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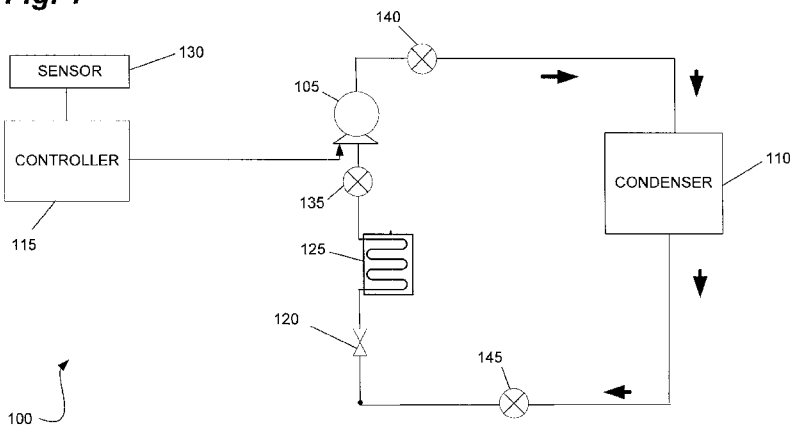
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(54) Title: LOADING AND UNLOADING OF COMPRESSORS IN A COOLING SYSTEM

Fig. 1



(57) Abstract: A system and method of loading and unloading a compressor in a cooling system. The method includes detecting a temperature, determining a compressor should be turned on/off to supply/stop supplying cooling based on the temperature, turning the compressor on/off, and opening/closing a plurality of valves when the compressor is turned on/off.

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LOADING AND UNLOADING OF COMPRESSORS IN A COOLING SYSTEM

BACKGROUND

[0001] The present invention relates to cycling of compressors, specifically rapid cycling of scroll compressors.

[0002] Compressors are integral parts of cooling systems (e.g., air conditioners, refrigerators, etc.). Compressors compress refrigerant which later expands and draws heat out of the environment. The amount the refrigerant is compressed is directly related to the amount of heat the evaporating refrigerant can remove from the environment. The compressors are turned on or off (loaded/unloaded) to control the pressure of the refrigerant and the cooling capacity of the system. The turning on and off of a compressor causes wear and tear on the compressor that can lead to higher maintenance costs and reduce the life of the compressor. The wear and tear is increased when the compressor is cycled on and off too rapidly. Thus, compressors are controlled to have minimum-cycle-times (e.g., a minimum of three minutes on and a minimum of three minutes off) to reduce the wear and tear on the compressor. These-cycle-times reduce the ability to tightly control the cooling effects of the system (e.g., resulting in excessively wide temperature swings), and reduce the efficiency of the system (e.g. resulting in increased energy usage).

SUMMARY

[0003] In one embodiment, the invention provides a method of loading and unloading a compressor in a cooling system. The method includes detecting a temperature, determining a compressor should be turned on to supply cooling based on the temperature, determining a point in time when the impact of turning on a motor of the compressor is minimized using point-on-wave analysis, and turning on the compressor at about the determined point in time.

[0004] In another embodiment the invention provides a method of loading and unloading a compressor in a cooling system. The method includes detecting a temperature, determining a compressor should be turned on to supply cooling based on the temperature, turning on the compressor, and opening a plurality of valves when the compressor is turned on.

[0005] In another embodiment the invention provides a cooling system. The cooling system includes a compressor; a temperature sensor, a compressor intake valve, a compressor output valve, and a controller. The temperature sensor is configured to provide

an indication of a temperature. The compressor intake valve is coupled to an input of the compressor. The compressor output valve is coupled to an output of the compressor. The controller is coupled to the compressor, the temperature sensor, the compressor intake valve, and the compressor output valve. The controller is also configured to receive the indication of the temperature from the temperature sensor, determine that the compressor should be turned off to stop providing cooling based on the indication of temperature received from the temperature sensor, turn off the compressor, close the compressor intake valve, and close the compressor output valve, wherein closing the compressor intake valve and the compressor output valve maintains a pressure of refrigerant across the compressor while the compressor is off.

[0006] Other aspects of the invention will become apparent by consideration of the detailed description and accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] Fig. 1 is a block diagram of a single compressor cooling system.

[0008] Fig. 2 is a block diagram of a multiple compressor cooling system.

[0009] Fig. 3A is a graph showing the operation of a prior-art cooling system.

[0010] Fig. 3B is a graph showing the operation of a cooling system employing the invention.

DETAILED DESCRIPTION

[0011] Before any embodiments of the invention are explained in detail, it is to be understood that the invention is not limited in its application to the details of construction and the arrangement of components set forth in the following description or illustrated in the following drawings. The invention is capable of other embodiments and of being practiced or of being carried out in various ways.

[0012] The examples described below show various cooling systems. However, the invention has application in other constructions such as heat pumps as well.

[0013] Fig. 1 is a block diagram of a cooling system 100 (e.g., a residential air-conditioner). The system 100 includes a compressor 105, a condenser 110, a controller 115, an expansion valve 120, an evaporator 125, a temperature sensor 130, a first valve 135 (a compressor intake valve), a second valve 140 (a compressor output valve), and a third valve 145 (an evaporator valve).

[0014] The controller 115 receives an indication of a temperature from the temperature sensor 130. Depending on the system, the temperature can be an air temperature (e.g., a direct cooling system) or a temperature of a coolant (e.g., chiller water or a refrigerant).

[0015] The controller 115 determines if cooling is needed, turning on the compressor 105 when cooling is needed, and turning off the compressor 105 when cooling is not needed. In some embodiments, the controller 115 anticipates the need for cooling, turning the compressor 105 on prior to the temperature reaching a turn-on set-point, and turning off the compressor 105 prior to reaching a turn-off set-point. In some constructions, the controller uses a proportional-integral-derivative (PID) control scheme to operate the compressor 105. United States Patent No. 5,415,346, filed January 28, 1994, and entitled "Apparatus and Method for Reducing Overshoot in Response to the Setpoint Change of an Air Conditioning System," the entire content of which is hereby incorporated by reference, describes such a method of controlling the operation of an air conditioning system. In some embodiments, as described below, the controller 115 also controls the compressor 105 using a scheme designed to reduce wear and tear on the compressor 105.

[0016] When the controller 115 turns the compressor 105 on, the compressor 105 compresses a refrigerant in the cooling system 100 to provide cooling capacity for the system 100. The refrigerant flows through piping to the condenser 110 which condenses the refrigerant into a liquid. The refrigerant continues on to the expansion valve 120. The expansion value 120 causes the refrigerant to expand and transform into a gas. This process occurs as the refrigerant passes through the evaporator 125. As this happens, the refrigerant, in the evaporator 125, removes heat from the air surrounding the evaporator 125, resulting in the air (or water) being cooled. The refrigerant then continues on back to the compressor 105.

[0017] In addition to turning the compressor 105 on and off, the controller 115 also opens (when turning on the compressor 105) and closes (when turning off the compressor

105) the first, second, and third valves 135, 140, and 145. As the pressure of the refrigerant varies significantly throughout the cooling system 100, closing the valves 135, 140, and 145 traps the pressure of the refrigerant in zones or sections of the system 100. This enables the refrigerant exiting the compressor 105 to achieve its full pressure nearly immediately upon the compressor 105 being turned on, improving the performance of the system 100. Other schemes are contemplated as well, including sequencing of the opening and closing of the valves 135, 140, and 145, and timing the opening and closing of the valves 135, 140, and 145 such that they open or close before or after the compressor 105 is turned on/off.

[0018] In some constructions, the temperature sensor 130 is a thermostat. The thermostat 130 provides a signal to the controller 115 (e.g., a motor controller) indicating whether the controller 115 should turn on the compressor 105 or turn off the compressor 105 based on a temperature set-point, and a dead-band. The thermostat 130 may or may not have intelligence enabling the thermostat 130 to anticipate the thermal inertia of the area to be cooled.

[0019] Fig. 2 is a block diagram of an exemplary large-scale cooling system 200 (e.g., for cooling a commercial building, for cooling a plurality of refrigerated display cases, etc.). The cooling system 200 includes at least one compressor 205, a condenser 210, a receiver 215 (optional), a controller 220, a suction header 230, a plurality of expansion valves 235, a plurality of evaporators 240, a plurality of intake valves 245, and a plurality of output valves 250. In some constructions, where all of the compressors 205 are operated in unison (i.e., all the compressors 205 are turned on and turned off at the same time), a single intake valve 245 is used prior to the suction header 230 and/or a single output valve 250 is used after common piping for the compressors 205. In addition, the system 200 includes an evaporator valve 255 between the receiver 215 and the expansion valves 235. In some constructions, multiple evaporator valves 255 are used, e.g., an evaporator valve 255 positioned before each expansion valve 235.

[0020] One or more temperature sensors may be used to detect the temperature of an area or a coolant cooled by the evaporators 240. The controller 220 receives an indication of the temperature from the sensor, and controls the compressors 205 based on the temperature as described above with respect to cooling system 100.

[0021] The compressor 205 compresses a refrigerant in the cooling system 200 to provide cooling capacity for the system. In a cooling system 200 with more than one compressor 205, the compressors 205 can turn on and off at the same or different times to meet the demand required by the system. In some constructions, all of the compressors 205

are of one or more fixed capacities, and the controller 220 stages or loads the compressors 205 into the system as necessary, for example as described in United States Patent No. 5,123,256, filed May 7, 1991, and entitled "Method of Compressor Staging for a Multi-Compressor Refrigeration System," the entire content of which is hereby incorporated by reference. When a compressor 205 is turned off, the intake valve 245 and the output valve 250 associated with the compressor 205 are closed, maintaining high-side and low-side pressures within the evaporator 110 and condenser 125. When the compressor 205 is turned on, the intake valve 245 and the output valve 250 associated with the compressor 205 are opened, and the compressor 205 gets to operating pressure nearly immediately. If all of the compressors 205 in the system 200 are turned off, the evaporator valve 255 is also closed.

[0022] In some embodiments, the controller 220 controls the compressors 105/205 using a scheme designed to reduce wear and tear on the compressors 205. U.S. Patent No. 7,812,563, the entire content of which is hereby incorporated by reference, discloses a technology referred to a point-on-wave (POW) switching. POW switching determines when to power (i.e., switch on) a winding (i.e., a phase) of a motor based on the relationship between the wave of the phase of AC power to be supplied with the wave(s) of the phase(s) of AC power presently supplied to the other winding(s) of the motor. The invention monitors each phase of AC voltage supplied to the windings of the motor(s) of the compressor(s) through precision DC contactors (although AC contactors could be used instead), switching a contactor and powering a phase only when the relationship between the phases will result in the least amount of stress on the compressor motor.

[0023] The use of POW switching, and the maintaining of pressure zones using valves, enables the invention to reduce or eliminate cycling delays for compressors of cooling systems, increasing efficiency and comfort. Some prior art cooling systems have used multiple smaller compressors to improve the performance of the cooling system (e.g., to narrow the temperature control range). The invention enables the use of a single larger compressor while achieving the same or better levels of performance and efficiency, than achieved using multiple smaller compressors.

[0024] Fig. 3A shows a graph of temperature TEMP versus a set point, and a related on/off indication 400 of a compressor of a prior art system. When the temperature TEMP is above the set point, the controller turns the compressor on if a minimum off-cycle-time has been met. Conversely, when the temperature TEMP is below the set point, the controller turns the compressor off if a minimum on-cycle-time has been met. In the graph shown in

Fig. 3A, the temperature is changing faster than the-cycle-times. Thus, there is a delay of ΔD_1 between when the temperature TEMP rises above the set point, and when the controller turns the compressor on. A similar time delay ΔD_2 occurs when the temperature TEMP drops below the deadband before the controller turns the compressor off.

[0025] These delays, caused by the cycle times, result in the compressor running longer (ΔD_2) than necessary, wasting energy. In addition, the delays (ΔD_1 and ΔD_2) cause the temperature range (ΔT_1) to be greater than necessary, potentially causing discomfort to occupants of the area cooled by the cooling system.

[0026] As shown in Fig. 3B, by being able to turn compressors on and off at any time (i.e., without cycle delays), and maintaining pressure in the compressors when they are off, the delays (ΔD_1 and ΔD_2) are eliminated. In fact, the compressors can be turned on and off in anticipation of the temperature being above/below the set-point/deadband (ΔD_3 and ΔD_4). This reduces energy usage, and results in a much narrower temperature range (ΔT_2 versus ΔT_1) increasing the comfort of occupants.

[0027] Various features and advantages of the invention are set forth in the following claims.

CLAIMS

What is claimed is:

1. A method of loading and unloading a compressor in a cooling system, the method comprising:

detecting a temperature;

determining a compressor should be turned on to supply cooling based on the temperature;

determining a point in time when the impact of turning on a motor of the compressor is minimized using point-on-wave analysis; and

turning on the compressor at about the determined point in time.

2. The method of claim 1, further comprising

determining a compressor should be turned off to stop supplying cooling based on the detected temperature;

determining a second point in time when the impact of turning off the motor of the compressor is minimized using point-on-wave analysis; and

turning off the compressor at about the determined second point in time.

3. The method of claim 2, further comprising closing a compressor intake valve and a compressor output valve when the compressor is turned off.

4. The method of claim 1, further comprising opening a compressor intake valve and a compressor output valve when the compressor is turned on.

5. The method of claim 1, wherein the cooling system is a residential air conditioner.

6. The method of claim 1, wherein the power to the compressor is applied by closing a DC contactor.

7. The method of claim 1, further comprising anticipating that cooling will be required, wherein the compressor is turned on prior to a set-point temperature being reached.

8. The method of claim 1, wherein the compressor is one of a plurality of compressors for the cooling system, and the acts of claim 1 are performed for loading each of the plurality of compressors.

9. The method of claim 1, further comprising opening an evaporator valve when the compressor is turned on and closing the evaporator valve when the compressor is turned off.

10. A method of loading and unloading a compressor in a cooling system, the method comprising:

detecting a temperature;

determining a compressor should be turned on to supply cooling based on the temperature;

turning on the compressor; and

opening a plurality of valves when the compressor is turned on.

11. The method of claim 10, wherein the plurality of valves includes a compressor intake valve and a compressor outlet valve.

12. The method of claim 10, further comprising

determining the compressor should be turned off to stop supplying cooling based on the temperature;

turning off the compressor;

closing the plurality of valves when the compressor is turned off.

13. The method of claim 10, wherein the plurality of valves includes a compressor intake valve and a compressor outlet valve.

14. The method of claim 10, wherein a pressure across the compressor is maintained when the compressor is off by the closing of the plurality of valves.

15. A cooling system, the system comprising:

a compressor;

a temperature sensor configured to provide an indication of a temperature;

a compressor intake valve coupled to an input of the compressor;

a compressor output valve coupled to an output of the compressor; and

a controller coupled to the compressor, the temperature sensor, the compressor intake valve, and the compressor output valve, the controller configured to

receive the indication of the temperature from the temperature sensor,

determine that the compressor should be turned off to stop providing cooling based on the indication of temperature received from the temperature sensor,

turn off the compressor,

close the compressor intake valve, and

close the compressor output valve,

wherein closing the compressor intake valve and the compressor output valve maintains a pressure of refrigerant across the compressor while the compressor is off.

16. The method of claim 15, the controller is further configured to determine a point in time when an impact on the motor is minimized using point-on-wave analysis, and to turn on the compressor at the determined point in time.

17. The cooling system of claim 15, wherein the controller is further configured to

determine that the compressor should be turned on to provide cooling based on the indication of temperature received from the temperature sensor,

turn on the compressor,

open the compressor intake valve, and

open the compressor output valve.

18. The cooling system of claim 15, wherein the compressor is a scroll compressor.

19. The cooling system of claim 15, wherein the temperature sensor is a thermostat.

20. The cooling system of claim 15, wherein the cooling system includes a plurality of compressors, and the controller is configured to perform the acts for each compressor of the plurality of compressors.

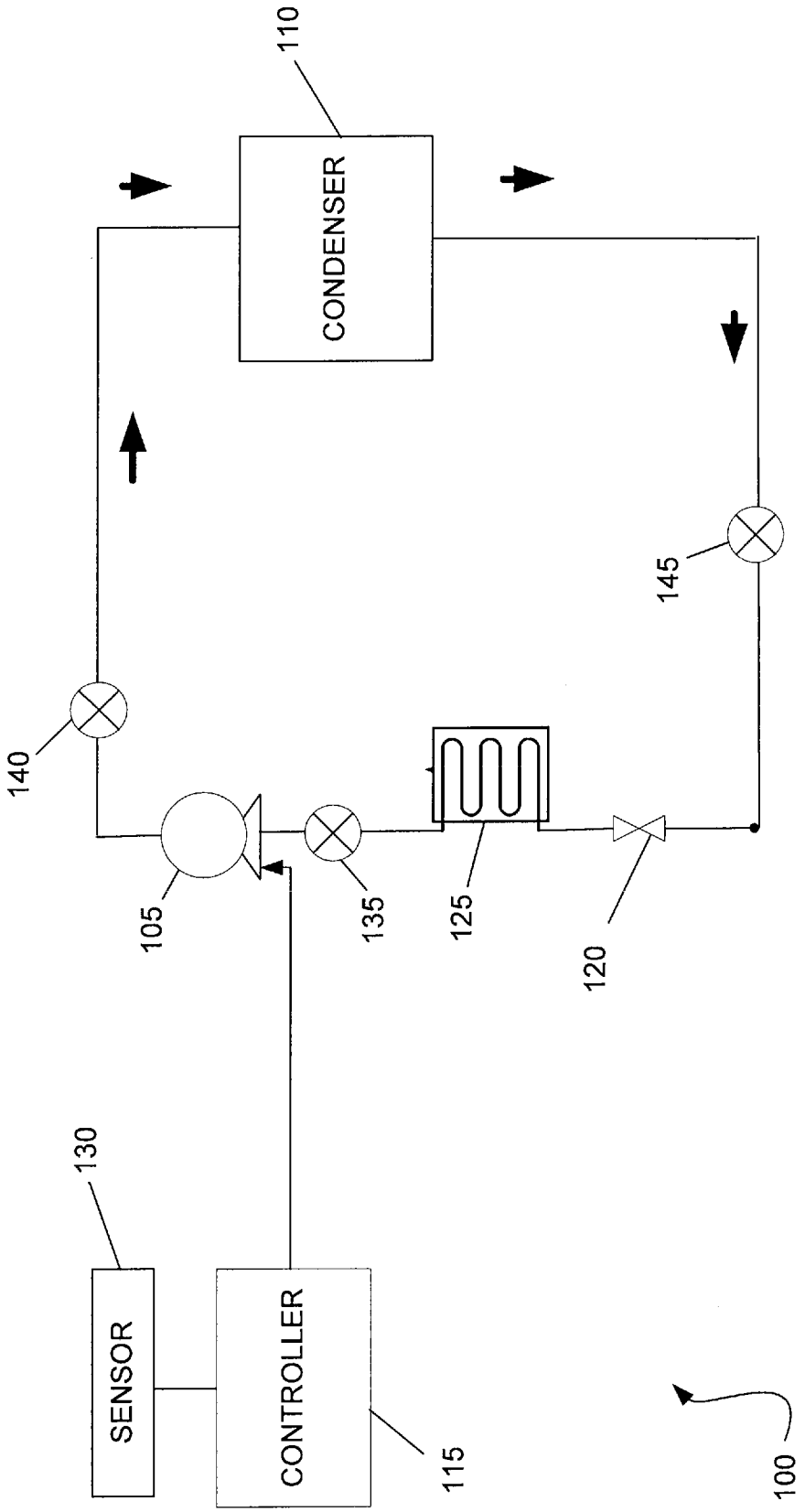

110
CONDENSER
145
140
105
135
125
120
130
SENSOR
CONTROLLER
115
100

Fig. 1

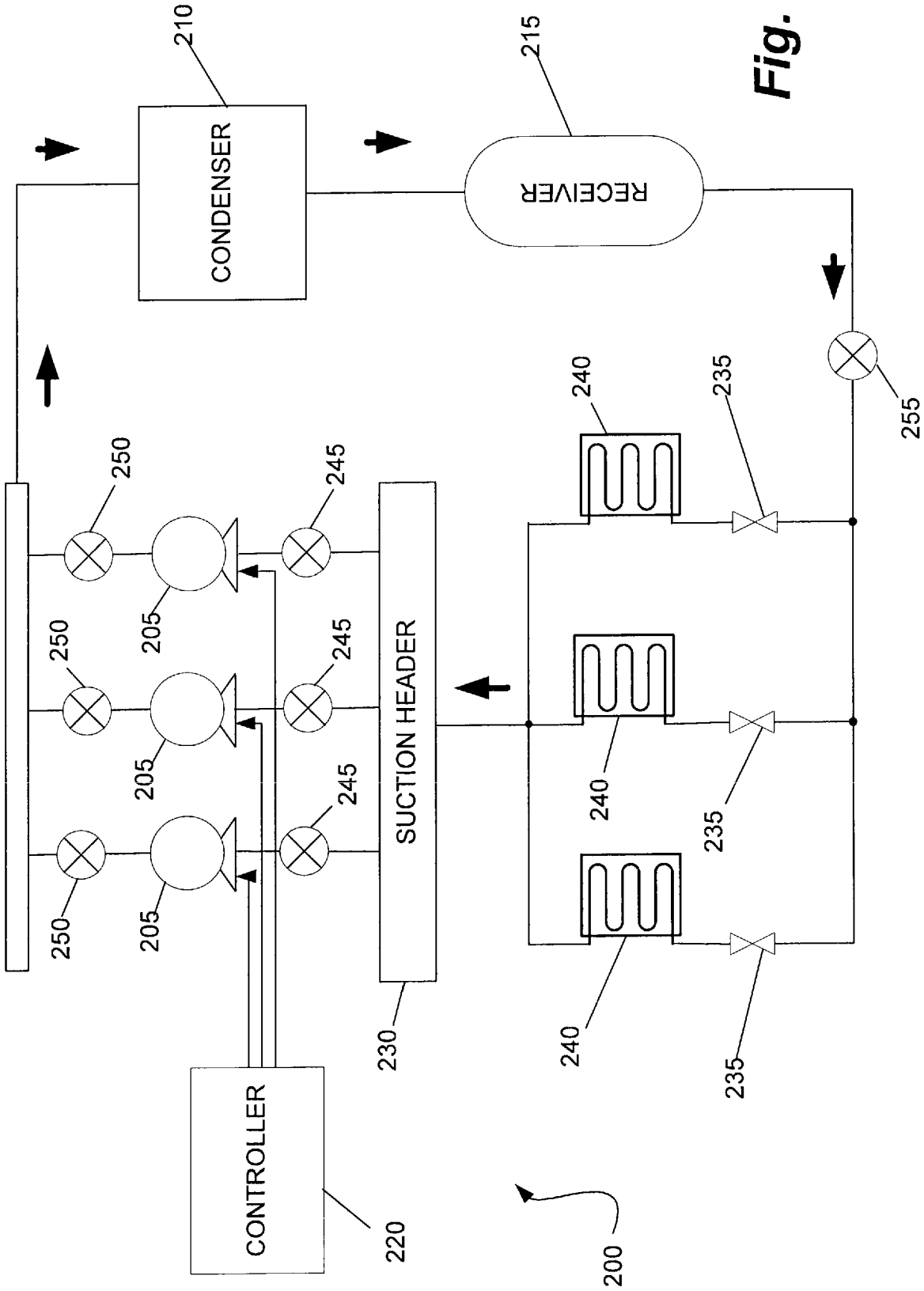
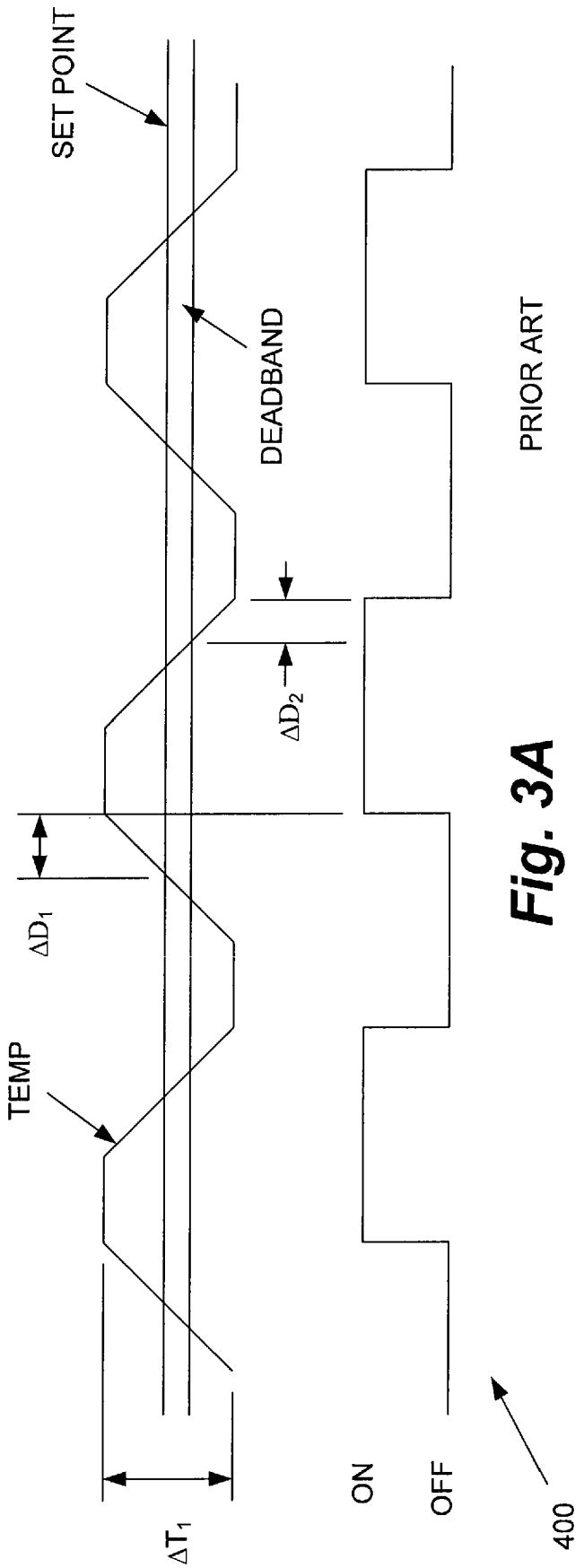

CONDENSER
210
RECEIVER
215
255
240
235
250
245
205
SUCTION HEADER
230
CONTROLLER
220
200

Fig. 2



PRIOR ART

Fig. 3A

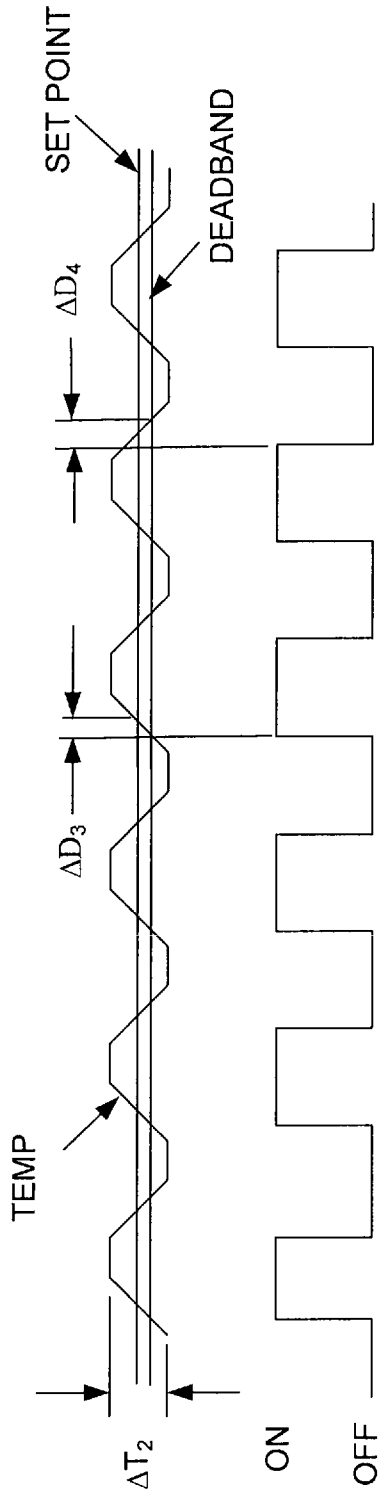


Fig. 3B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2012/048159

A. CLASSIFICATION OF SUBJECT MATTER

F25B 49/02(2006.01)i, F25B 1/00(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

F25B 49/02; F25B 41/04; F25D 11/02; H02P 1/32; H02P 1/26; F25B 1/00

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & Keywords: compressor, temperature, valve, turn on, point on wave, stop, loading, unloading

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 2007-205681 A (TOSHIBA CORP et al.) 16 August 2007	10-15,17-20
A	See paragraphs [0002]-[0021] and figures 2-5.	1-9,16
Y	JP 11-294904 A (MATSUSHITA ELECTRIC IND CO LTD) 29 October 1999	10-15,17-20
A	See paragraphs [0015]-[0038] and figures 1-10.	1-9,16
A	US 2008-0150471 A1 (UNSWORTH PETER et al.) 26 June 2008	1-20
	See paragraphs [0008]-[0010] and figures 1-2.	

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
08 JANUARY 2013 (08.01.2013)	**10 JANUARY 2013 (10.01.2013)**

Name and mailing address of the ISA/KR

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Facsimile No. 82-42-472-7140

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2012/048159

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

I. Claims 1-9 directed to a method of loading and unloading a compressor characterized by determining a point in time when the impact of turning on a motor of the compressor is minimized using point-on-wave analysis.
II. Claims 10-14 directed to a method of loading and unloading a compressor characterized by opening a plurality of valves when the compressor is turned on.
III. Claims 15-20 directed to a cooling system characterized by closing the intake and output valve when the compressor is turned off.

1. ☐ As all required addtional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☒ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2012/048159

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