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— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

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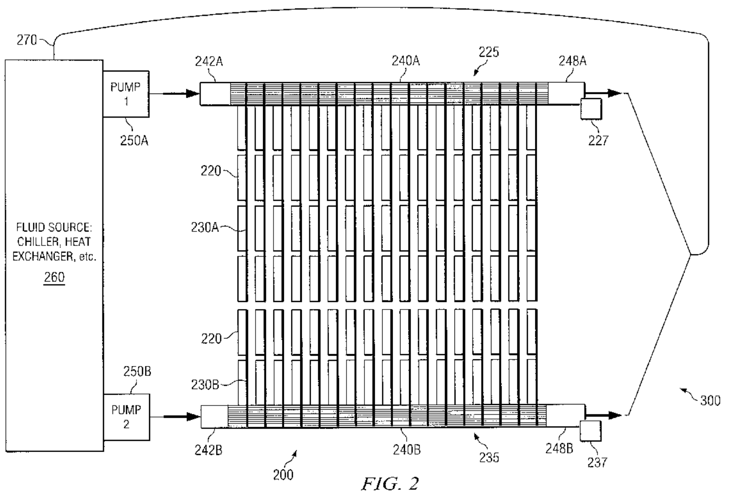

FIG. 2

(57) Abstract: According to one embodiment of the disclosure, a cooling system for a heat generating structure comprises a first cooling segment and a second cooling segment. The first cooling segment and the second cooling segment each respectively comprise a cooling segment conduit and at least one cooling segment tube. The cooling segment conduits are operable to receive a fluid coolant and dispense of the fluid coolant after the fluid coolant has received thermal energy. The at least one cooling segment tubes are in thermal communication with both the cooling segment conduits and the heat generating structure. The at least one cooling segment tubes have a cooling fluid operable to transfer thermal energy from the heat generating structure to the cooling segment conduits. The cooling segment conduits transfer thermal energy from the cooling fluid to the fluid coolant. A heat transfer rate associated with the first cooling segment is substantially similar to a heat transfer rate associated with the second cooling segment.

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SYSTEM AND METHOD FOR COOLING A HEAT GENERATING STRUCTURE

TECHNICAL FIELD OF THE DISCLOSURE

This disclosure relates generally to the field of cooling systems and, more particularly, to a system and method for cooling a heat generating structure.

BACKGROUND OF THE DISCLOSURE

A variety of different types of structures can generate heat or thermal energy in operation. To prevent such structures from over heating, a variety of different types of cooling systems may be utilized to dissipate the thermal energy, including air conditioning systems.

SUMMARY OF THE DISCLOSURE

According to one embodiment of the disclosure, a cooling system for a heat generating structure comprises a first cooling segment and a second cooling segment. The first cooling segment and the second cooling segment each respectively comprise a cooling segment conduit and at least one cooling segment tube. The cooling segment conduits are operable to receive a fluid coolant and dispense of the fluid coolant after the fluid coolant has received thermal energy. The at least one cooling segment tubes are in thermal communication with both the cooling segment conduits and the heat generating structure. The at least one cooling segment tubes have a cooling fluid operable to transfer thermal energy from the heat generating structure to the cooling segment conduits. The cooling segment conduits transfer thermal energy from the cooling fluid to the fluid coolant. A heat transfer rate associated with the first cooling segment is substantially similar to a heat transfer rate associated with the second cooling segment.

Certain embodiments of the disclosure may provide numerous technical advantages. For example, a technical advantage of one embodiment may include the capability to use heat pipes over lengths that heat pipes traditionally can not be used. Other technical advantages of other embodiments may include the capability to tune a heat transfer rate associated with one set of heat pipes and a condenser to the heat transfer rate of another set of heat pipes and a condenser. Yet other technical advantages of other embodiments may include the capability to tune heat transfer rates associated with sets of heat pipes and condensers by adjusting temperatures and flow rates of fluid traveling through the condensers. Still yet other technical advantages of other embodiments may include the capability to adjust characteristics of condensers including, but not limited to, using different heat transfer pin fins and different cross sectional areas in order to tune heat transfer rates associated with sets of heat pipes and condensers.

Although specific advantages have been enumerated above, various embodiments may include all, some, or none of the enumerated advantages. Additionally, other technical advantages may become readily apparent to one of ordinary skill in the art after review of the following figures and description.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of example embodiments of the present disclosure and its advantages, reference is now made to the following description, taken in conjunction with the accompanying drawings, in which:

FIGURE 1 shows a configuration of heat pipes that may be utilized by embodiments of the invention; and

FIGURE 2 shows a system, according to an embodiment of the invention.

DETAILED DESCRIPTION OF THE DISCLOSURE

It should be understood at the outset that although example embodiments of the present disclosure are illustrated below, the present disclosure may be implemented using any number of techniques, whether currently known or in existence. The present disclosure should in no way be limited to the example embodiments, drawings, and techniques illustrated below, including the embodiments and implementation illustrated and described herein. Additionally, the drawings are not necessarily drawn to scale.

Heat pipes are a tempting solution for applications that require low temperature gradients. Specifically, when heat pipes are well designed, such heat pipes are almost gradient-free over the length of the evaporator. Such heat pipes, however, have the disadvantage of being sensitive to orientation.

FIGURE 1 shows a configuration 100 of heat pipes 130 that may be utilized by embodiments of the invention. The configuration 100 of FIGURE 1 shows heat pipes 130, a heat generating structure 120, and a condenser 140. In the configuration 100, the condenser 140 is positioned on top of the heat pipes 130 and the heat generating structure 120. The heat generating structure 120 may be any of variety of devices that generate thermal energy during operation, including, but not limited to, an antenna array or other types of electronics.

As a non-limiting example of operation, similar or different fluids may be contained in the heat pipes 130 and the condenser 140. The condenser may include an inlet 142 to receive fluid and outlet 148 to dispense of fluid. As the heat generating structure 120 operates, thermal energy from the heat generating structure 120 is transferred to the heat pipes 130, for example, through a cold plate, causing the fluid in the heat pipes 130 to evaporate. Upon evaporation, the fluid in the heat pipes 130 migrates towards the condenser 140, for example, in the form of vapor. The thermal energy contained in the fluid traveling through the heat pipes 130 is transferred to the fluid in the condenser 140 and carried away, for example, through the outlet 148 of the condenser 140. Upon release of the thermal energy, the condensed fluid in the heat pipes 130 may migrate back down towards the far end of the heat pipes 130.

The configuration 100 of FIGURE 1 is advantageous because it uses gravity to assist with the transport of fluid to the far end of the heat pipes 130. Notwithstanding this advantageous configuration, difficulties can arise when a length of the heat pipes 130 increase. For example, the vapor mass flow rate to remove the total heat may get too large relative to the cross-sectional area and length of the heat pipe. In such a scenario, an undesirably excessive pressure drop may occur. Accordingly, even with a heat pipe in a preferred orientation, there were be a limit to the capacity of such a heat pipe. Given this, teaching of embodiments of the invention recognize a system and method that enables the use of heat pipes over longer lengths.

FIGURE 2 shows a system 200, according to an embodiment of the invention. The system 200 has similar features to the configuration 100 of FIGURE 1 except that the system 200 includes two cooling segments 225, 235. Cooling segment 225 includes heat pipes 230A and a condenser 240A. Cooling segment 235 includes heat pipes 230B and a condenser 240B. The use of a plurality of heat pipes 230A, 230B and condensers 240A, 240B allows heat pipes to be used over a greater lengths of a heat-generating structure 220 without creating difficulties inherent to heat pipes. Specifically, each of the heat pipes 230A, 230B respectively absorb a portion of the thermal energy from the heat generating structure 220. Although two cooling segments 225, 235 are shown in the embodiment of FIGURE 2, more than two cooling segments may be used in other embodiments.

As will be described further below, the cooling segments 225, 235 in particular embodiments may be part of a cooling loop 300 that include features such as a fluid source 260, pumps 250A, 250B, and a return line 270. Although a specific cooling loop 300 has been shown in FIGURE 2, any of a variety of cooling loops may be used in other embodiments, including, but not limited to cooling loops that operate at subambient temperatures.

Each respective cooling segment 225, 235 may operate in a similar manner as described with reference to the configuration 100 of FIGURE 1. For example, fluid may be contained in both the heat pipes 230A, 230B and the condensers 240A, 240B. The fluid in each of these four may be similar or different. Examples of fluid include, but are not limited to water or other suitable types of refrigerants or coolants.

The condensers 240A, 240B may include inlet 242A, 242B to receive fluid and outlets 248A, 248B to dispense of fluid. As the heat generating structure 220 operates, thermal energy from the heat generating structure 220 is transferred to the heat pipes 230A, 230B through any suitable thermal energy transfer mechanism, including but not limited to, a cold plate. The transfer of thermal energy causes the fluid in the heat pipes 230A, 230B to evaporate. Upon evaporation, the fluid in the heat pipes 230A, 230B migrates towards the condensers 240A, 240B, for example, in the form of vapor. The thermal energy contained in the fluid traveling through the heat pipes 230 is transferred to the fluid in the condenser 240A, 240B and carried away, for example, through the outlets 248A, 248B of the condensers 240A, 240B. Upon release of the thermal energy, the condensed fluid in the heat pipes 230A, 230B may migrate back towards the far end of the heat pipes 230A, 230B. To compensate for that fact that the heat pipes 230B are adversely oriented (for example, working against gravity in the transport to the far end of the heat pipes), heat pipes 230B are shorter than heat pipes 230A.

In operation, cooling segment 225 has different thermal operating characteristics than cooling segment 235. Specifically, according to one embodiment, cooling segment 225 has a different effective thermal conductivity or heat transfer rate than cooling segment 235. Because it desirable to have uniformly cool the heat generating structure 220 (e.g., avoiding hot spots or large temperature gradients), it is desirable for the heat transfer rate of cooling segment 225 to be substantially the same as cooling segment 235. In order to make the heat pipes 230A, 230B have substantially the same heat transfer rate, a variety of techniques may be utilize to tune one or both of the cooling segments 225, 235. Examples of such tuning techniques will be described below.

As one tuning technique, the flow rate entering one or both of inlets 242A, 242B of condensers 240A, 240B may be adjusted or varied. Such an adjustment of the flow rate may be carried out, for example, in certain embodiments through modifications to a speed of a pump 250A, 250B providing fluid to each respective condenser. Other techniques may also be used to adjust the flow rate entering the condensers 240A, 240B.

As another tuning technique, the temperature of the fluid entering one or both of inlets 242A, 242B of condensers 240A, 240B may be adjusted or varied. Any of a variety of techniques may be used vary the temperature of the fluid, including changing characteristics of the fluid source 260. In particular embodiments, a mixture of different temperature fluids may be adjusted to quickly change the temperature fluid entering one or both of the inlets 242A, 242B. Additionally, in particular embodiments, fluid may enter one cooling segment 225 before the other cooling segment 235.

As yet another tuning technique, different fin stock (e.g., wavy, straight, pin, staggered, etc.) may be used in one or both of the condensers 240A, 240B. Other surface enhancement / stream changing characteristics may also be utilized, according to other embodiments.

As yet another tuning technique, the channel characteristics (e.g., width, depth) of the condensers 240A, 240B can be modified to adjust, among other things, the velocity of the fluid moving through the condenser 240A, 240B.

As yet another tuning technique, pressures associated with the fluid entering the condensers 240A, 240B may be modified to adjust a heat transfer rate of the cooling segments 225, 235.

In addition to the above specific techniques, a variety of other techniques may additionally be utilized as will become apparent after review of this specification. Furthermore, in particular embodiments, combinations of techniques may be utilized.

In particular embodiments, the adjustments or variations provided for in these techniques may be done real-time, for example, using sensors that monitor the dynamics of how the cooling segments 225, 235 are operating. As just one example, intended for illustrative purpose only, sensors 227, 237 may monitor characteristics (e.g., temperature, velocity, pressure) of fluid exiting the outlets 248A, 248B and provide dynamic feedback to other components of the cooling loop 300, for example to adjust pumps 250A, 250B, fluid source 260, channel width characteristics of condensers 240A, 240B, or other components, or combinations of the preceding. Although one example of a sensor has been shown, sensors may also located in other locations.

While this disclosure has been described in terms of certain embodiments and generally associated methods, alterations and permutations of the embodiments and methods will be apparent to those skilled in the art. Accordingly, the above description of example embodiments does not constrain this disclosure. Other changes, substitutions, and alterations are also possible without departing from the spirit and scope of this disclosure, as defined by the following claims.

WHAT IS CLAIMED IS:

1. A cooling system for a heat generating structure, the cooling system comprising:

a first cooling segment comprising:

a first cooling segment conduit operable to receive a first fluid coolant and dispense of the first fluid coolant after the first fluid coolant has received thermal energy;

at least one first cooling segment tube in thermal communication with both the first cooling segment conduit and the heat generating structure, the at least one first cooling segment tube having a first cooling fluid operable to transfer thermal energy from the heat generating structure to the first cooling segment conduit, the first cooling segment conduit operable to transfer thermal energy from the first cooling fluid to the first fluid coolant;

a second cooling segment comprising:

a second cooling segment conduit operable to receive a second fluid coolant and dispense of the second fluid coolant after the second fluid coolant has received thermal energy;

at least one second cooling segment tube in thermal communication with both the second cooling segment conduit and the heat generating structure, the at least one second cooling segment tube having a second cooling fluid operable to transfer thermal energy from the heat generating structure to the second cooling segment conduit, the second cooling segment conduit operable to transfer thermal energy from the second cooling fluid to the second fluid coolant; and

wherein a heat transfer rate associated with the first cooling segment is substantially similar to a heat transfer rate associated with the second cooling segment.

2. The cooling system of claim 1, wherein the at least one first cooling segment tube is a plurality of first cooling segment tubes and the at least one second cooling segment tube is a plurality of second cooling segment tubes.

3. The cooling system of claim 2, wherein:

the first cooling segment conduit is vertically positioned above the plurality of first cooling segment tubes;

the second cooling segment conduit is vertically positioned below the plurality of second cooling segment tubes; and

the plurality of first cooling segment tubes are longer than the plurality of second cooling segment tubes.

4. The cooling system of claim 1, wherein the heat transfer rate associated with the first cooling segment and the heat transfer rate associated with the second cooling segment are at least partially maintained at a substantially similar level by controlling at least one of the flow rate of the first fluid coolant through the first cooling segment conduit or the flow rate of the second fluid coolant through the second cooling segment conduit.

5. The cooling system of claim 4, wherein the flow rate of the first fluid coolant through the first cooling segment conduit or the second fluid coolant through the second cooling segment conduit is controlled in part by varying the cross-sectional area of the first cooling segment conduit or the second cooling segment conduit.

6. The cooling system of claim 4, wherein:

the flow rate of the first fluid coolant through the first cooling segment conduit is controlled in part by a first pump associated with the first cooling segment; and

the flow rate of the second fluid coolant through the second cooling segment conduit is controlled in part by a second pump associated with the second cooling segment.

7. The cooling system of claim 4, wherein the flow rate of the first fluid coolant through the first cooling segment conduit is different than the flow rate of the second fluid coolant through the second cooling segment conduit.

8. The cooling system of claim 1, wherein the heat transfer rate associated with the first cooling segment and the heat transfer rate associated with the second cooling segment are at least partially maintained at a substantially similar level

by controlling at least one of the temperature of the first fluid coolant entering the first cooling segment conduit or the temperature of the second fluid coolant entering the second cooling segment conduit.

9. The cooling system of claim 1, wherein the first fluid coolant and the second fluid coolant are the same fluid, and the first fluid coolant is directed through the first cooling segment conduit prior to directing the flow of the second fluid coolant through the second cooling segment conduit.

10. The cooling system of claim 1, wherein the heat transfer rate associated with the first cooling segment and the heat transfer rate associated with the second cooling segment are maintained at a substantially similar level by using different heat transfer pin fins in each of the first cooling segments and the second cooling segments.

11. The cooling system of claim 1, further comprising:

at least one sensor operable to measure a characteristic of at least one of the first cooling segment or the second cooling segment, the sensor providing dynamic feedback to a component of the cooling system to maintain the heat transfer rate of at least one of the first cooling segment or the second cooling segment.

12. The cooling system of claim 11, wherein the dynamic feedback initiates a change of at least one of a temperature, pressure, or flow rate of at least one of the first fluid coolant in the first cooling segment conduit or the second fluid coolant in the second cooling segment conduit.

13. A method for cooling a heat generating structure comprising:

directing a first fluid coolant through a first cooling segment and a second fluid coolant through a second cooling segment, wherein:

the first cooling segment comprises:

a first cooling segment conduit operable to receive the first fluid coolant and dispense of the first fluid coolant after the first fluid coolant has received thermal energy, and at least one first cooling segment tube in thermal communication with both the first cooling segment conduit and the heat generating structure, the at least one first cooling segment tube having a first cooling fluid operable to transfer thermal energy from the heat generating structure to the first cooling segment conduit, the first cooling segment conduit operable to transfer thermal energy from the first cooling fluid to the first fluid coolant; and

the second cooling segment comprises:

a second cooling segment conduit operable to receive the second fluid coolant and dispense of the second fluid coolant after the second fluid coolant has received thermal energy;

at least one second cooling segment tube in thermal communication with both the second cooling segment conduit and the heat generating structure, the at least one second cooling segment tube having a second cooling fluid operable to transfer thermal energy from the heat generating structure to the second cooling segment conduit, the second cooling segment conduit operable to transfer thermal energy from the second cooling fluid to the second fluid coolant; and

maintaining a heat transfer rate associated with the first cooling segment at a level that is substantially similar to a heat transfer rate associated with the second cooling segment.

14. The method structure of claim 13, wherein:

the at least one first cooling segment tube is a plurality of first cooling segment tubes and the at least one second cooling segment tube is a plurality of second cooling segment tubes;

the first cooling segment conduit is vertically positioned above the plurality of first cooling segment tubes;

the second cooling segment conduit is vertically positioned below the plurality of second cooling segment tubes; and

the plurality of first cooling segment tubes are longer than the plurality of second cooling segment tubes.

15. The method of claim 13, wherein at least a portion of maintaining the heat transfer rate associated with the first cooling segment at a level substantially similar to the heat transfer rate associated with the second cooling segment comprises controlling at least one of the flow rate of the first fluid coolant through the first cooling segment conduit or the flow rate of the second fluid coolant through the second cooling segment conduit.

16. The method of claim 15, wherein the flow rate of the first fluid coolant through the first cooling segment conduit or the second fluid coolant through the second cooling segment conduit is controlled in part by varying the cross-sectional area of the first cooling segment conduit or the second cooling segment conduit.

17. The method of claim 15, wherein:

the flow rate of the first fluid coolant through the first cooling segment conduit is controlled in part by a first pump associated with the first cooling segment; and

the flow rate of the second fluid coolant through the second cooling segment conduit is controlled in part by a second pump associated with the second cooling segment.

18. The method of claim 13, wherein at least a portion of maintaining the heat transfer rate associated with the first cooling segment at a level substantially similar to the heat transfer rate associated with the second cooling segment comprises controlling at least one of the temperature of the first fluid coolant entering the first cooling segment conduit or the temperature of the second fluid coolant entering the second cooling segment conduit.

19. The method of claim 13, wherein the first fluid coolant and the second fluid coolant are the same fluid, and the first fluid coolant is directed through the first cooling segment conduit prior to directing the flow of the second fluid coolant through the second cooling segment conduit.

20. The method of claim 13, wherein at least a portion of maintaining the heat transfer rate associated with the first cooling segment at a level substantially

similar to the heat transfer rate associated with the second cooling segment comprises using different heat transfer pin fins in each of the first cooling segments and the second cooling segments.

21. The method of claim 13, further comprising:

monitoring, with at least one sensor, a characteristic of at least one of the first cooling segment or the second cooling segment; and

providing dynamic feedback to a component of the cooling system to maintain the heat transfer rate of at least one of the first cooling segment or the second cooling segment.

22. The method of claim 13, further comprising:

in response to the dynamic feedback, initiating a change of at least one of a temperature, pressure, or flow rate of at least one of the first fluid coolant in the first cooling segment conduit or the second fluid coolant in the second cooling segment conduit.

23. A cooling system for a heat generating structure, the cooling system comprising:

a first cooling segment comprising:

a first condenser operable to receive a first fluid coolant and dispense of the first fluid coolant after the first fluid coolant has received thermal energy;

at least one first heat pipe in thermal communication with both the first condenser and the heat generating structure, the at least one first heat pipe having a first cooling fluid operable to transfer thermal energy from the heat generating structure to the first condenser, the first condenser operable to transfer thermal energy from the first cooling fluid to the first fluid coolant;

a second cooling segment comprising:

a second condenser operable to receive a second fluid coolant and dispense of the second fluid coolant after the second fluid coolant has received thermal energy;

at least one second heat pipe in thermal communication with both the second condenser and the heat generating structure, the at least one second heat pipe having a second cooling fluid operable to transfer thermal energy from the heat generating structure to the second condenser, the second condenser operable to transfer thermal energy from the second cooling fluid to the second fluid coolant;

wherein a heat transfer rate associated with the first heat pipe is substantially similar to a heat transfer rate associated with the second cooling segment.

24. The cooling system of claim 23, further comprising:

a first cooling segment comprising:

the at least one first heat pipe is a plurality of first heat pipes and the at least one second heat pipe is a plurality of second heat pipes;

the first condenser is vertically positioned above the plurality of first heat pipes;

the second condenser is vertically positioned below the plurality of second c heat pipes; and

the plurality of first heat pipes are longer than the plurality of second heat pipes.

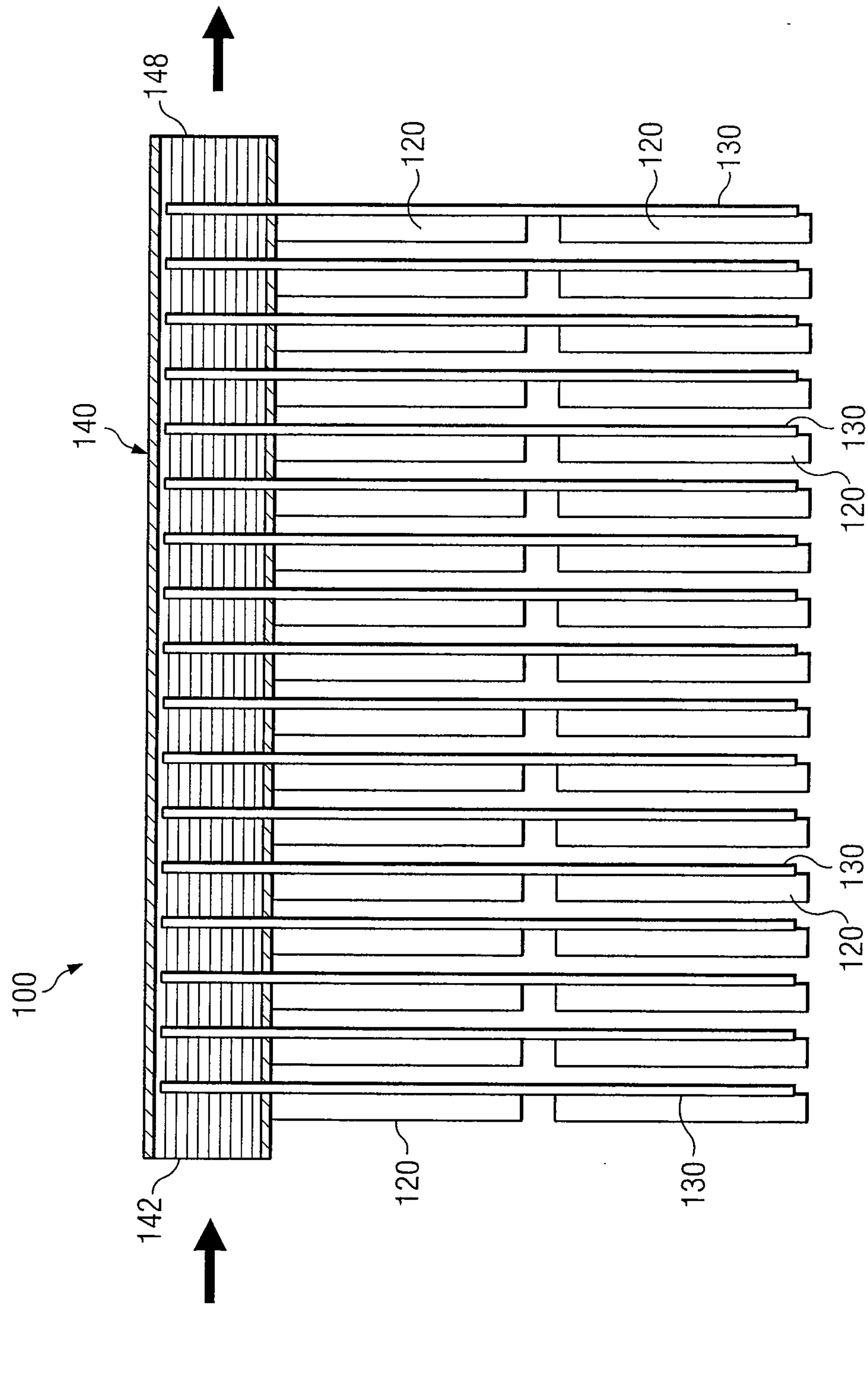

FIG. 1

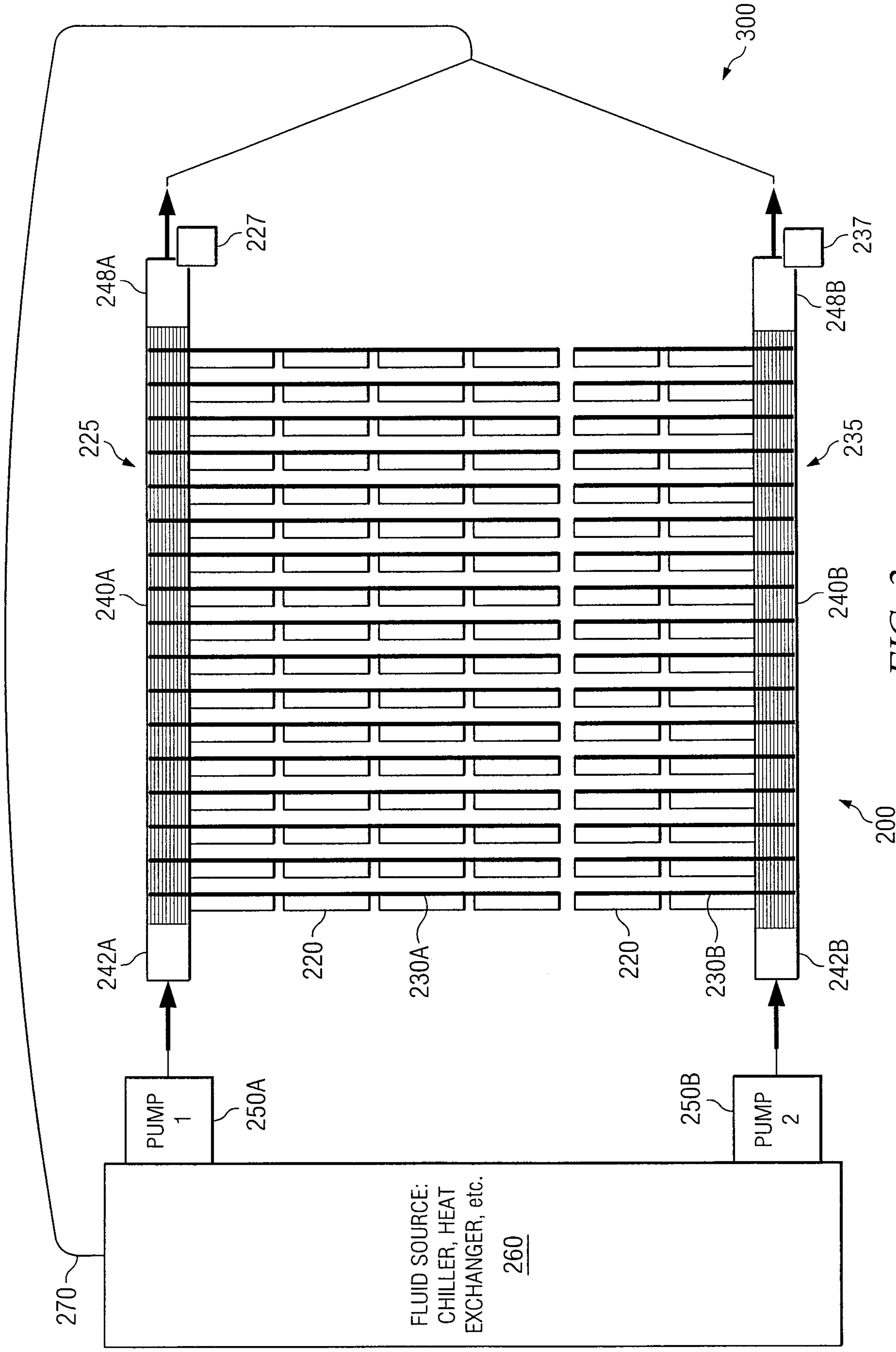
300
227
237
248A
248B
225
235
240A
240B
200
242A
242B
220
230A
220
230B
PUMP 1
250A
250B
PUMP 2
FLUID SOURCE: CHILLER, HEAT EXCHANGER, etc.
260
270

FIG. 2

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2009/034609

A. CLASSIFICATION OF SUBJECT MATTER
INV. F28D15/02

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)
F28D

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

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

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 201 08 088 U1 (TSAI MING KUN [TW]) 26 July 2001 (2001-07-26) abstract; figure 1	1-10, 13-20, 23,24
X	US 6 220 337 B1 (CHEN SHI-LI [TW] ET AL) 24 April 2001 (2001-04-24) figures 1,14	1-7, 9-17, 19-24
A	US 2007/230183 A1 (SHUY GEOFFREY W [HK] SHUY GEOFFREY WEN-TAI [HK]) 4 October 2007 (2007-10-04) the whole document	10
A	EP 1 601 043 A (RAYTHEON CO [US]) 30 November 2005 (2005-11-30) the whole document	11,12

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[X] Further documents are listed in the continuation of Box C.

[X] 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

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Date of the actual completion of the international search	Date of mailing of the international search report
29 May 2009	05/06/2009

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Vassoille, Bruno

Form PCT/ISA/210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2009/034609

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 817 263 A (NIPPON ELECTRIC CO [JP] NIPPON ELECTRIC CO) 7 January 1998 (1998-01-07) the whole document -----	1

Form PCT/ISA/210 (continuation of second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2009/034609

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