational parameters comprise at least one of:

a temperature measurement from a temperature sensor that is located downstream of a heat exchanger with respect to a fluid flow through the heat exchanger;
a temperature measurement from a temperature sensor downstream of the heat exchanger with respect to the fluid flow through the heat exchanger;
a temperature measurement from a temperature sensor downstream of a bypass and upstream of the one or more cooling coils with respect to a fluid flow through the variable flow system; and
a temperature measurement from a tempera-

ture sensor upstream of a bypass pipe by downstream of the one or more cooling coils with respect to the fluid flow through the variable flow system.

[0036] The examples disclosed in this application are to be considered in all respects as illustrative and not limitative. The scope of the invention is indicated by the appended claims rather than by the foregoing description; and all changes which come within the meaning and range of equivalency of the claims are intended to be embraced therein.

Claims

1. A variable flow system comprising:

a pump,
a chiller including a compressor and a heat exchanger,
at least one sensor measuring one or more operational parameters of the variable flow system,
one or more cooling coils, and
a processor, connected to the at least one sensor and the compressor, the processor:

determines, based on at least one of the one or more operational parameters, whether a stopping threshold is satisfied;
commands the compressor to stop when the stopping threshold is satisfied;
determines, based on at least one of the one or more operational parameters, whether a starting threshold is satisfied;
determines a starting condition for the compressor;
operates the compressor, based on the starting condition and the satisfaction of the starting threshold.

2. The variable flow system of claim 1, wherein the one or more operational parameters comprises at least one of:

a temperature measurement from a temperature sensor located upstream of the heat exchanger with respect to a fluid flow through the heat exchanger;
a temperature measurement from a temperature sensor downstream of the heat exchanger with respect to the fluid flow through the heat exchanger;
a temperature measurement from a temperature sensor downstream of a bypass and upstream of the one or more cooling coils with respect to a fluid flow through the variable flow system; and
a temperature measurement from a temperature sensor upstream of a bypass pipe by downstream of the one or more cooling coils with respect to the fluid flow through the variable flow system.

3. The variable flow system of claim 1 or 2, wherein the processor sets a delay period preventing starting of the compressor for a period of time following the starting of the compressor and the delay period is a dynamic value based on a number of compressor starts within a predetermined time period.

4. The variable flow system of any preceding claim, wherein the starting condition for the compressor comprises a soft loading period and the soft loading period is determined based on the number of starting operations of the compressor in a selected time period.

5. The variable flow system of any of claims 1-3, wherein the starting condition for the compressor comprises a soft loading period and the soft loading period is determined based on variable flow system design conditions and a temperature measurement.

6. The variable flow system of any of claims 1-3, wherein the starting condition for the compressor is a soft loading rate of loading and the soft loading rate of loading is determined based on the number of starting operations of the compressor in a selected time period.

7. The variable flow system of any of claims 1-3, wherein the starting condition for the compressor is a soft loading rate of loading and the soft loading rate of loading is determined based on variable flow system design conditions and a temperature measurement.

8. A method for controlling a compressor in a variable flow system, comprising:

measuring one or more operational parameters of the variable flow system;
comparing the at least one of the one or more operational parameters to a starting threshold;
determining, based on a starting condition, a compressor start procedure;
operating the compressor according to the determined compressor start procedure.

9. The method of claim 8, wherein the one or more operational parameters comprise a first temperature measured by a temperature sensor that is located upstream from a heat exchanger connected to the compressor with respect to the direction of fluid flow in the variable flow system.

10. The method of claim 8 or 9, further comprising:

comparing at least one of the one or more operational parameters to a stopping threshold; and
stopping the compressor based on the comparison of the at least one of the one or more operational parameters and the stopping threshold.

11. The method of claim 10, wherein the one or more operational parameters comprise a temperature measured by a temperature sensor that is located downstream from a heat exchanger connected to the compressor with respect to the direction of fluid flow in the variable flow system.

12. The method of any of claims 8-11, wherein the starting condition comprises a delay period between starting operations for the compressor and the determined start procedure comprises a time at which to start the compressor.

13. The method of any of claims 8-11, wherein the starting condition comprises a soft loading period for the compressor and the determined start procedure comprises a compressor capacity and a period of time to operate the compressor at the compressor capacity.

14. A control system for a compressor, comprising:

at least one sensor measuring one or more operational parameters,
a memory, storing a starting threshold temperature and a stopping threshold temperature;
a processor, connected to the at least one sensor and the compressor, the processor:

determines, based on at least one of the one or more operational parameters, whether a stopping threshold satisfied;
commands the compressor to stop when the stopping threshold is satisfied;
determines, based on at least one of the one or more operational parameters, whether a starting threshold is satisfied;
determines a starting condition for the compressor; and
operates the compressor, based on the starting condition and the satisfaction of the starting threshold.

15. The control system of claim 14, wherein the one or more operational parameters comprise at least one of:

a temperature measurement from a temperature sensor that is located downstream of a heat exchanger with respect to a fluid flow through the heat exchanger;
a temperature measurement from a temperature sensor downstream of the heat exchanger with respect to the fluid flow through the heat exchanger;
a temperature measurement from a temperature sensor downstream of a bypass and upstream of the one or more cooling coils with respect to a fluid flow through the variable flow system; and
a temperature measurement from a temperature sensor upstream of a bypass pipe by downstream of the one or more cooling coils with respect to the fluid flow through the variable flow system.

Fig. 1

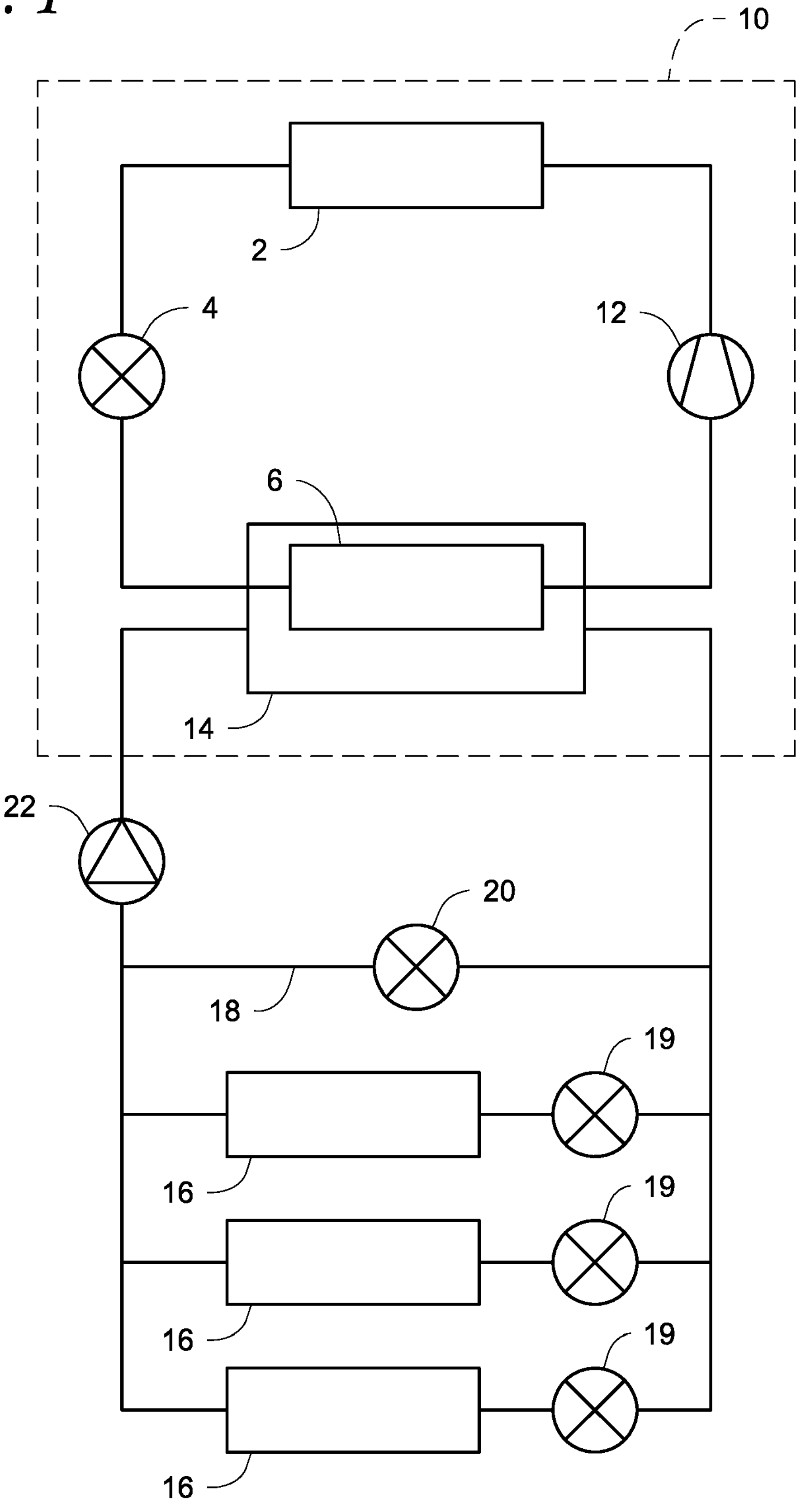
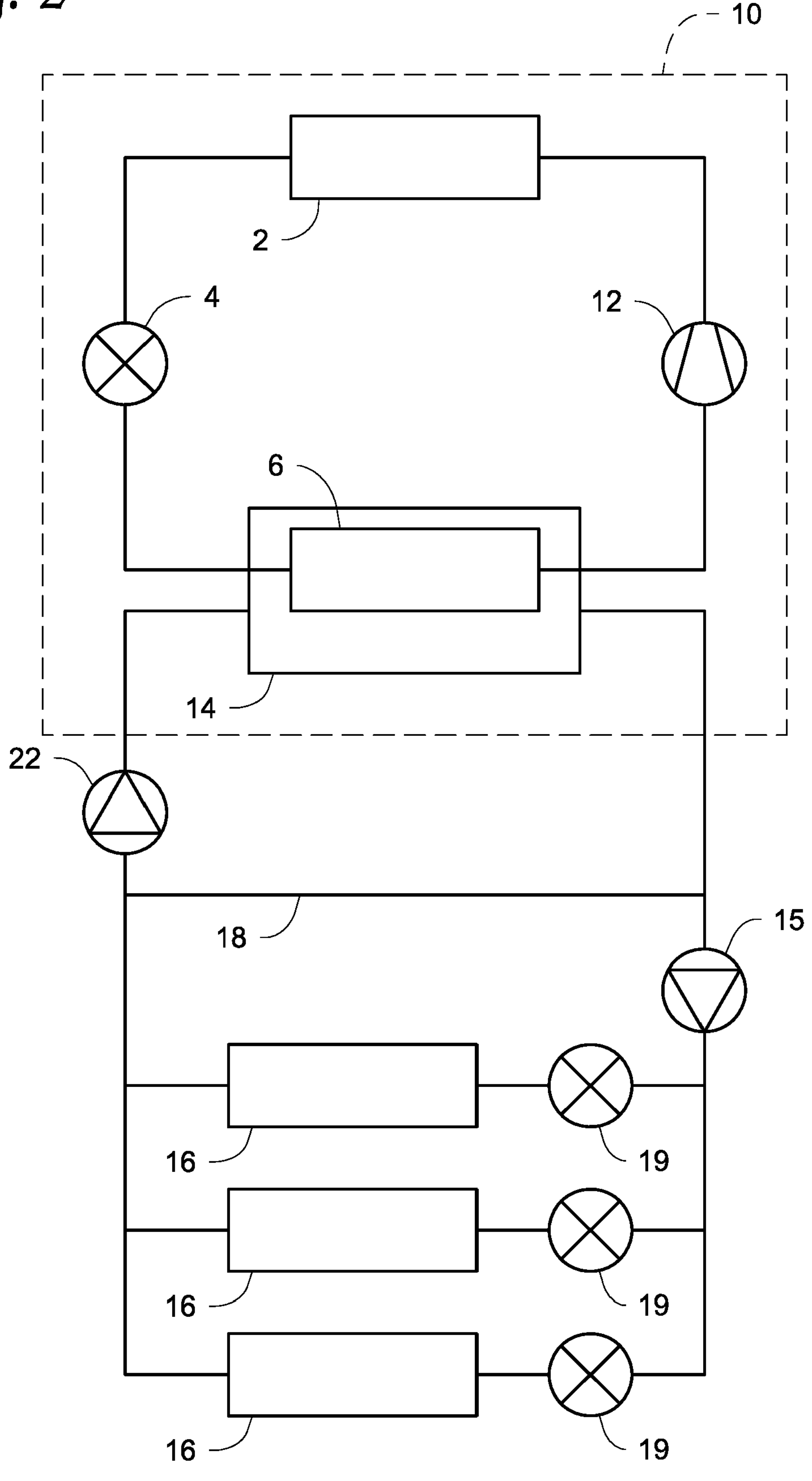


Fig. 2



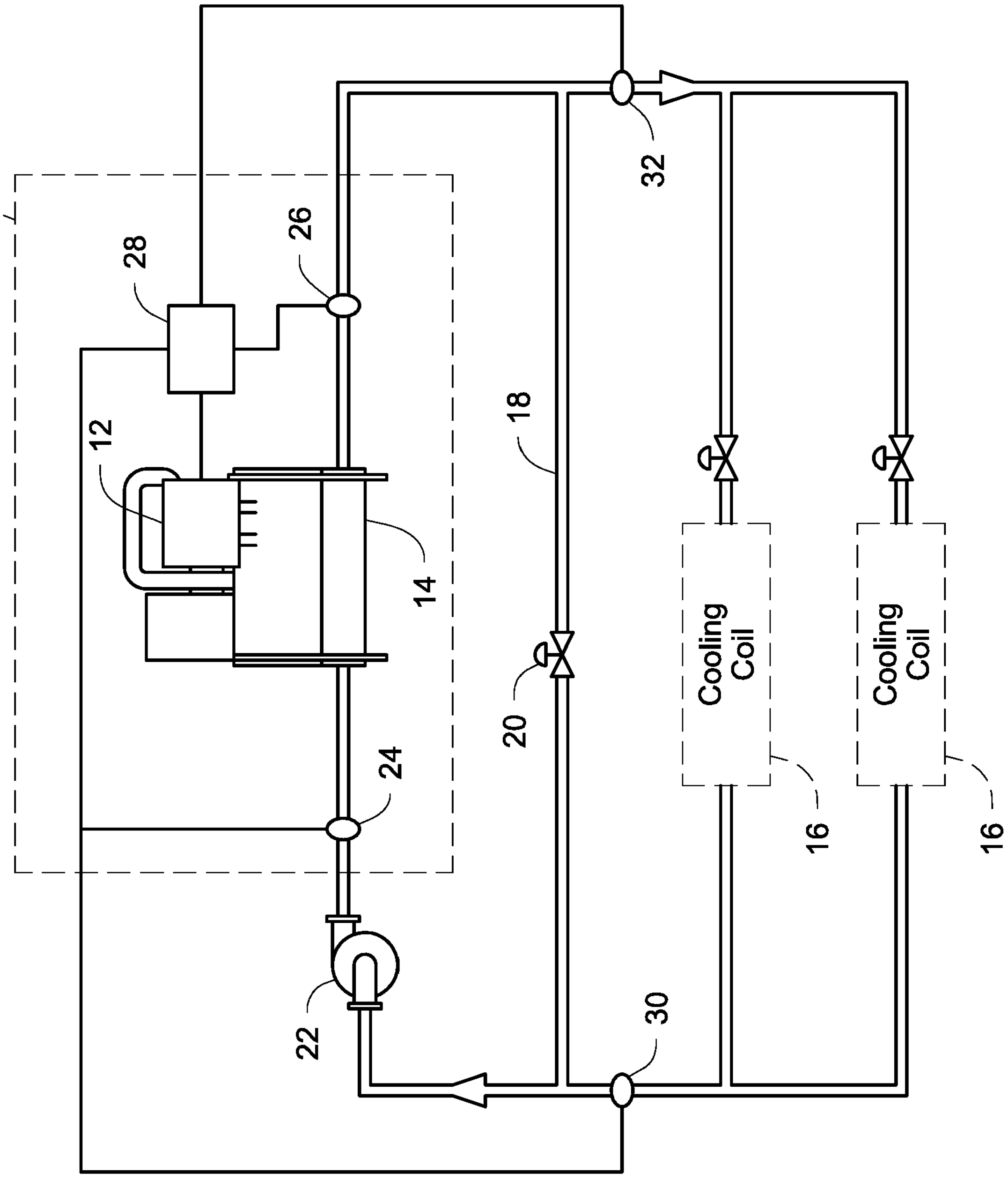


Fig. 3

Fig. 4

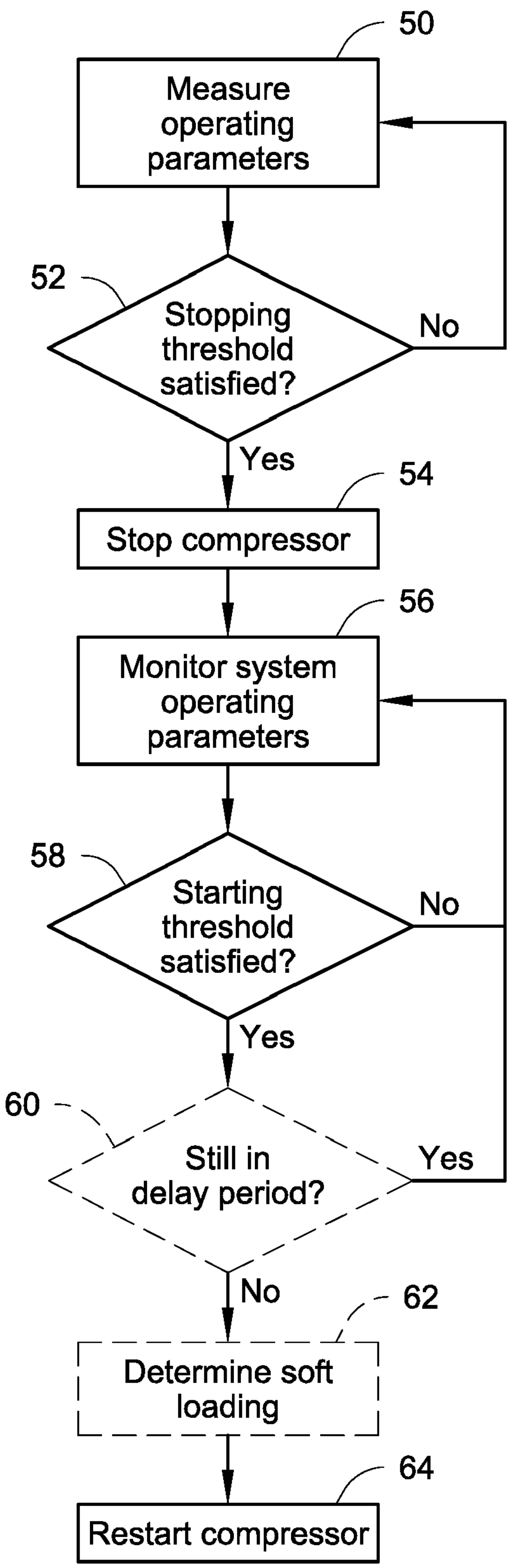
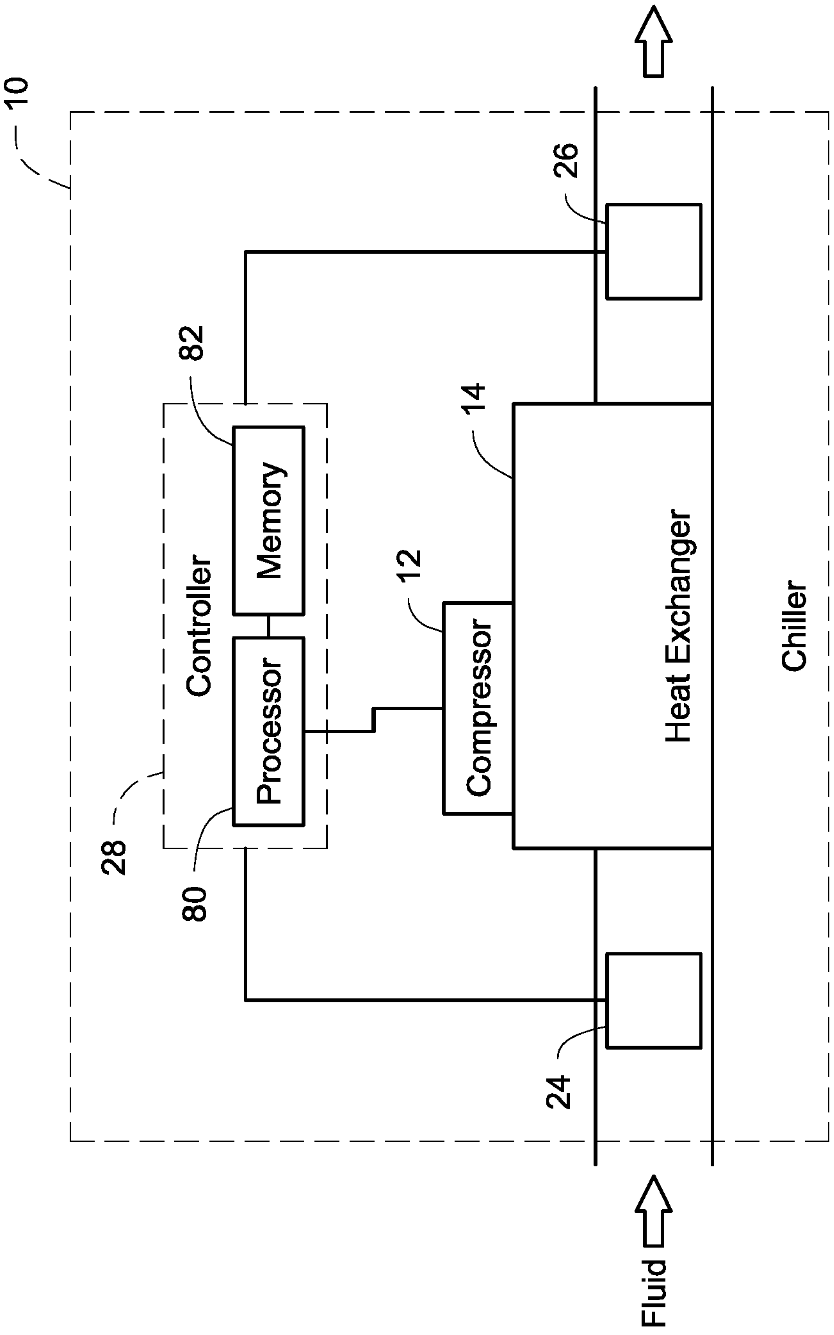

50
Measure operating parameters
52
Stopping threshold satisfied?
No
Yes
54
Stop compressor
56
Monitor system operating parameters
58
Starting threshold satisfied?
No
Yes
60
Still in delay period?
Yes
No
62
Determine soft loading
64
Restart compressor

Fig. 5


10
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Processor
82
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Heat Exchanger
Chiller
24
26
Fluid

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EUROPEAN SEARCH REPORT

Application Number
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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	2 November 2018	Lepers, Joachim

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