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(54) **METHODS AND SYSTEMS FOR COMPRESSOR OPERATION**

VERFAHREN UND SYSTEME FÜR KOMPRESSORBETRIEB

PROCÉDÉS ET SYSTÈMES D'UTILISATION D'UN COMPRESSEUR

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Description

[0001] The present invention relates to methods and systems for compressor operation before and during compressor startup and/or shutdown and in particular to methods and systems for reliable startup of a compressor, even at low ambient temperatures.

[0002] Conventional refrigeration or airconditioning systems typically comprise a compressor, a heat rejecting heat exchanger or condenser, an expansion valve or device and a heat accepting heat exchanger or evaporator. In operation, refrigerant is circulated through these components in a closed circuit. The pressure and temperature of the refrigerant vapour is increased by the compressor before entering the heat rejecting heat exchanger where it is cooled. The high pressure, lower temperature liquid is then expanded to a lower pressure by means of the expansion valve. In the heat accepting heat exchanger, the refrigerant boils and absorbs heat from its surroundings. The vapour at the heat accepting heat exchanger outlet is drawn into the compressor, completing the cycle.

[0003] However on compressor shutdown and restart the components of the system, particularly the compressor, can be damaged or fail particularly in low ambient temperatures. Document EP-A-1 702 667 discloses a refrigeration system according to the preamble of claim 1 and a method according to the preamble of claim 7. It is therefore an object of the present invention to provide a refrigeration system and a method of operating a refrigeration system, particularly although not exclusively for a transport refrigeration unit, the refrigeration system comprising a compressor and being operable such that failures of the system due to or on compressor start up are minimised, particularly when the compressor is started at low ambient temperatures. This is achieved with a refrigeration system according to claim 1 and a method according to claim 7. Preferably the refrigeration system is operable in at least one of a plurality of predetermined sequences, and the particular sequence (or sequences) used is preferably determined based on at least one parameter of the refrigeration system. Preferably the parameter (or parameters) comprises a system parameter measured by at least one sensor.

[0004] Heating of the component(s) of the compressor is carried out in any suitable manner. In a particularly preferred embodiment, the stator windings of a motor associated with the compressor, for example the internal electric alternating current motor (synchronous or asynchronous) of the compressor are electrically connected to an electrical source, e.g. a direct current source, to thereby heat the windings and thus heat the compressor.

[0005] The pressure equalisation valve can be opened prior to compressor start up, but in preferred embodiments the pressure equalisation valve is opened when the compressor is started (preferably at substantially the same time as the compressor is started). For example in the embodiment where the pressure equalisation valve is a bypass passage, the passage is opened as the compressor is started to allow pressure balancing between the compressor suction and discharge by bypassing the compressor. Preferably the pressure equalisation valve is opened after the preheating steps discussed above.

[0006] Preferably the compressor is started slowly, e.g. at a speed or frequency considerably lower than a standard operating frequency. Starting the compressor and opening the pressure equalisation valve allows oil in the compressor to be mixed. This is advantageous because in a shutdown compressor the temperature of the oil is not homogeneous in the compressor shell. When the compressor is started slowly with the pressure equalisation valve open (and therefore with very low refrigerant flow), the hot oil from the motor is mixed with the cold oil from the other parts and the oil is warmed. Furthermore the oil and other parts of the compressor are heated by the refrigerant that bypasses the compressor via the pressure equalisation valve, the vapour refrigerant from the discharge valve in the compressor being hotter than the actual suction gas refrigerant and when passing through the bypass and the compressor suction, the vapour heats the mechanical parts of the compressor and the oil. That is the bypass line generally emits heat to the compressor and heats the oil that is circulating in the compressor. Pressure in the compressor body or shell is limited by the bypass.

[0007] In particularly preferred embodiments the oil temperature of the compressor is maintained above the saturated discharge temperature of the refrigerant in the compressor shell. At temperatures below the saturated discharge temperature the vapour refrigerant condenses and if the oil temperature is below the saturated discharge temperature, refrigerant will condense into the oil. Preferably the compressor shell temperature is also maintained above the saturated discharge temperature of the refrigerant. If the oil, and preferably also the mechanical components and the shell of the compressor, are above the saturated discharge temperature refrigerant will not condense in the compressor.

[0008] Preferably the speed of the compressor at startup is lower than the normal running speed of the compressor as previously mentioned. For example in preferred embodiments the compressor at startup operates at a frequency of 30 Hz. Low compressor speed is desirable at startup because a low flow rate through the compressor minimises refrigerant condensation in the compressor.

[0009] Preferably the liquid valve is closed prior to and during compressor startup. In particularly preferred embodiments the liquid valve closes as the compressor stops and remains closed during compressor shutdown. Closing the liquid valve on compressor shutdown limits the flow of refrigerant into the compressor limiting condensation in the compressor oil.

[0010] Preferably at an appropriate time after compressor startup the liquid valve is opened. Therefore the system is operating in some states with both the pressure equalisation valve and the liquid valve open and the compressor operating at low frequency. This enables increased flow of refrigerant at the compressor suction, although the refrigerant flow is still lower than during normal system operation because the pressure equalisation valve is open (i.e. the compressor remains bypassed at this stage). Preferably the liquid valve is opened when it is determined that a system parameter is at a desired level. For example in a preferred embodiment the system parameter is the oil temperature and when the oil temperature is determined (for example by measurement with a temperature sensor) to be sufficiently high (for example above a predetermined limit, and/or above the saturated discharge temperature of the refrigerant in the compressor, etc.), then the liquid valve is opened. Other suitable parameters and limits could of course be used. For example in a preferred embodiment the parameter is alternatively or additionally the pressure in the compressor shell. Furthermore it is envisaged that the liquid valve could instead or additionally be opened in response to other events, for example after a predetermined period of time (e.g. from compressor startup, and/or from opening of the pressure equalisation valve, or from any other action or event, etc.).

[0011] Preferably after the liquid valve is opened the pressure equalisation valve is closed. This occurs in response to any one or more of the following: after a predetermined period of time since opening the liquid valve; after a period of time has elapsed following any other suitable event; after a period of time has elapsed following one or more system parameters being determined to have reached a particular level; immediately after opening the liquid valve; etc. In a preferred embodiment the system parameter comprises either the compressor discharge temperature or the oil temperature and when the temperature is determined (for example by measurement with a temperature sensor) to be sufficiently high (for example above a predetermined limit, and/or above the saturated discharge temperature in the compressor, etc.), then the pressure equalisation valve is closed. The pressure of the suction and discharge of the compressor are therefore no longer balanced and refrigerant passes through the compressor at a greater flow rate than when the pressure equalisation valve was open (e.g. refrigerant no longer bypasses the compressor).

[0012] The compressor speed is preferably then increased, either immediately or preferably in response to a measured system parameter reaching a predetermined limit and/or after a period of time has elapsed, etc. Preferably the compressor speed is slowly increased, preferably by a predetermined amount and/or at a predetermined rate, until a maximum or optimum speed is achieved and/or a predetermined time period has elapsed. Alternatively or additionally, when a measured system parameter is determined to have reached a predetermined level, the compressor speed may be set to the maximum (i.e. standard) operating speed (which is preferably after a period of slow increase in compressor speed from the initial startup speed). In a preferred embodiment, when the compressor discharge temperature and/or oil temperature of the compressor has reached a predetermined level, the compressor is controlled to operate at normal operating speeds.

[0013] The above preferred systems and operational steps provide compressor starting sequences that enable a compressor to be started with minimal risk of failure which otherwise might occur due to condensation of refrigerant in the compressor, particularly at low ambient temperatures, after compressor shutdown. Refrigerant condensation is detrimental in a compressor because condensed refrigerant can become mixed with oil in the compressor sump, and if the oil temperature in the compressor is below the saturated discharge temperature of the refrigerant then refrigerant can condense in the oil. When the compressor is started refrigerant in the oil is pumped by the oil pump and may fail. Furthermore the oil viscosity is affected by the presence of refrigerant and therefore may be inappropriate for compressor operation causing damage to components that should be lubricated. These problems are solved by the preferred embodiments of the present invention and by the preferred methods discussed below. The present invention provides a method according to claim 7. The starting speed of the compressor f_1 is less than the compressor standard operating speed f_s. Preferably f_1 is about 30 Hz. Preferably fs is about 60 Hz, preferably about 65 Hz or greater. Preferably the method comprises the further steps of: further increasing the frequency of operation of the compressor to a standard operating frequency, preferably in response to a third event.

[0014] Preferably the first event comprises at least one of a first predetermined period of time elapsing and a measured compressor oil temperature being determinide to be above a predetermined threshold. Preferably the second event comprises at least one of a second predetermined period of time elapsing and a measured compressor oil temperature being determined to be above a predetermined threshold.

[0015] Preferably the method further comprises the steps of providing at least one system sensor and measuring at least one parameter of the system with the sensor, and operating the system in at least one of a plurality of predetermined sequences based on the at least one parameter measured by the sensor.

[0016] Preferably the step of preheating at least one component of the compressor comprises the steps of providing means for heating at least one component of the compressor, and activating the heating means to heat the component when it is determined that compressor startup is required. Preferably the means for heating at least one component of the compressor comprises means for heating at least one of the compressor body or shell, the oil in the compressor, and the compressor motor: In a particularly preferred embodiment the heating means comprises means for supplying DC electricity to the stator windings of an internal AC motor of the compressor. Preferably the method further comprises providing at least one sensor and measuring at least one parameter of the system with the sensor, and the heating means is activated for a predetermined period of time based on the at least one parameter. Preferably the predetermined period is based on at least one of the temperature of the oil in the compressor, the compressor shell temperature, the compressor discharge temperature, the ambient temperature and the length of time for which the compressor has been inactive.

[0017] Preferably the method further comprises the steps of measuring the temperature of oil in the compressor, determining the saturated discharge temperature of refrigerant in the compressor, and heating at least one component of the compressor such that the oil is maintained at a temperature above the saturated discharge temperature.

[0018] As discussed above, preheating a refrigeration system prior to compressor start up and controlling a liquid valve and a pressure equalisation valve before and during start up can advantageously reduce or eliminate refrigerant condensation problems, particularly in low ambient temperatures.

[0019] The above-mentioned and other features of the various embodiments of the present invention will now be described, by way of example only and with reference to the accompanying drawings, in which:

Figure 1 shows a schematic representation a refrigeration system in accordance with an embodiment of the present invention;

Figure 2 shows a flow diagram illustrating the modes of operation of a refrigeration system in accordance with an embodiment of the present invention;

Figure 3 shows a first, standard operating sequence for starting a compressor of a refrigeration system in accordance with an embodiment of the present invention;

Figure 4 shows a second, long operating sequence for starting a compressor of a refrigeration system in accordance with an embodiment of the present invention; -

Figure 5 shows a third, short operating sequence for starting a compressor of a refrigeration system in accordance with an embodiment of the present invention;

Figure 6 shows a schematic representation of a refrigeration system which does not belong to the invention;

Figure 7A shows a schematic representation of a refrigeration system which does not belong to the invention;

Figure 7B shows a system, that does not have the pressure equalisation valve of the embodiment of figure 7A, in two states, the first being shortly after compressor shutdown and the second being some time after compressor shutdown; and

Figure 8 shows a schematic representation of a refrigeration system in accordance with another embodiment of the present invention.

[0020] The principles of the present invention can be incorporated within any suitable system. Examples of such suitable systems include refrigeration and airconditioning systems and particularly, although not exclusively, transport or truck refrigeration systems. For ease of reference, the specific embodiments discussed herein are described with reference to a refrigeration system suitable for a transport refrigeration unit or the like.

[0021] Figure 1 schematically shows a refrigeration system 10 having a refrigerant cycle or circuit 20 such that refrigerant can flow around the system. The system comprises a compressor 12 connected from an outlet or discharge 13 thereof via flow path 22 to a heat rejecting heat exchanger, which in this embodiment is-a condenser 14. The condenser 14 is connected via flow path 24 to expansion device 16, which is connected via flow path 26 to a heat accepting heat exchanger, which in this embodiment is an evaporator 18. The evaporator 18 is connected to the compressor 12 at an inlet or suction 11 thereof via flow path 28. The expansion device 16 is preferably a thermostatic expansion valve and in this embodiment is controlled in response to conditions of the system 10 via control line 36. The system condition which controls opening of the expansion valve 16 could for example be the temperature of the evaporator 18, or a related temperature such as a bulb temperature at the evaporator outlet, etc. In this embodiment, additional optional components accumulator 32 and dryer 34 are also provided on flow path 24 between the condenser 14 and the valve 16.

[0022] The system 10 further comprises a pressure equalisation valve (PEV) across the compressor 12, i.e. connecting the compressor suction 11 to the discharge 13. The PEV comprises a bypass passage 40 and means 42, such as a valve, far opening and closing the passage 40.

[0023] The system 10 further comprises a liquid valve (LV), which in preferred embodiments is a liquid solenoid valve 44, in the flow path 24 between the condenser 14 and the expansion valve 16. The LV 44 can be energised to open or close as required, thereby opening or closing the flow path 24 to enable or disable refrigerant flow around the circuit 20.

[0024] In operation, high pressure and high temperature refrigerant vapour exits the compressor 12 and enters the condenser 14 where it is cooled to a lower temperature, high pressure liquid refrigerant. This liquid is then expanded to a lower pressure by the expansion valve 16 and passes to the evaporator 18 where the refrigerant boils and absorbs heat from its surroundings. The vapour at the evaporator 18 outlet is drawn into the compressor 12, completing the cycle.

[0025] When the compressor 12 is shut drown, refrigerant may be present in the compressor 12 and, particularly if the compressor 12 is shut down for prolonged periods, additional refrigerant can migrate from the condenser 14 to the compressor 12 as discussed in more detail below.

[0026] The refrigerant in the compressor 12 may condense on the compressor shell, particularly at low ambient temperatures, and the condensed refrigerant will mix with the compressor oil which has an affinity for refrigerant. If the compressor oil temperature is below the saturated discharge temperature of the refrigerant, the refrigerant can condense in the oil. The refrigerant dilutes the oil and, when the compressor 12 is restarted, the diluted oil is less effective at lubricating the components of the compressor 12, which may lead to damage. Furthermore the compressor oil pump will draw in refrigerant which may also lead to damage.

[0027] Therefore in accordance with embodiments of the present invention, one or more compressor startup sequences are employed to minimise or eliminate refrigerant condensation in the compressor 12. Figure 2 is a flow diagram of one embodiment of the present invention in which a control means or the like determines the state of a system 10 (for example the system 10 of any of figures 1, 6, 7A or 8) and in particular the length of time T_{stop} that the compressor has been shut down and the discharge temperature T_{ref} of the compressor 12. If the compressor 12 is shut down for a reasonably long period of time, the discharge temperature T_{ref} is substantially equal to the ambient temperature. In other embodiments the ambient temperature may be measured. The control means determines from these parameters what steps before and during compressor startup should be taken to minimise or eliminate the problems of refrigerant condensation in the compressor 12. Of course, other parameters could alternatively or additionally be used in this determination, such as the temperature of the oil in the compressor 12, the temperature of the refrigerant in the compressor 12, and/or the pressure inside the compressor shell, etc. The parameters used may depend on the sensors that are present in the system 10 and so what can be measured for making this determination.

[0028] In the figure 2 embodiment, the sequence begins at step 1.1 and the time since the compressor 12 stopped T_{stop} is determined in step 1.2. If it is less than 1 hour, the time is further determined in step 2.1 and still further in step 3.2 if T_{stop} is less than 1/2 hour. For shutdown periods less than 1/2 hour, it is determined unnecessary to preheat the compressor 12 and a normal starting sequence (for example as shown in figure 3) begins in step 4.3. For shutdown periods between 1/2 and 1 hour, the discharge temperature, T_{ref} is determined in step 3.1 and if it is low (less than 20°C), a short (3 minute) preheat of the compressor 12 is initiated in step 4.2 and as discussed below, before the normal starting sequence begins in step 5.2. However if T_{ref} is sufficiently high already, no preheat is required and a short starting sequence (for example as shown in figure 5) begins in step 4.1.

[0029] When the compressor 12 has been shut down for longer than 1 hour, the discharge temperature T_{ref} is determined in step 1.3 and dependent on the temperature, also in steps 1.4, 1.5. 1.6, 1.7 and 1.8. Furthermore, dependent on T_{ref}, the compressor 12 is preheated for 12, 9, 6 or 3 minutes (steps 2.2, 2.3, 2.4 and 2.5 respectively) before a long starting sequence (for example as shown in figure 4) begins in step 3.3. However if T_{ref} is sufficiently high (between 0 and 20°C) as determined in step 1.7, a 3 minute preheat is initiated in step 2.6 before the normal starting sequence begins in step 3.4. If T_{ref} is already even higher than 20°C as determined is steps 1.8 and 1.9, then no preheat is required and either a normal starting sequence is initiated in step 2.7 or for very high temperatures (greater than 40°C) a short starting sequence is initiated in step 2.8.

[0030] The above sequences ensure that if the discharge temperature of the compressor 12 is low, the compressor 12 is heated, preferably prior to compressor startup, to raise the compressor temperature, including the oil temperature. This is advantageous not only because the viscosity of the oil is improved making the oil more suitable for lubricating the compressor components on startup, but also because a sufficiently high oil temperature (greater than the saturation discharge temperature of the refrigerant) reduces or eliminates refrigerant condensation in the compressor 12 that occurs when the compressor shell and oil are cool.

[0031] Figures 3, 4 and 5 schematically illustrate preferred embodiments of the starting sequences for starting a compressor 12 after shutdown. Figure 3 shows a "normal" or default starting sequence, figure 4 shows a long starting sequence and figure 5 shows a short starting sequence. In preferred embodiments the starting sequences disclosed in figure 2 correspond with the figure 3, 4 sand 5 sequences, but it is also envisaged that this could differ or be modified by the skilled person. Furthermore the preheat sequences disclosed in figures 3, 4 and 5 may correspond with the preheat sequences of figure 2, or may differ or be modified.

[0032] Figure 3 shows a normal starting sequence for a compressor 12. In preferred embodiments, some or all of the steps of the figure 2 sequence are carried out as the first step of the normal starting sequence. Therefore the discharge temperature of the compressor 12 is preferably at least 20°C or the compressor shutdown period was less than 1/2 hour. Referring to a system 10 as exemplified in figure 1, the pressure equalisation valve (PEV) 40, 42 is initially closed and so is the liquid valve (LV) 44. When the compressor 12 is to be started, the PEV is opened thereby opening a bypass of the compressor 12. The compressor 12 is started, but with a relatively low frequency of about 30 Hz (which is significantly less than the full operating speed of the compressor 12). Heat from the bypassed refrigerant gas that passes through the PEV is transferred to the compressor 12 and to the compressor oil when the compressor 12 is started. Thus the oil in the compressor 12 is (further) heated and the condensation risk is further minimised, particularly as the refrigerant bypassing the compressor 12 cannot condense in the compressor 12. Furthermore the LV is closed to limit the flow of refrigerant into the compressor 12 thus further reducing the risk of condensation.

[0033] When the oil temperature in the compressor 12 is sufficiently high, e.g. when it is measured, determined or otherwise expected to be greater than the saturated discharge temperature of the refrigerant, and/or in this embodiment after the oil has been heated for a sufficient period of time which in the normal starting sequence is 20 seconds, the liquid valve is opened and the PEV remains open. The refrigerant flow at the compressor suction 11 increases slightly, but is still relatively low as the compressor 12 is still bypassed by the open PEV. When the oil temperature in the compressor 12 is sufficiently high, e.g. when it is again measured, determined and/or expected to be greater than the saturated discharge temperature of the refrigerant, and/or in this embodiment after it has been heated for a sufficient period of time which in the normal starting sequence is a further 20 seconds, the PEV is closed whilst the liquid valve remains open. Refrigerant therefore flows around the circuit 20 of system 10 under the influence of the compressor 12, which is no longer bypassed.

[0034] When the oil temperature in the compressor 12 is sufficiently high, e.g. when it is yet again measured, determined or otherwise expected to be greater than the saturated discharge temperature of the refrigerant, and/or in this embodiment after it has been heated for a sufficient period of time which in the normal starting sequence is a still further 20 seconds, the speed of the compressor 12 is gradually increased, preferably by 5 Hz per second until an optimum or normal operating frequency is reached, after which standard compressor speed control is applied as is known in the art. In other embodiments, the standard operating speed control can be started after it is again determined or otherwise expected that the oil temperature is still higher than the saturated discharge temperature.

[0035] However a normal starting sequence may not be appropriate under certain circumstances, for example when the temperature of the shutdown compressor 12 is low (e.g. less than about 5°C) and/or when the compressor 12 has been shutdown for a long period (more than about one hour). Instead a long starting sequence as shown in figure 4 may be more appropriate. The long starting sequence differs from the normal starting sequence in that the periods between events are generally significantly longer. For example the LV is kept closed after compressor startup for 5 minutes rather than 20 seconds, thereby allowing the oil additional time to heat up. The delay before closing the PEV is also longer and is about 2 minutes thus allowing the system 10 to operate at a reduced flow rate for longer. The period of time before the compressor frequency is increased is also longer and is about 2 1/2 minutes after which the frequency is increased more slowly than the normal starting sequence, at about 1 Hz per 5 seconds. The long starting sequence differs at this stage from the normal starting sequence in that an additional step is included before standard compressor speed control is initiated, during which the compressor is operated at a maximum frequency of 60 Hz for 1 minute. The long starting sequence is significantly slower than the normal starting sequence thereby allowing the system temperature to increase gradually before fully loading the compressor 12, which is appropriate in colder conditions, particularly if the compressor 12 has been inactive for a long period of time. Furthermore it may be appropriate to heat the oil for a longer period prior to initiating the long starting sequence, as discussed in relation to figure 2.

[0036] However under other circumstances neither a normal nor a long starting sequence may be appropriate, for example when the temperature of the shutdown compressor 12 is relatively high (e.g. more than about 40°C) and/or when the compressor 12 has been shutdown for only a brief period (less than an hour). In such circumstances a short starting sequence as shown in figure 5 may be more appropriate. The short starting sequence differs from the normal starting sequence in that the periods between events are generally much shorter and in some embodiments, little or no delay between events is needed. For example the LV is not kept closed after compressor startup but instead is opened up quickly as the oil perhaps does not need any additional time to heat up at the lower operating speed. The delay before closing the PEV is also short or may not even be required and the PEV can be closed quickly after compressor startup. The period of time before the compressor frequency is increased is also short and is about 5 seconds, after which the frequency is increased at a slower rate than the normal starting sequence, at about 1 Hz per second. The short starting sequence is significantly faster than the normal starting sequence as the system temperature does not need to increase gradually and the compressor 12 is capable of operating under full load relatively quickly. Furthermore it may not even be necessary to heat the oil prior to initiating the short starting sequence, as shown in figure 2.

[0037] Figure 6 schematically illustrates a refrigeration system which does not belong to the invention, although this system 10 could be and preferably is combined with the system 10 shown in figure 1 simply by adding the PEV of figure 1 (for example as shown in figure 8) or indeed with figure 7A. In the figure 6 embodiment, the components are mostly the same as those of the figure 1 embodiment and have like reference numerals. However the figure 6 embodiment further comprises a check valve 46 which is a one-way valve that prevents flow or migration of fluid in one direction (from the condenser 14 towards the compressor 12) but permits flow of fluid in the other direction (towards the condenser 14 from the compressor 12).

[0038] The system 10 of figure 6 operates as normal when the compressor 12 is running. However, in prior art systems when the compressor is shut down refrigerant migrates from the condenser and/or evaporator to the compressor due to the pressure and temperature differences, and the refrigerant can condense in the compressor and mix with the oil which is undesirable as discussed above. In the figure 6 embodiment however, refrigerant is effectively trapped between the check valve 46 and the liquid valve (LV) 44 and therefore does not reach the compressor 12. This embodiment operates as follows. When the compressor 12 is stopped, the LV is closed (preferably the LV is a liquid solenoid valve and the valve is closed by energising the solenoid) and the check valve 46 is closed (preferably the check valve is also a solenoid valve and the valve is closed by energising the solenoid, or the check valve may be closed by the pressure differential between the condenser 14 and the compressor 12. Refrigerant, that would otherwise migrate to the compressor 12, is therefore retained in the refrigerant circuit 20 between the two valves 44, 46. Even if the pressure at the inlet and outlets of the check valve 46 are balanced, the check valve 46 will not open, because the check valve 46 in this embodiment comprises a spring inside (not shown) so that no leak occurs if the pressure is balanced. The inlet pressure of the check valve 46 must be above the outlet pressure to permit circulation of the fluid. Any additional components such as an accumulator 32 and a dryer 34 in the circuit 20 help to store the refrigerant during compressor shutdown. When the compressor 12 is restarted, the LV is energised to be opened and the check valve 46 is energised or opens due to the changed pressure differential.

[0039] Figure 7A illustrates a refrigeration system which does not belong to the invention The system 10 comprises similar components as the other embodiments, including the pressure equalisation valve 40, 42 discussed with regard to figure 1 and the figure 1 embodiment can be operated in accordance with the following disclosure as well.

[0040] A conventional refrigeration system 110 is shown in figure 7B and is shown in a first state shortly after compressor shutdown and in a second state a longer time after shutdown. When the compressor 112 is shut down a large pressure differential exists between the compressor suction 111 and the compressor discharge 113, which effectively pushes the compressor oil 100 out of the compressor 112 on the suction side of the circuit 120, into line 128 and towards the evaporator 118. Therefore on compressor startup there is less oil than should be present, and in some cases little or no oil, in the compressor 112 and the compressor components are likely to be damaged. Furthermore as shown in the second diagram of figure 7B, after a period of time the oil 100 can migrate and begin to fill the evaporator 118 and also the relatively hot oil can fill the bulb of the expansion valve 116 control means 136 that is located at the exit of the evaporator 118 (i.e. in line 128). This can cause the expansion valve 116 to open even if that is not desired, further affecting the system performance on compressor startup and liquid in the compressor suction line can damage the compressor.

[0041] The refrigeration system 10 of the embodiment of figure 7A overcomes this problem by provision of the PEV, which is opened during or preferably just after compressor shutdown. This equalises the pressure differential between the compressor suction 11 and discharge 13 and thus prevents migration of oil from the compressor to the low side of the system 10.

[0042] Figure 8 schematically illustrates another embodiment of the present invention. In this embodiment, the system 10 comprises a check valve 46, a liquid valve 44 and a pressure equalisation valve 40, 42. Therefore all of the advantages disclosed in relation to the other embodiments and discussed above are provided by this system having the combination of all the valves.

Claims

1. A refrigeration system (10) comprising:

a compressor (12) having a suction and a discharge;
a heat rejecting heat exchanger (14);
an expansion valve (16);
a heat accepting heat exchanger (18);
a pressure equalisation valve (40,42) for equalising the pressure differential between the compressor suction and compressor discharge, the pressure equalisation valve comprising a bypass passage (40) connecting the compressor suction to the compressor discharge to enable the compressor to be bypassed and a valve (42) to control flow of refrigerant therethrough; and
a liquid valve (44), preferably a liquid solenoid valve, arranged in a flow line between the heat rejecting heat exchanger (14) and the expansion valve (16); **characterised by** further comprising:
means for heating at least one component of the compressor (12);
control means for activating the heating means when it is determined that compressor-startup is required, the control means starting the compressor after heating the at least one component; and
at least one sensor, the sensor sensing at least one of the temperature of the oil in the compressor (12), the compressor shell temperature, the compressor discharge temperature, the ambient temperature and the length of time for which the compressor has been inactive;
wherein the control means activates the heating means for a predetermined period of time based on at least one parameter of the system measured by the sensor, the predetermined period being based on at least one of the temperature of the oil in the compressor (12), the compressor

shell temperature, the compressor discharge temperature, the ambient temperature and the length of time for which the compressor (12) has been inactive.

2. A refrigeration system as claimed in claim 1, further comprising:

control means for operating the system in at least one of a plurality of predetermined sequences; and
at least one sensor, wherein the control means operates the system in a particular one of the plurality of predetermined sequences based on at least one parameter of the system measured by the sensor.

3. A refrigeration system as claimed in claim 1 or 2, wherein the means for heating at least one component of the compressor (12) comprises means for heating at least one of the compressor body or shell, the oil in the compressor, and the compressor motor.

4. A refrigeration system as claimed in any preceding claim, further comprising:

a sensor for sensing the temperature of oil in the compressor (12);
means for determining the saturated discharge temperature of refrigerant in the compressor (12); and
control means, wherein the means for heating at least one component of the compressor comprises means for heating at least the oil in the compressor, and wherein the control means controls the heating means such that the oil is maintained at a temperature above the saturated discharge temperature.

5. A refrigeration system as claimed in any preceding claim, wherein the heating means comprises:

means for providing an electrical current to windings of a motor of the compressor (12) to thereby heat the windings, and further comprising:

control means for controlling heating of the windings, wherein the electrical current provided to the motor windings comprises direct current (DC) and is provided for at least one predetermined periods of time.

6. A refrigeration system as claimed in any preceding claim, further comprising:

control means, wherein the control means opens the pressure equalisation valve (40,42) at substantially the same time as starting the compressor (12).

7. A method of optimizing startup of a compressor of a refrigeration system comprising the steps of:

providing a refrigeration system comprising a compressor (12), a heat rejecting heat exchanger (14), an expansion valve (16), a heat accepting heat exchanger (18), and a pressure equalisation valve (40,42) that connects a suction and a discharge of the compressor (12) for equalising the- -pressure- differential between the compressor suction and compressor discharge;
opening the pressure equalisation valve (40,42) to thereby reduce the pressure differential between the compressor suction and discharge;
and starting the compressor (12), preferably at substantially the same time as opening the pressure equalisation valve; **characterised by**
preheating at least one component of the compressor (12) the step of preheating at least one component of the compressor (12) comprising the steps of:

providing means for heating at least one component of the compressor (12); and
activating the heating means to heat the component when it is determined that compressor startup is required; and by
the step of starting the compressor (12) comprising operating the compressor (12) at a predetermined frequency f_1 that is less than the operating frequency f_n of the compressor (12) during normal operating conditions of the system, and by further comprising the step of:

opening a liquid valve (44), provided in a refrigerant flow path between the heat rejecting heat exchanger (14) and the expansion valve (16), in response to a first event;
closing the pressure equalisation valve (40,42) in response to a second event; and
increasing the operating frequency of the compressor (12).

8. A method as claimed in claim 7, further comprising the step of:

further increasing the frequency of operation of the compressor (12) to the operating frequency f_n of the compressor (12) during normal operating conditions of the system.

9. A method as claimed in claims 7 or 8, wherein:

the first event comprises at least one of a first predetermined period of time elapsing and a measured compressor oil temperature being determined to be above a predetermined threshold; and
the second event comprises at least one of a second predetermined period of time elapsing and a measured compressor oil temperature being determined to be above a predetermined threshold.

10. A method as claimed in claim 7, 8 or 9, further comprising the steps of:

providing at least one system sensor and measuring at least one parameter of the system with the sensor; and
operating the system in at least one of a plurality of predetermined sequences based on the at least one parameter measured by the sensor.

11. A method as claimed in claims 7 to 10, wherein, the means for heating at least one component of the compressor comprises means for heating at least one of the compressor body or shell, the oil in the compressor (12) and the compressor motor.

12. A method as claimed in claim 11, further comprising the step of:

providing at least one sensor and measuring at least one parameter of the system with the sensor; and wherein the heating means is activated for a predetermined period of time based on the at least one parameter.

13. A method as claimed in claim 12, wherein the predetermined period is based on at least one of the temperature of the oil in the compressor (12), the compressor shell temperature, the compressor discharge temperature, the ambient temperature and the length of time for which the compressor (12) has been inactive.

14. A method as claimed in any of claims 7 to 13, further comprising the step of:

measuring the temperature of oil in the compressor (12);
determining the saturated discharge temperature of refrigerant in the compressor (12); and
heating at least one component of the compressor such that the oil is maintained at a temperature above the saturated discharge temperature.

Patentansprüche

1. Kühlsystem (10), umfassend:

einen Kompressor (12), der einen Einlass und einen Austritt aufweist;
einen wärmeabweisenden Wärmetauscher (14);
ein Expansionsventil (16);
einen wärmeannehmenden Wärmetauscher (18);
ein Druckausgleichsventil (40, 42) zum Ausgleichen des Druckunterschieds zwischen dem Kompressoreinlass und dem Kompressoraustritt, wobei das Druckausgleichsventil einen Bypass-Kanal (40) umfasst, der den Kompressoreinlass mit dem Kompressoraustritt verbindet, um dem Kompressor zu ermöglichen, umgangen zu werden und einem Ventil (42), den Fluss von Kühlmittel dort hindurch zu steuern; und
ein Flüssigkeitsventil (44), vorzugsweise ein Flüssigkeitsmagnetventil, angeordnet in einer Flusslinie zwischen dem wärmeabweisenden Wärmetauscher (14) und dem Expansionsventil (16); **dadurch gekennzeichnet, dass** es ferner Folgendes umfasst:

Mittel zum Erwärmen von zumindest einer Komponente des Kompressors (12);
Steuermittel zum Aktivieren der Mittel zum Erwärmen, wenn bestimmt wird, dass eine Inbetriebsetzung des Kompressors erforderlich ist, wobei die Steuermittel den Kompressor nach dem Erwärmen der zumindest einen Komponente in Betrieb setzen; und
zumindest einen Sensor, wobei der Sensor zumindest eines von der Temperatur des Öls im Kompressor (12), der Kompressormanteltemperatur, der Kompressoraustrittstemperatur, der Umgebungstemperatur und der Länge der Zeit, über die der Kompressor inaktiv gewesen ist, fühlt;
wobei das Steuermittel das Mittel zum Erwärmen für einen zuvor festgelegten Zeitraum auf Grundlage von zumindest einem Parameter des Systems, der vom Sensor gemessen wurde, aktiviert, wobei der zuvor festgelegte Zeitraum auf zumindest einem von der Temperatur des Öls im Kompressor (12), der Kompressormanteltemperatur, der Kompressoraustrittstemperatur, der Umgebungstemperatur und der Länge der Zeit, über die der Kompressor (12) inaktiv gewesen ist, basiert.

2. Kühlsystem nach Anspruch 1, ferner umfassend:

Steuermittel zum Betreiben des Systems in zu-

mindest einer aus einer Vielzahl von zuvor festgelegten Sequenzen; und
zumindest einen Sensor, wobei das Steuermittel das System basierend auf zumindest einem von dem Sensor gemessenen Parameter des Systems in einer bestimmten aus der Vielzahl von zuvor festgelegten Sequenzen betreibt.

3. Kühlsystem nach Anspruch 1 oder 2, wobei das Mittel zum Erwärmen von zumindest einer Komponente des Kompressors (12) Mittel zum Erwärmen von zumindest einem von dem Kompressorkörper oder -mantel, dem Öl im Kompressor und dem Kompressormotor umfasst.

4. Kühlsystem nach einem vorhergehenden Anspruch, ferner umfassend:

einen Sensor zum Fühlen der Temperatur des Öls im Kompressor (12);
Mittel zum Bestimmen der gesättigten Austrittstemperatur des Kühlmittels im Kompressor (12); und
Steuermittel, wobei die Mittel zum Erwärmen von zumindest einer Komponente des Kompressors Mittel zum Erwärmen von zumindest dem Öl im Kompressor umfasst, und wobei das Steuermittel das Mittel zum Erwärmen derart steuert, dass das Öl bei einer Temperatur oberhalb der gesättigten Austrittstemperatur gehalten wird.

5. Kühlsystem nach einem vorhergehenden Anspruch, wobei das Mittel zum Erwärmen Folgendes umfasst:

Mittel zum Bereitstellen eines elektrischen Stroms an Gewinde eines Motors des Kompressors (12), um dadurch die Gewinde zu erwärmen, und ferner umfassend:

Steuermittel zum Steuern der Erwärmung der Gewinde, wobei der den Motorgewinden bereitgestellte elektrische Strom Gleichstrom (DC) umfasst und über zumindest einen zuvor festgelegten Zeitraum bereitgestellt wird.

6. Kühlsystem nach einem vorhergehenden Anspruch, ferner umfassend:

Steuermittel, wobei das Steuermittel das Druckausgleichsventil (40, 42) im Wesentlichen zur gleichen Zeit, zu der der Kompressor (12) in Betrieb genommen wird, öffnet.

7. Verfahren zum Optimieren der Inbetriebnahme eines Kompressors eines Kühlsystems, umfassend die folgenden Schritte:

Bereitstellen eines Kühlsystems, umfassend einen Kompressor (12), einen wärmeabweisenden Wärmetauscher (14), ein Expansionsventil (16), einen wärmeannehmenden Wärmetauscher (18) und ein Druckausgleichsventil (40, 42), das einen Einlass und einen Austritt des Kompressors (12) verbindet, um den Druckunterschied zwischen dem Kompressoreinlass und dem Kompressoraustritt auszugleichen;
Öffnen des Druckausgleichsventils (40, 42), um dadurch den Druckunterschied zwischen dem Kompressoreinlass und -austritt zu reduzieren; und
Inbetriebnahme des Kompressors (12), vorzugsweise im Wesentlichen zur gleichen Zeit, zu der das Druckausgleichsventil geöffnet wird;
gekennzeichnet durch Vorwärmen von zumindest einer Komponente des Kompressors (12), wobei der Schritt des Vorwärmens von zumindest einer Komponente des Kompressors (12) die folgenden Schritte umfasst:

Bereitstellen von Mitteln zum Erwärmen von zumindest einer Komponente des Kompressors (12); und
Aktivieren der Mittel zum Erwärmen, um die Komponente zu erwärmen, wenn bestimmt wird, dass eine Inbetriebnahme des Kompressors erforderlich ist; und durch
den Schritt der Inbetriebnahme des Kompressors (12), umfassend das Betreiben des Kompressors (12) bei einer zuvor festgelegten Frequenz f_1, die geringer als die Betriebsfrequenz f_n des Kompressors (12) während normaler Betriebsbedingungen des Systems ist, und ferner durch Umfassen des Schrittes des: Öffnens eines Flüssigkeitsventils (44), bereitgestellt in einem Kühlmittelflussweg zwischen dem wärmeabweisenden Wärmetauscher (14) und dem Expansionsventil (16), als Reaktion auf ein erstes Ereignis;
Schließens des Druckausgleichsventils (40, 42) als Reaktion auf ein zweites Ereignis; und
Erhöhens der Betriebsfrequenz des Kompressors (12).

8. Verfahren nach Anspruch 7, ferner den folgenden Schritt umfassend:

weiteres Erhöhen der Betriebsfrequenz des Kompressors (12) auf die Betriebsfrequenz f_n des Kompressors (12) während normaler Betriebsbedingungen des Systems.

9. Verfahren nach Anspruch 7 oder 8, wobei:

das erste Ereignis zumindest eines von einem ersten zuvor festgelegten ablaufenden Zeitraum und einer gemessenen Kompressoröltemperatur, in Bezug auf die bestimmt wird, dass sie oberhalb einer zuvor festgelegten Schwelle liegt, umfasst; und

das zweite Ereignis zumindest eines von einem zweiten zuvor festgelegten ablaufenden Zeitraum und einer gemessenen Kompressoröltemperatur, in Bezug auf die bestimmt wird, dass sie oberhalb einer zuvor festgelegten Schwelle liegt, umfasst.

10. Verfahren nach Anspruch 7, 8 oder 9, ferner die folgenden Schritte umfassend:

Bereitstellen von zumindest einem Systemsensor und Messen von zumindest einem Parameter des Systems mit dem Sensor; und

Betreiben des Systems in zumindest einer aus einer Vielzahl von zuvor festgelegten Sequenzen basierend auf dem zumindest einen von dem Sensor gemessenen Parameter.

11. Verfahren nach Anspruch 7 bis 10, wobei das Mittel zum Erwärmen von zumindest einer Komponente des Kompressors Mittel zum Erwärmen von zumindest einem von dem Kompressorkörper oder -mantel, dem Öl im Kompressor (12) und dem Kompressormotor umfasst.

12. Verfahren nach Anspruch 11, ferner umfassend den Schritt des:

Bereitstellens von zumindest einem Sensor und Messens von zumindest einem Parameter des Systems mit dem Sensor; und

wobei das Mittel zum Erwärmen für einen zuvor festgelegten Zeitraum basierend auf dem zumindest einen Parameter aktiviert wird.

13. Verfahren nach Anspruch 12, wobei der zuvor festgelegte Zeitraum auf zumindest einem von der Temperatur des Öls im Kompressor (12), der Kompressormanteltemperatur, der Kompressoraustrittstemperatur, der Umgebungstemperatur und der Länge der Zeit, über die der Kompressor (12) inaktiv gewesen ist, basiert.

14. Verfahren nach einem der Ansprüche 7 bis 13, ferner umfassend den folgenden Schritt:

Messen der Temperatur des Öls im Kompressor (12);

Bestimmen der gesättigten Austrittstemperatur des Kühlmittels im Kompressor (12); und

Erwärmen von zumindest einer Komponente des Kompressors, sodass das Öl bei einer Temperatur oberhalb der gesättigten Austrittstemperatur gehalten wird.

Revendications

1. Système de réfrigération (10) comprenant :

un compresseur (12) ayant une aspiration et une sortie ;

un échangeur de chaleur rejetant la chaleur (14) ;

un détendeur (16) ;

un échangeur de chaleur acceptant la chaleur (18) ;

une vanne d'égalisation de pression (40, 42) pour égaliser le différentiel de pression entre l'aspiration du compresseur et la sortie du compresseur, la vanne d'égalisation de pression comprenant un passage de dérivation (40) reliant l'aspiration du compresseur à la sortie du compresseur pour permettre de contourner le compresseur et une vanne (42) pour commander le flux de réfrigérant à travers celui-ci ; et

une vanne de liquide (44), de préférence une vanne solénoïde de liquide, agencée dans une conduite d'écoulement entre l'échangeur de chaleur rejetant la chaleur (14) et le détendeur (16) ;

caractérisé en ce qu'il comprend en outre :

un moyen pour chauffer au moins un composant du compresseur (12) ;

un moyen de commande pour activer le moyen de chauffage lorsqu'il est déterminé que le démarrage du compresseur est nécessaire, le moyen de commande démarrant le compresseur après chauffage de l'au moins un composant ; et

au moins un capteur, le capteur détectant au moins une parmi la température de l'huile dans le compresseur (12), la température de l'enveloppe du compresseur, la température de refoulement du compresseur, la température ambiante et la longueur de temps pendant laquelle le compresseur a été inactif ;

dans lequel le moyen de commande active le moyen de chauffage pendant une période prédéterminée en fonction d'au moins un paramètre du système mesuré par le capteur, la période prédéterminée étant fonction d'au moins une parmi la température de l'huile dans le compresseur (12), la température de l'enveloppe du compresseur, la température de refoulement du compresseur, la température ambiante et la longueur de temps pendant laquelle le compresseur (12) a été inactif.

2. Système de réfrigération selon la revendication 1, comprenant en outre :

un moyen de commande pour actionner le système dans au moins une parmi une pluralité de séquences prédéterminées ; et
au moins un capteur, dans lequel le moyen de commande actionne le système dans une en particulier parmi la pluralité de séquences prédéterminées en fonction d'au moins un paramètre du système mesuré par le capteur.

3. Système de réfrigération selon la revendication 1 ou 2, dans lequel le moyen pour chauffer au moins un composant du compresseur (12) comprend un moyen pour chauffer au moins un parmi le corps ou l'enveloppe du compresseur, l'huile dans le compresseur, et le moteur du compresseur.

4. Système de réfrigération selon une quelconque revendication précédente, comprenant en outre :

un capteur pour détecter la température de l'huile dans le compresseur (12) ;
un moyen pour déterminer la température de refoulement saturée de réfrigérant dans le compresseur (12) ; et
un moyen de commande, dans lequel le moyen pour chauffer au moins un composant du compresseur comprend un moyen pour chauffer au moins l'huile dans le compresseur, et dans lequel le moyen de commande commande le moyen de chauffage de telle sorte que l'huile est maintenue à une température supérieure à la température de refoulement saturée.

5. Système de réfrigération selon une quelconque revendication précédente, dans lequel le moyen de chauffage comprend :

un moyen pour fournir un courant électrique à des enroulements d'un moteur du compresseur (12) pour chauffer ainsi les enroulements, et comprenant en outre :

un moyen de commande pour commander le chauffage des enroulements, dans lequel le courant électrique fourni aux enroulements du moteur comprend du courant continu (DC) et est fourni pendant au moins une période prédéterminée.

6. Système de réfrigération selon une quelconque revendication précédente, comprenant en outre :

un moyen de commande, dans lequel le moyen de commande ouvre la vanne d'égalisation de pression (40, 42) sensiblement en même temps que le démarrage du compresseur (12).

7. Procédé pour optimiser le démarrage d'un compresseur d'un système de réfrigération, comprenant les étapes consistant à : prévoir un système de réfrigération comprenant un compresseur (12), un échangeur de chaleur rejetant la chaleur (14), un détendeur (16), un échangeur de chaleur acceptant la chaleur (18), et une vanne d'égalisation de pression (40, 42) qui relie une aspiration et une sortie du compresseur (12) pour égaliser le différentiel de pression entre l'aspiration du compresseur et la sortie du compresseur ;
ouvrir la vanne d'égalisation de pression (40, 42) pour réduire ainsi le différentiel de pression entre l'aspiration et la sortie du compresseur ; et
démarrer le compresseur (12), de préférence sensiblement en même temps que l'ouverture de la vanne d'égalisation de pression ; **caractérisé par**
le préchauffage d'au moins un composant du compresseur (12) l'étape de préchauffage d'au moins un composant du compresseur (12) comprenant les étapes consistant à :

prévoir un moyen pour chauffer au moins un composant du compresseur (12) ; et
activer le moyen de chauffage pour chauffer le composant lorsqu'il est déterminé que le démarrage du compresseur est nécessaire ; et par
l'étape de démarrage du compresseur (12) comprenant l'actionnement du compresseur (12) à une fréquence prédéterminée f_1 qui est inférieure à la fréquence de fonctionnement f_n du compresseur (12) dans des conditions normales de fonctionnement du système, et par le fait qu'il comprend en outre l'étape consistant à :

ouvrir une vanne de liquide (44), prévue dans une trajectoire de réfrigérant entre l'échangeur de chaleur rejetant la chaleur (14) et le détendeur (16), en réponse à un premier événement ;
fermer la vanne d'égalisation de pression (40, 42) en réponse à un second événement ; et
augmenter la fréquence de fonctionnement du compresseur (12).

8. Procédé selon la revendication 7, comprenant en outre l'étape consistant à :

augmenter encore la fréquence de fonctionnement du compresseur (12) jusqu'à la fréquence de fonctionnement f_n du compresseur (12) dans des conditions normales de fonctionnement du système.

9. Procédé selon les revendications 7 ou 8, dans lequel :

le premier événement comprend au moins un parmi l'écoulement d'une première période prédéterminée et la détermination d'une température d'huile de compresseur mesurée comme étant supérieure à un seuil prédéterminé ; et
le second événement comprend au moins un parmi l'écoulement d'une seconde période prédéterminée et la détermination d'une température d'huile de compresseur mesurée comme étant supérieure à un seuil prédéterminé.

10. Procédé selon la revendication 7, 8 ou 9, comprenant en outre les étapes consistant à :

prévoir au moins un capteur de système et mesurer au moins un paramètre du système avec le capteur ; et
actionner le système dans au moins une parmi une pluralité de séquences prédéterminées en fonction de l'au moins un paramètre mesuré par le capteur.

11. Procédé selon les revendications 7 à 10, dans lequel, le moyen pour chauffer au moins un composant du compresseur comprend un moyen pour chauffer au moins un parmi le corps ou l'enveloppe du compresseur, l'huile dans le compresseur (12) et le moteur du compresseur.

12. Procédé selon la revendication 11, comprenant en outre l'étape consistant à :

prévoir au moins un capteur et mesurer au moins un paramètre du système avec le capteur ; et dans lequel le moyen de chauffage est activé pour une période prédéterminée en fonction de l'au moins un paramètre.

13. Procédé selon la revendication 12, dans lequel la période prédéterminée est fonction d'au moins une parmi la température de l'huile dans le compresseur (12), la température de l'enveloppe du compresseur, la température de refoulement du compresseur, la température ambiante et la longueur de temps pendant laquelle le compresseur (12) a été inactif.

14. Procédé selon l'une quelconque des revendications 7 à 13, comprenant en outre l'étape consistant à :

mesurer la température de l'huile dans le compresseur (12) ;
déterminer la température de refoulement saturée de réfrigérant dans le compresseur (12) ; et
chauffer au moins un composant du compresseur de telle sorte que l'huile est maintenue à une température supérieure à la température de refoulement saturée.

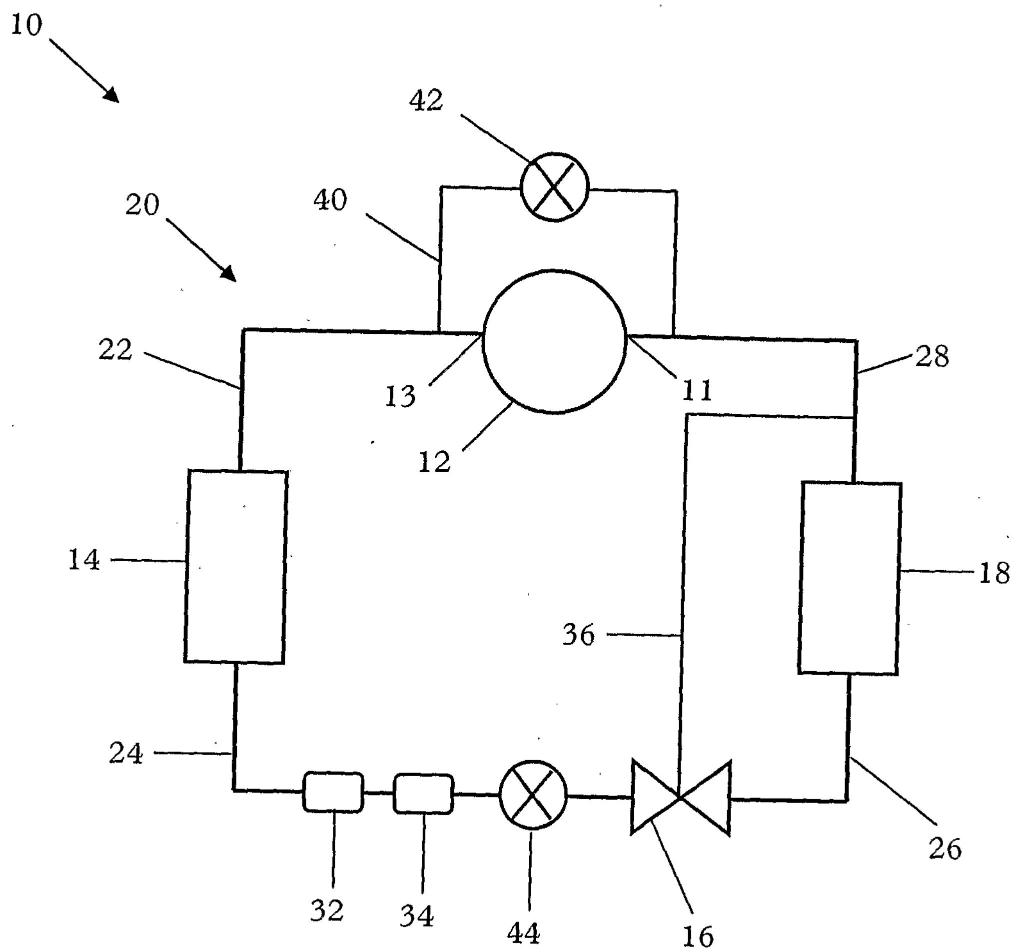

Figure 1

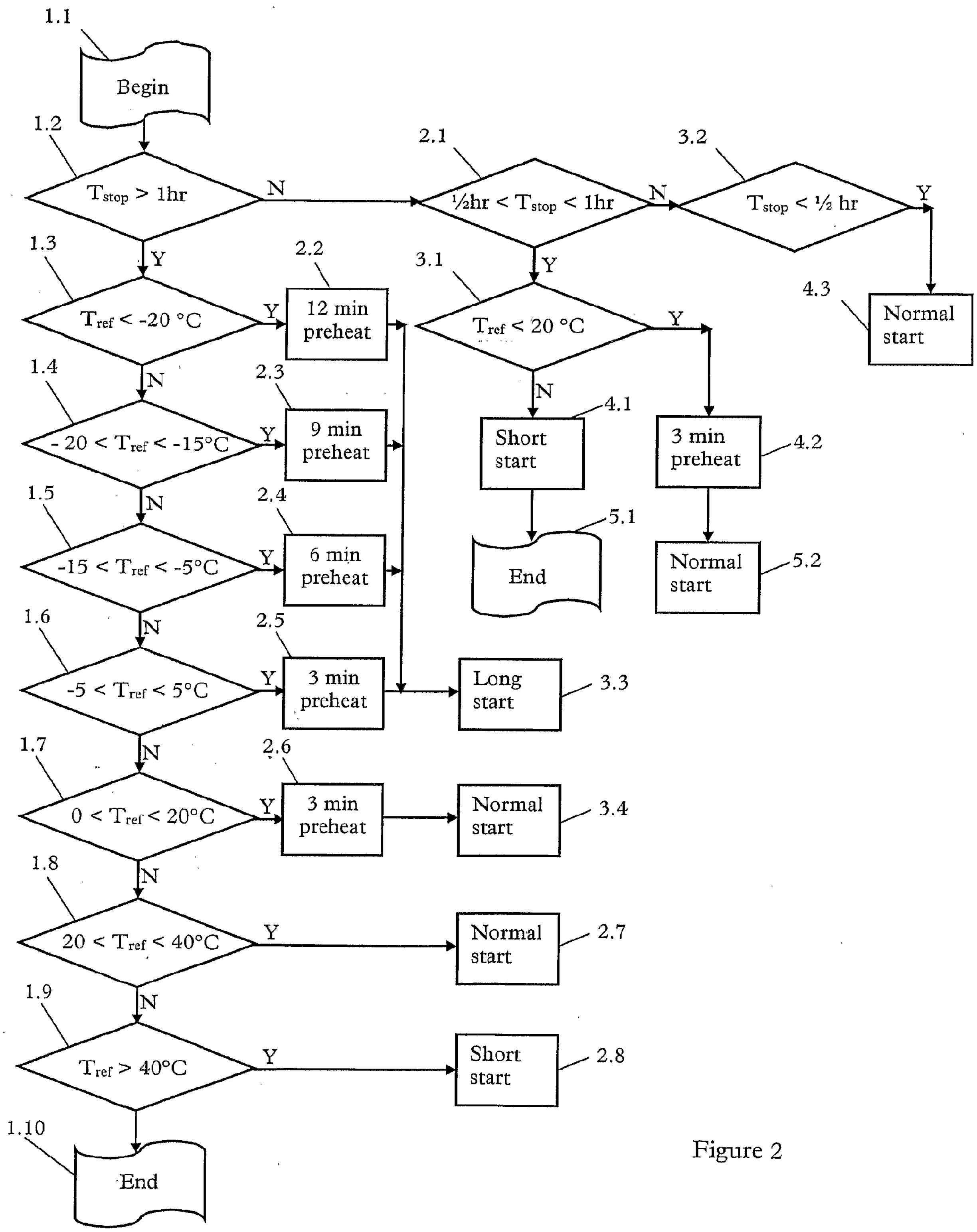
1.1
Begin
1.2
T_{stop} > 1hr
N
Y
2.1
½hr < T_{stop} < 1hr
N
3.2
T_{stop} < ½ hr
Y
4.3
Normal start
1.3
T_{ref} < -20 °C
Y
2.2
12 min preheat
3.1
T_{ref} < 20 °C
Y
N
4.1
Short start
3 min preheat
4.2
5.1
End
Normal start
5.2
1.4
- 20 < T_{ref} < -15°C
2.3
9 min preheat
1.5
-15 < T_{ref} < -5°C
2.4
6 min preheat
1.6
-5 < T_{ref} < 5°C
2.5
3 min preheat
Long start
3.3
1.7
0 < T_{ref} < 20°C
2.6
3 min preheat
Normal start
3.4
1.8
20 < T_{ref} < 40°C
Normal start
2.7
1.9
T_{ref} > 40°C
Short start
2.8
1.10
End

Figure 2

Normal

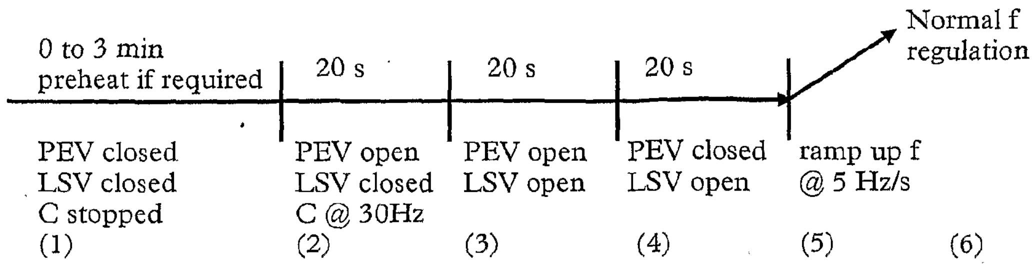

Figure 3

Long

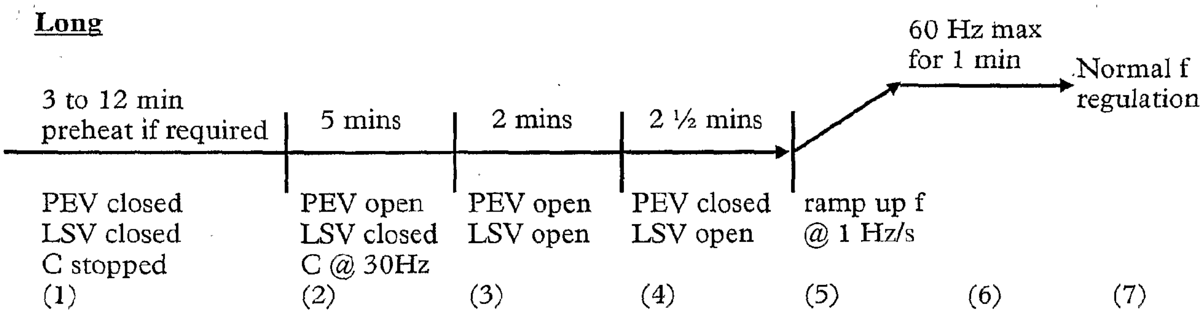

Figure 4

Short

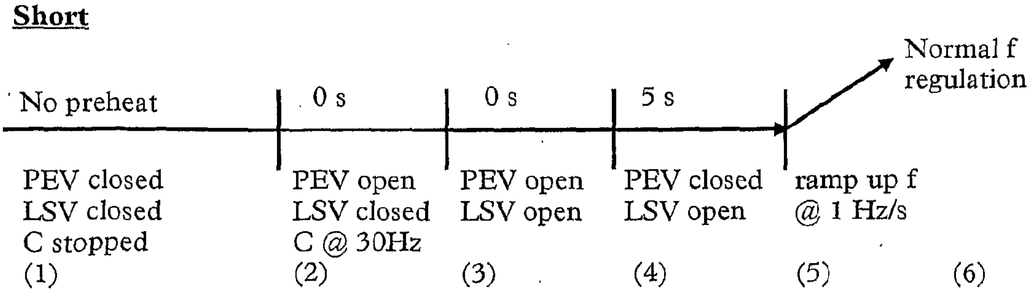

Figure 5

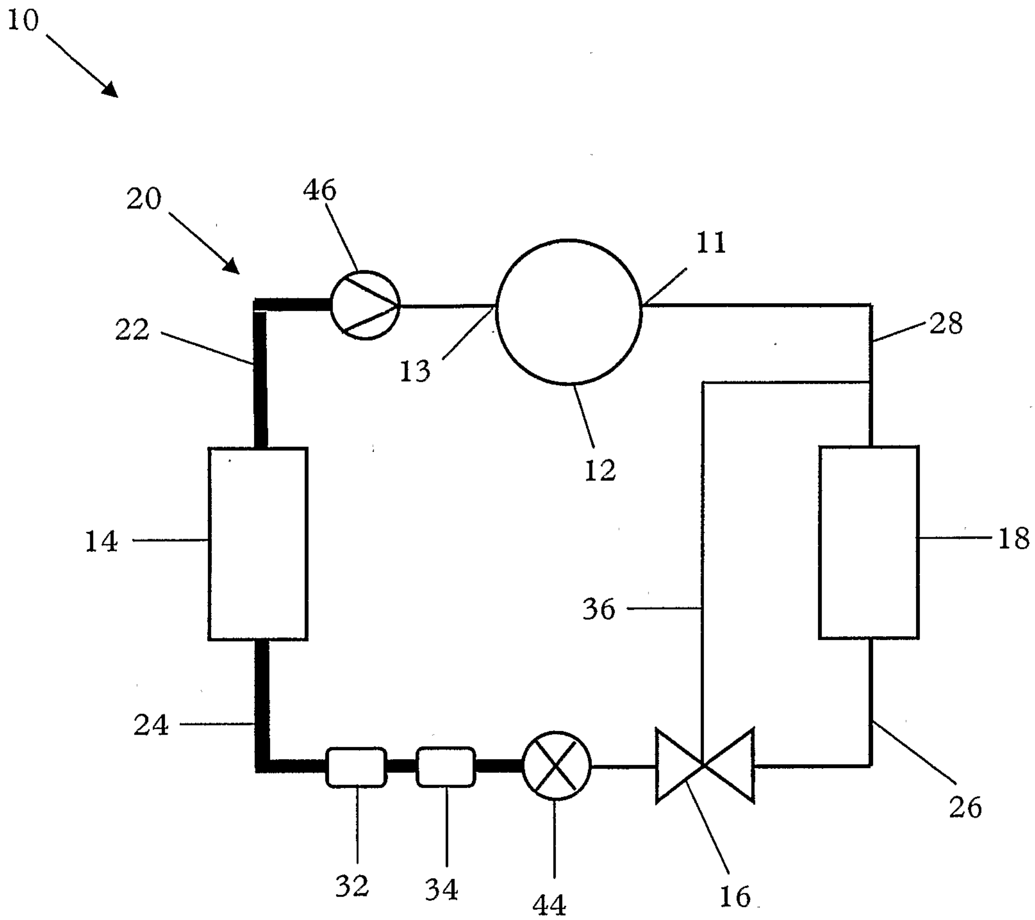

Figure 6

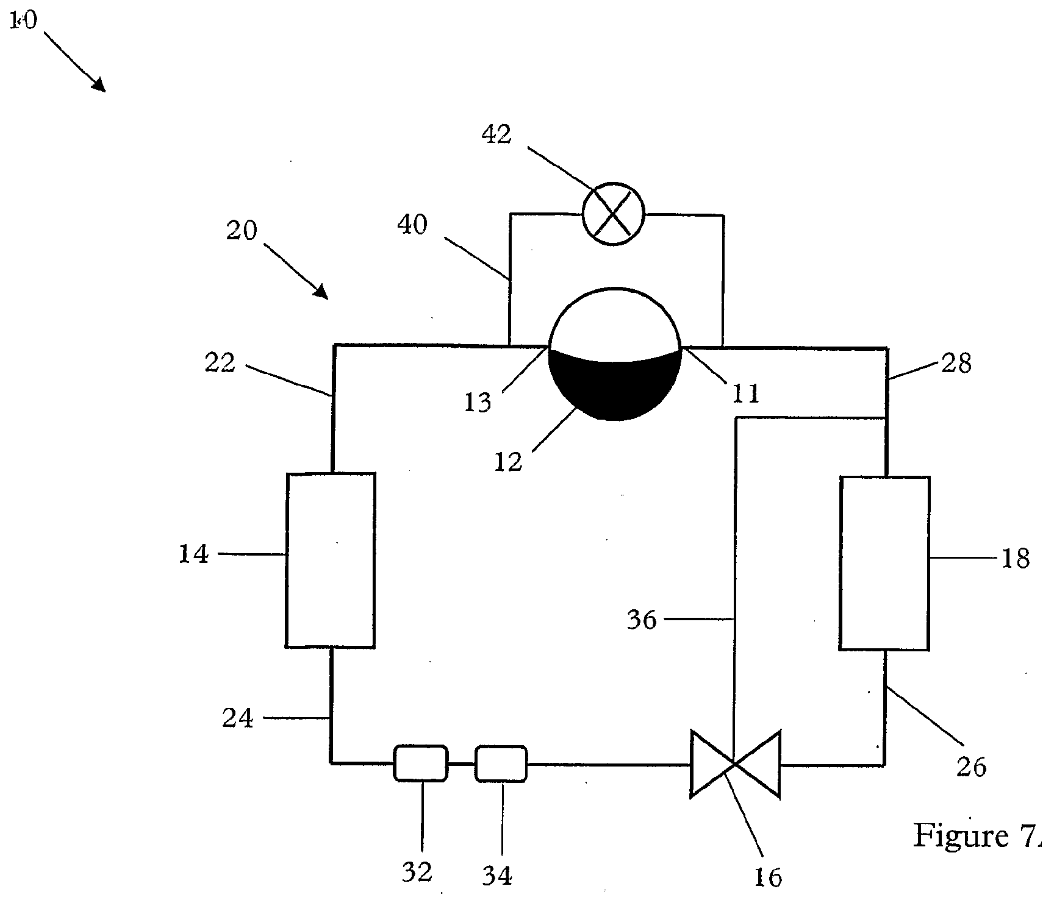

Figure 7A

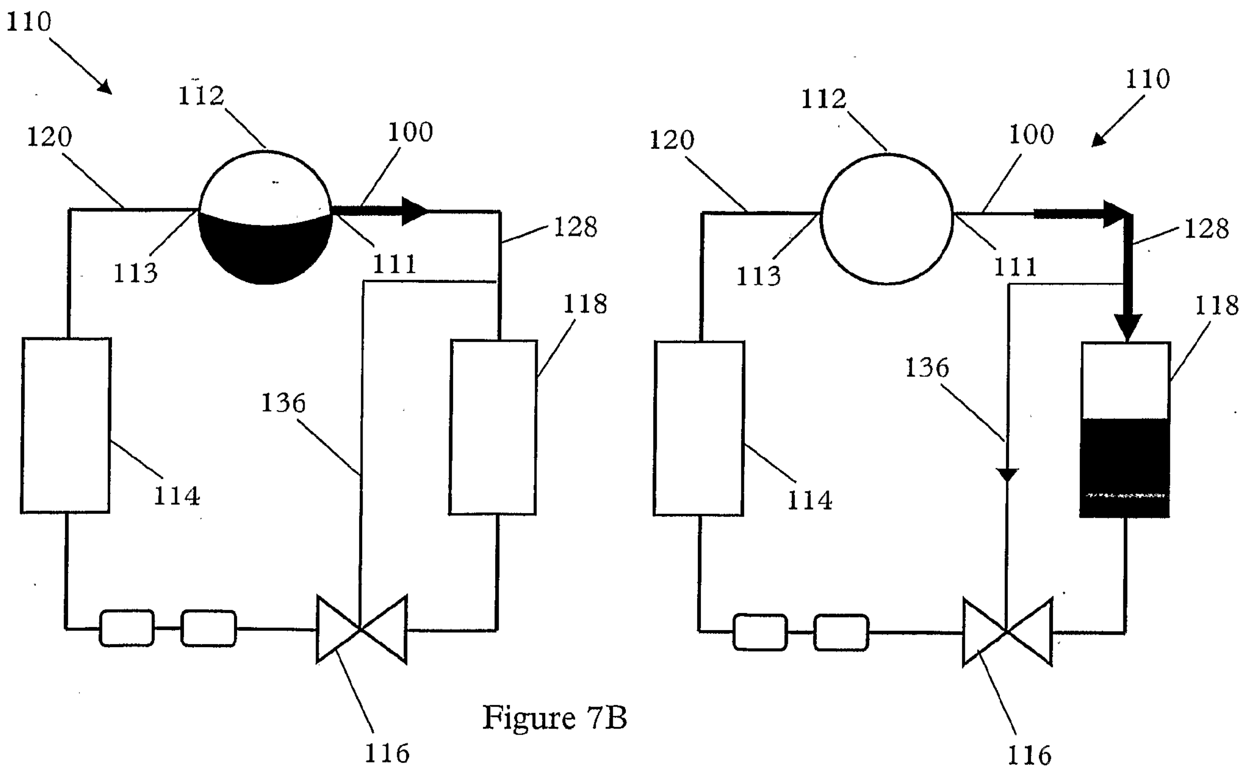

Figure 7B

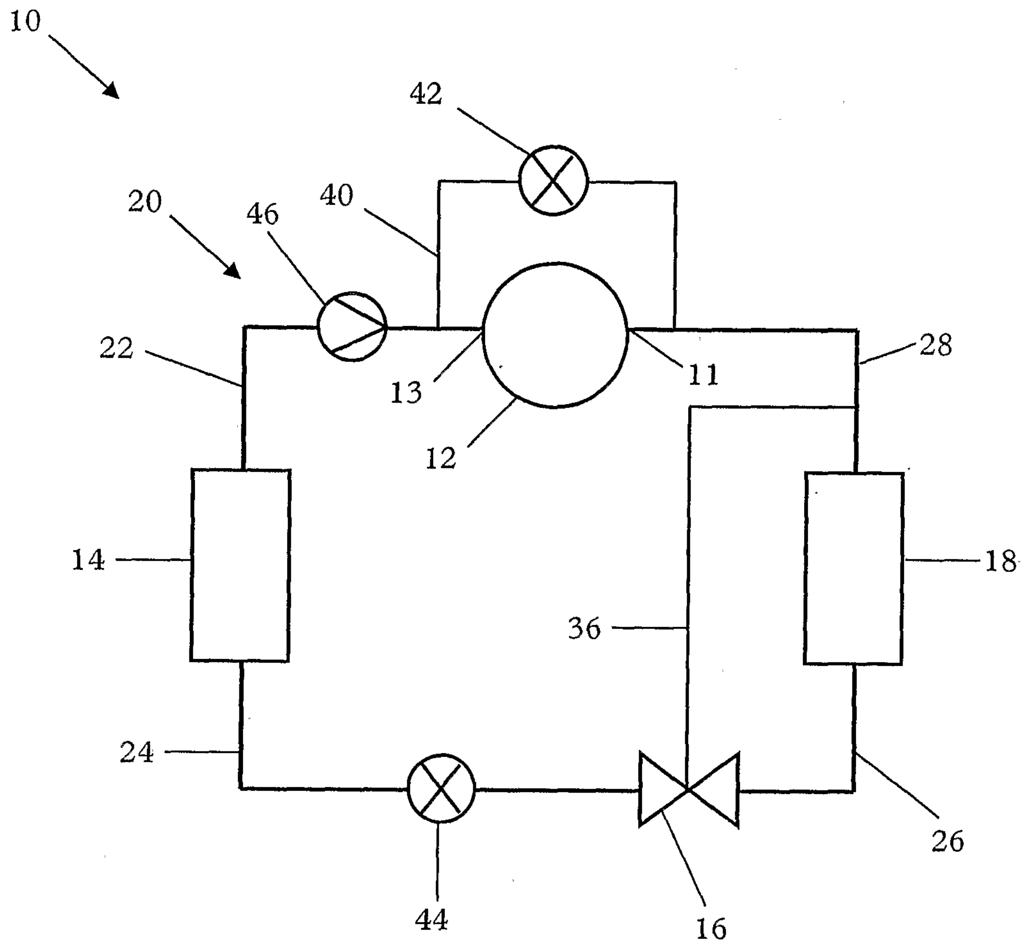

Figure 8

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- EP 1702667 A **[0003]**