

SPRAY COOLING METHOD AND APPARATUS

Field of the Invention

5 The present invention relates to a cooling system. More particularly, the present invention relates to a spray cooling system and a method for cooling heat generating devices, such as integrated circuits or chips, using a spray cooling system.

Background of the Invention

10 Recent increases in microprocessor processing speeds have been achieved by increases in transistor densities, amongst other factors. While a microprocessor operates, it generates an amount of heat proportional to the number of transistors. This heat needs dissipating; otherwise it creates thermal stress, which affects the microprocessor's performance. The problem is that the greater the transistor density,
15 the greater the heat generated within a smaller area and the more difficult sufficient dissipation becomes. Dissipation of heat generated by a microprocessor so that it can work under its design-preferred temperature becomes critical for the performance of the microprocessor.

20 Conventional air-cooling techniques incorporating heat sinks and/or fans are widely used for cooling microprocessors in enclosed systems in which microprocessors are installed. However, cooling efficiency is generally limited to the size of cooling fan and heat sink.

25 In some applications, for example, in military avionics equipment, electronic modules are normally not allowed to have direct contact with air, which might otherwise be used as a cooling medium, as air contaminants will cause damage to the equipment. Instead, the common method of cooling involves conduction heat transfer from the modules to a cold wall. However, with expected high transistor
30 densities, such systems would not deliver sufficient heat dissipation.

Spray cooling techniques have been investigated in the search for better cooling. They have been found to have high overall rating in various aspects such as cost, weight, complexity, and cooling capacity in comparison with other known
35 cooling methods. In particular spray cooling provides a quantum improvement of cooling capacity for electronics, in the order of a 100-fold increase in the rate of heat

flux removal when compared to air cooling methods. This is due to the combined effects of convection cooling plus vaporisation cooling.

5 Patent publication WO-A-01/01741 describes a spray cooling device for spraying electronic components in an enclosed chassis. It continuously sprays fluid directly into the enclosed chassis from nozzles along the walls. This has the disadvantage of spraying everything all the time, whether it needs it or not.

10 Patent publication WO-A-01/02962 discloses incremental spray cooling by way of an ink-jet type spray device. A number of spray nozzles are directed at the same number of heat generating devices on a circuit board. The nozzles and circuit board are enclosed in a sealed compartment. Such sealed compartments do not allow flexibility of any reworking or modifications.

15 SUMMARY OF THE INVENTION

It is an object of the present invention to provide a spray cooling system, which preferably overcomes or at least partially alleviates drawbacks with existing systems.

20 According to one aspect of the present invention there is provided a spray module for removably mounting in a spray cooling assembly, which assembly is for cooling a plurality of heat sources, the spray module comprising:

a cavity within a first body, for containing a cooling fluid;

25 an input port for receiving cooling fluid to said cavity;

a second body moveable relative to the first body between first and second positions; and

30 a plurality of output ports being in fluid communication with the cavity when the second body is in the second position relative to the first body, and out of fluid communication with the cavity when the second body is in the first position relative to the first body.

According to a second aspect of the present invention, there is provided a spray cooling apparatus comprising a spray cooling chamber having:

35 mounting means for removably mounting a plurality of spray modules with spaces to accommodate a plurality of heat sources directly between successive

spray modules; and

a fluid collecting surface for receiving and collecting fluid sprayed within the chamber from the plurality of spray modules.

5 According to a further aspect of the present invention, there is provided a method of spray cooling a plurality of heat source means, each heat source means having one or more heat sensors associated therewith and one or more spray modules associated therewith, comprising:

10 sensing the heat from the individual heat source means by way of their associated one or more heat sensors; and

for those heat source means for which the sensed heat is above a first threshold, selectively operating the one or more spray modules associated therewith to cool spray their respective heat source means.

15 For example, the invention may provide a spray module having a body and a cavity with a sliding plate within it. Incoming control signals move the sliding plate between an open position, in which holes in the plate align with holes in the body, to allow cooling spraying to occur, and a closed position, in which no spraying occurs. A plurality of these spray modules are removably mounted in parallel, one in front of
20 the other, in a spray chamber. Each module has its body holes directed at one or more heat sources on a circuit board or some such, the circuit boards being placed between adjacent spray modules. Separate temperature sensors detect the temperatures of different heat sources. Based on these detected temperatures, a controller selectively sends signals to specific spray modules to spray those heat
25 sources whose temperature is too high. Sprayed coolant from all the spray modules falls to the gravimetric bottom of the spray chamber in whichever orientation the chamber is in and is collected, condensed and sent back to the spray modules.

BRIEF DESCRIPTION OF DRAWINGS

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Further features of the present invention will readily be apparent from the following detailed description of a non-limitative example, with reference to the accompanying drawings, in which:-

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Figure 1 is a plan view of a spray chamber according to a preferred embodiment of the present invention;

Figure 2 is a block diagram showing a cooling fluid cycle of the spray chamber of Figure 1;

5 Figure 3A is a cross section of a top plan view of a spray module and circuit board pair used in the spray chamber of Figure 1 in a first configuration;

10 Figure 3B is a cross section of a top plan view of the spray module and circuit board pair of Figure 3A in a second configuration;

15 Figure 4 is a cross section of a side elevation of the spray module of Figure 3A;

20 Figure 5 is a block diagram illustrating components of a heat control device used with the spray chamber of Figure 1; and

25 Figure 6 is a flow chart detailing the flow logic of the heat control device of Figure 5.

DETAILED DESCRIPTION

Where the same reference numeral appears in more than one of the accompanying drawings, it is used to denote the same element.

25 Figure 1 illustrates a top plan view of a spray chamber 100 of a spray cooling system in accordance with one embodiment of the present invention. The chamber has two side walls 102, a first end wall 104 (being the left end of the chamber in Figure 1), a second end wall 106 (being the right end of the chamber in Figure 1), a bottom wall 108 and a top wall (not shown – and removed for the purpose of Figure 1). In use the spray chamber 100 is sealed and emptied of air.

30 The two side walls 102 are hollow and each has a cooling fluid reservoir 110 within it. A spray module and circuit board pair 112, having a spray module 114 and a circuit board 116 is mounted orthogonally between the two side walls 102. In normal use there would usually be a number of such pairs mounted spaced apart

and in parallel, but only one is shown in Figure 1 for clarity. A condenser 118 is mounted on the outside of the second end wall 106.

Support frames 120 are mounted on the internal faces of the two side walls 102, opposing each other. The support frames have projecting portions 122, with recess portions 124 between them at regular intervals, forming slots. Spray module and circuit board pairs 112 are mounted on the support frames 120, one per paired projecting portion 122 and recess portion 124 at each end, although only one such spray module and circuit board pair 112 is shown in the Figures for simplicity. Within a spray module and circuit board pair 112, the ends of the circuit board 116 fit within opposing recess portions 124 of the support frames 120 and the ends of the spray module 114 have a slight clearance with opposing projecting portions 122 of the support frames 120.

The width of the recess portion 124 between two adjacent projecting portions 122 of a support frame 120 is greater than the thickness of the circuit board 116. Therefore wedge clamps 126 (or some other means) are used to hold the ends of each circuit board 116 in place within their respective recess portions 124. More particularly, a wedge clamp 126 is placed in a recess portion 124 between an end of a circuit board 116 and the projecting portion 122 paired with that recess 124 (that is the same projecting portion to which the end of the spray module 114 of that spray module and circuit board pair 112 is adjacent), and the clamp 126 is tightened. The clamps can be undone in order to allow easy removal of the spray module and circuit board pairs 112.

The circuit boards 116 also plug into electrical I/O connectors (not shown) in a known manner. The electrical I/O connectors are mounted above the bottom wall 108 of the spray chamber 100, between the side walls 102. Spray chamber I/O connectors 127 are mounted on the outside of the first end wall 104, for connecting the spray chamber (and the electronics it is cooling) to the host machine (for example an aeroplane in avionics use). Electrical signal and power lines (not shown) pass through the first end wall 104 to where they are required.

Supply holes 128 extend through the internal faces of the two side walls 102 to the reservoirs 110. The supply holes 128 exit from the side walls 102 above the projecting portions 122, there being one such supply hole 128 for each projecting

portion 122 (although that may not be necessary, but allows greater flexibility). Supply tubes 130 connect the supply holes 128 to supply inlet ports 132 in the respective spray modules 114.

5 As this embodiment is intended for avionics use, every internal surface is potentially a fluid collecting surface (as an aircraft may be flying flat, upwards or downwards, upright or inverted, straight or in a turn). Each internal surface is flat but may be slightly convex in the centre and shaped to drain any liquid out towards its corners, in other embodiments. Each of the eight corners within the spray chamber
10 100 has a drain aperture 132 for collecting liquid. The apertures are actually in the top and bottom wall 108 surfaces, although can extend into the corners of the other two surfaces in each vertex. Two collection pipes 134 extend lengthways within both the top and bottom walls 108, one pipe near each edge of those walls. Each drain aperture 132 leads to one of the collection pipes 134, one drain aperture 132 at each
15 end of each collection pipe 134, although each drain aperture may have a separate collection pipe in alternative embodiments. One-way valves between the drain apertures 132 and the collection pipes 134 prevent fluid back flow. The collection pipes 134 extend through the second end wall 106 to the condenser 118.

20 The condenser 118 includes a condenser reservoir, which feeds into the two side wall reservoirs 110, by way of two reservoir supply pipes 136. The reservoir supply pipes 136 pass to the inside of the spray chamber 100 through the second end wall 106 and through the inner surfaces of the two side walls 102 to the side wall reservoirs 110. A supply pump 138 is situated within each reservoir supply pipe 136.

25 The purpose of the spray chamber 100 is to spray a coolant fluid 140 from the spray modules 114 at heat sources 142 on the circuit boards 116 and to recycle the coolant fluid back to the spray modules 114. The coolant fluid will typically be a liquid. It is ideally electronically inert and preferably non-corrosive and incapable of
30 causing damage to any parts within the spray cooling system 100 or the electronics to be cooled. Fluorinated liquids, especially or perfluorocarbons (PFCs) have shown themselves to be useful in this regard. For example, members of the Fluorinert™ series electronic liquid, for example Fluorinert™ FC-72, from 3M™ Corporation could be used.

35 Figure 2 is a block diagram showing a cooling fluid cycle for fluid within the

spray chamber 100 of Figure 1.

Coolant fluid 140 stored in the side wall reservoirs 110 is distributed to the plurality of spray modules 114 via the supply holes 128 and the supply tubes 130.

5 The fluid is sprayed out of the spray modules 114 directly onto heat sources 142 (in the form of integrated chips) on the circuit boards 116. Heat is transferred from the heat sources 142 to the fluid, thereby reducing the temperature of the heat sources 142, whilst raising that of the fluid 140. Most of the fluid is vaporised upon contact with the heat sources 142. The vapour then condenses on cooler surfaces (which
10 are most of the other surfaces). The condensed liquid together with the unvaporised liquid flows freely down to the fluid collecting surface, which is normally the internal surface of the bottom wall 108. There the fluid is directed to the four corners and drains into the drain apertures 132.

15 Fluid passes through the one-way valves 144 and along the collection pipes 134 to the condenser 118. The condenser 118 removes heat from the fluid 140, cooling it down again. That removed heat is then dissipated more easily, now that it is outside the spray chamber 100 and space is not such an issue. The cooled fluid passes to the condenser reservoir 146, from where it is pumped back to the side wall
20 reservoirs 110, through the reservoir supply pipes 136 and supply pumps 138 to complete the fluid cooling cycle. The condenser reservoir 146 is useful for ensuring that the returned fluid is cooled down sufficiently before being re-supplied to the side wall reservoirs 110 and thence to the spray modules 114. Relief lines extend from the supply pumps 138 back to the condenser reservoir 146.

25 Figure 3A is a cross section of a top plan view of a spray module and circuit board pair 112 used in the spray chamber of Figure 1 in a first configuration. Figure 3B is a cross section of a top plan view of the spray module and circuit board pair of Figure 3A in a second configuration. Figure 4 is a cross section of a side elevation of
30 the spray module of Figure 3A. In the configuration of both Figures 3A and 4, the spray module 114 is closed, that is it is not able to spray the heat sources 142 of the circuit board 116. On the other hand, in the configuration of Figure 3B, the spray module 114 is open, and the heat sources 142 of the circuit board 116 are being sprayed.

35 The spray module 114 is made up of first and second recessed body plates

202, 204, mounted together so that their combined recesses form a module cavity 206. The two body plates 202, 204 may be screwed together, for ease of dismantling. A gasket 208 surrounds the module cavity 206 to prevent any leakage. The module cavity 206 is connected to the top surface of the spray module 114 by way of supply ports 210, one at each end of the first recessed body plate 202. These supply ports 210 extend into nipples at the top of the spray module 114, where they are joined by the supply tubes 130 of Figure 1 (not shown in Figure 3A or 3B). Thus the module cavity 206 is usually filled with coolant fluid.

The spray module 114 is mounted on the circuit board 116 by way of a hollow frame 212, which separates the spray module 114 from the heat sources 142 of the circuit board 116. The spray module 114 is usually screwed onto the circuit board 116 through this hollow frame 212. Thus when the circuit board is mounted on the support frame 120 of Figure 1, it also mounts the spray module 114.

The recesses of the first and second recessed body plates 202, 204 are generally parallelepiped in shape, with flat surfaces. The only exits in the walls of the first recessed body plate 202 are through the supply ports 210. On the other hand, there is a plurality of exit ports 214 through the major surface of the second recessed body plate 204, extending straight through to the outside. The number of exit ports 214 can be chosen according to the expected number of heat sources for which the module is intended, or it could be a relatively large number in a regular pattern as is apparent in Figure 4. There is also electrical line conduit 216 through one end of the second recessed body plate 204, for an electrical line to pass through.

A sliding plate 218 lies against the major surface of the second recessed body plate 204, extending over all the exit ports 214. It is slidable in a longitudinal direction relative to the second recessed body plate 204, between a first extreme position A (towards the left in Figures 3A, 3B and 4) and a second extreme position B (towards the right in Figures 3A, 3B and 4). The sliding plate 218 is kept in place against the major surface of the second recessed body plate 204 by way of two position guides 220, one along each edge, in the sliding direction. Two stops 222 are provided on each position guide 220, one at each end corresponding to the first and second extreme positions A, B.

Ideally the sliding plate 218 is self-lubricating, for example being PTFE

coated, for reduced wear and friction between it and the second recessed body plate 204.

5 The sliding plate 218 has a plurality of fluid through-holes 224, which are open at one end to the module cavity 206. The number and positions of the fluid through-holes 224 corresponds to those exit ports 214 in the second recessed body plate 204. In the first configuration, as shown in Figures 3A and 4, the sliding plate is at the first extreme position A, where the fluid through-holes 224 are all out of alignment with the exit ports 214. In this configuration, fluid cannot pass from the
10 fluid through-holes 224 to the exit ports 214 and no spraying occurs. On the other hand, in the second configuration, as shown in Figure 3B, the sliding plate is at the second extreme position B, where the fluid through-holes 224 are all in alignment with the exit ports 214. In this configuration, fluid passes from the module cavity 206, via the fluid through-holes 224, to the exit ports 214 sprays the heat sources 142.

15 In some instances, it may be wasteful to have a large number of exit ports 214 spraying the circuit board, especially if there are only a few heat sources 142 on the circuit board 116. In such cases, the sliding plate 218 itself may be customised to have only fluid through-holes 224 corresponding to those exit ports 214 adjacent
20 the actual heat sources 142. In that way, the module body does not need changing, but just the sliding plate 218. Alternatively, rather than changing the sliding plate 218, the fluid through-holes 224 that are not needed could be plugged from the inside of the spray module 114. In addition, as different integrated chips on a circuit board 116 may generate different amounts of heat, the sizes of the exit ports 214 could be
25 customised accordingly, although preferably, it would be the sliding plate 218 again that would be customised, with some fluid through-holes 224 having larger bores than others.

30 The movement of the sliding plate 218 is controlled by a motor 226 at one end (the right end in the Figures) of the recess of the second recessed body plate 204 and a number of tension springs 228 at the other end (the left end in the Figures). The motor 226 has two pulleys 230, one at each end of its rotor, to each of which is mounted one end of a cable 232. The other end of each cable is attached to the near end (the right end in the Figures) of the sliding plate 218. One end of each
35 spring 228 is attached to the wall of the recess of the second recessed body plate 204. The other end of spring 228 is attached to the near end (the left end in the

Figures) of the sliding plate 218.

The default position in the spray module 114 is that shown in Figures 3A and 4. This is the first configuration and the module 114 is closed, with the sliding plate at extreme position A, to the left. This is the default position, due to the tension in the springs 228. However, when an operation signal comes to the motor 226 via the electrical line in the electrical line conduit 216, it switches the motor 226 on and that pulls the cables 232. The force provided through the cables 232 is greater than that provided by the springs 228 and thus the sliding plate 218 is pulled to extreme position B, to the right. In this position, the module 114 is open and spraying starts.

The sliding plate 218 stays in the module open position for as long as the motor 226 is on. As soon as the motor is turned off, it stops pulling and the tension springs 228 pull the sliding plate 218 back to the extreme position A, to the left, the module closed position.

Alternatively, the motor can operate as a bi-state device, where a positive signal is required for any change. Thus a first signal would activate the motor 226 to pull the sliding plate 218 and a second signal would have to activate the motor 226 to release the sliding plate 218. A mere absence of power would not make any difference, e.g. release the sliding plate 218. Another possibility is for the module to have a fail-open arrangement, whereby, if anything in the control system fails, the sliding plate 218 will stay in the open position or automatically move to it.

In further alternative embodiments, the motor could be replaced with an actuator, to push or pull the sliding plate directly. In those or other embodiments, the tension springs could be replaced with one or more compression springs 222. Another possibility is for the sliding plate to rotate, rather than slide longitudinally. The plate could rotate about a central axle or about an axle towards one edge or side. In any of these embodiments, the plate does not need to be rectangular. It could be triangular, other quadrilateral shapes of other polygonal shapes, circular or a sector of a circle, etc., as appropriate.

Each spray module and circuit board pair 112 is shown as having a single spray module 114 per circuit board 116. The invention also covers the presence of two or more spray modules 114 per module and circuit board pair 112 or per circuit

board 116. Likewise, the invention also covers the presence of two or more circuit boards 116 per module and circuit board pair 112 or per spray module 114. Although the exemplified spray module and circuit board pair 112 has the two mounted together, they can be separate, each mounted independently of the other within the spray chamber 100.

Each spray module is shown as having a single sliding plate 218 and motor 226. In other embodiments, there could be two or more of each in a single spray module 114, each motor at least controlled individually.

The spray modules 114 are intended to be easily removable and replaceable, in case any particular one is not needed or needs replacing or if an upgrade is available, without needing to replace the whole system. This modular system also allows specific cooling requirements to be more easily tailored to.

The spray chamber 100 is controlled by means of a control system 300. This is not shown in any of Figures 1 to 4, but various components of the control system 300 are shown in Figure 5.

The control system 300 is based around a controller 302, with a microprocessor 304 (although there could be several of these in other embodiments). The controller 302 is mounted on a circuit board which is situated within the spray chamber 100, in one of the slots between the support frames 120 (although not shown in Figure 1). Indeed, if necessary, it too could have a spray module paired with it and cooled. The controller 302 is provided with power and turned on/off etc. through lines also connected to the spray chamber I/O connectors 127 mounted on the outside of the first end wall 104.

The controller 302 has input signals S_1 to S_m , through inputs 306 from m different temperature sensors 308 within the spray chamber 100. It provides n different output signals O_1 to O_n , through outputs 310, to the n spray modules within the spray chamber 100. These output signals O_1 to O_n run to the motors 226 in each spray module 114, along the side walls 102 (or top or bottom wall 108) then through the electrical lines in the spray module electrical line conduits 216. The different inputs and outputs allow individual control of the motors 226 and thereby the spray modules 114. There would normally be at least the same number of

temperature sensors 308 as spray modules 114, and preferably more, for more accurate temperature measurement of individual heat sources 142 (integrated circuits). There are also other control lines 312, for receiving and sending other signals, for instance from and to the pumps 138.

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A memory 314 within the controller 302 stores temperature threshold values Ti-High and Ti-Low (for each of the temperature sensors 308). These are threshold values associated with those heat sources 142 (integrated circuits) with which the temperature sensors 308 themselves are associated.

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Ti-High is the upper threshold level that is to be allowed before cooling will start. In this embodiment it is set at 10% below the maximum operating temperature of the heat source 142 (integrated circuit) with which the temperature sensor 308 is associated. If there is more than one heat source associated with a temperature sensor 308, it is based on the lowest maximum operating temperature of those heat sources (the worst-case electronic component). For instance if one chip associated with a temperature sensor 308 can operate up to 125 deg C, whilst another chip associated with the same temperature sensor 308 can only operate up to 85 deg C, Ti-High is set based on the worst case, that is 85 deg C. So Ti-High in this case would be about 77 deg C (10% below 85 deg C).

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Ti-Low is the lower threshold level for which no spray cooling is required. In this embodiment it is set at 30% below the maximum operating temperature of the worst-case electronic component. Thus, since the worst-case electronic component associated with the above particular temperature sensor 308 has a maximum operating temperature of 85 deg C, the Ti-Low for that temperature sensor 308 is set at 60 deg C (30% below 85 deg C). Spray cooling is to be cut off if a temperature below that level is detected, as the chips are in their comfortable operating range. However, when determining the Ti-Low for any temperature sensor 308, it should be ensured that the selected Ti-Low is not below the operating temperature of any chip associated with the temperature sensor 308. Otherwise, those chips may need dividing up between two or more temperature sensor 308.

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The temperature sensors 308 are mounted within the spray chamber 100. The number and arrangement of temperature sensors 308 can vary as is desired by the user. They may be mounted directly on individual heat sources 142 (integrated

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circuits) on the circuit boards 116, or spaced apart from them and not necessarily in a ratio of one temperature sensor 308 per one heat source 142 (integrated circuit). They may be situated in the recess portions 124 at the edges of the circuit boards 116. For instance they may be placed on the sides of projecting portions in contact with the reverse sides of the circuit boards 116, that is the sides of the circuit boards 116 on which the chips are not mounted. Such an arrangement would work best where the chips are generally similar and are uniformly mounted. The temperature sensors 308 may even be placed on the external surface of the spray modules 114, on the underside of the second recessed body plate 204, between the exit ports 214, preferably with suitable insulation against the cooler temperature of the spray module 114 itself. When the temperature sensors 308 are mounted on the spray modules 114, the output signals from the temperature sensors 308 can pass out through lines in the spray module electrical line conduits 216 (or out through other lines). This approach adds to the usefulness of the modular system.

An operation of the control system 300 of Figure 5 is now described with reference to Figure 6.

Once the system is operative, the controller 302 sets a variable, "i" to be zero (step S402). Next the controller 302 adds one to the current value of variable "i" (step S404). For the new current value of "i", the controller 302 detects the temperature T_i indicated by the input signal S_i , received from a specific temperature sensor 308 (step S406). This temperature T_i is compared with a T_i -High value stored in the memory of the controller 302 (step S408).

If the temperature is T_i above the T_i -High value, the controller determines if all the pumps and the condenser are on (step S410). If they are not on, then they are turned on (step S412). If they are already on, or once they are turned on (step S412), the output signal O_j , to the motor 226 of the associated spray module 114 is turned on or kept on, if it is already on. This causes the sliding plate 218 to be pulled, thereby aligning the fluid through-holes 224 with the exit ports 214. The pressure in the cavity 206, which is due to the pumps 138, causes coolant fluid to spray out, to cool the relevant heat sources which gave rise to the high temperature reading (step S414).

If the temperature T_i is below the T_i -High value, the controller compares this

same temperature with a Ti-Low value stored in the memory of the controller 302 (step S416). If the temperature Ti is below the Ti-Low value, the output signal Oj, to the motor 226 of the associated spray module 114 is turned off or allowed to stay off (step S418). If the temperature Ti is above the Ti-Low value, the output signal Oj, to the motor 226 of the associated spray module 114 is unchanged, remaining off if it is already off or remaining on if it is already on. This is because the relevant heat source(s) has either not been cooled sufficiently or has not got hot enough to need cooling.

10 Once the motor 226 of the associated spray module 114 has been turned on or kept on (step S414) or turned off or kept off (step S418) or allowed to remain unchanged (a "No" from step S416), the controller determines if the current value of "i" is "m" (i.e. has it gone through every temperature sensor 308?) (step S 420). If it is not "m", then the process returns to increase the value of "i" by one (step S404), to go through the process for the next temperature sensor 308. If it is "m", then the process returns to reset the value of "i" to zero (step S402).

20 The above process assumes one temperature sensor 308 per spray module motor 226. If there is more than one temperature sensor 308 per spray module motor 226, then safeguards need to be included so that a spray module that is on and needs to remain on is not turned off because a different sensor is reading a temperature below its relevant Ti-Low. For instance, the detect temperature step could detect the temperatures for every temperature sensor 308 associated with a single motor 226 and compare every one with its relevant Ti-High and turn the relevant motor on if even a single one of the temperatures exceeds its Ti-High. Likewise, if none exceeds its Ti-High, every one is compared with the relevant Ti-Low and the motor is only turned off if every one is lower than its Ti-Low. In this way, if only a single temperature sensor 308 senses a temperature above its Ti-High, the relevant spray module is turned on and remains on until the temperature sensed by every relevant temperature sensor is below its Ti-Low.

30 The above example assumes the Ti-High and Ti-Low associated with each sensor changes from one temperature sensor 308 to another. However, to simplify matters, for example when the chips are similar, the upper threshold Ti-High that is used can be the same for every temperature sensor 308 and the lower threshold Ti-Low that is used can be the same for every temperature sensor 308.

In the above embodiment, temperature sensors are used. However, this aspect of the invention can use other forms of heat sensors, with comparisons against heat emission or reception thresholds, rather than specifically just temperature.

It is understood by those skilled in the art that even though numerous characteristics and advantages of various preferred embodiments of the present invention have been set forth in the foregoing description, this disclosure is illustrative only. Other modifications may be made, especially in matters of structure, arrangement of parts and/or steps within the principles of the invention to the full extent indicated by the broad general meaning of the appended claims without departing from the scope of the invention.

CLAIMS

1. A spray module for removably in a spray cooling chamber of a spray cooling apparatus, said chamber having a plurality of heat sources, which module is for cooling the plurality of heat sources, the spray module comprising:
 - a cavity within a first body, for containing a cooling fluid;
 - an input port for receiving cooling fluid to said cavity;
 - a second body, in response to controller means of the spray cooling apparatus, operable to move relative to the first body between first and second positions; and
 - a plurality of output ports being in fluid communication with the cavity when the second body is in the second position relative to the first position relative to the first body;wherein the response is based on the amount of heat emitted by the plurality of heat sources sensed by heat sensors associated with the controller means.
2. A spray module according to claim 1, wherein the second body is a sliding plate, mounted against the first body.
3. A spray module according to claim 1 or 2, wherein the second body is mounted in said cavity.
4. A spray module according to claim 1, 2 or 3, wherein the second body comprises a self-lubricating material.
5. A spray cooling apparatus comprising a spray cooling chamber having:
 - mounting means for removably mounting a plurality of spray modules with spaces to accommodate a plurality of heat sources directly between successive spray modules;
 - a fluid collecting surface for receiving and collecting fluid sprayed within the chamber from the plurality of spray modules; and
 - controller means for controlling spraying by the plurality of spray modules;wherein each of said plurality of spray modules is as defined in any one of claims 1 to 4.
6. A spray cooling apparatus according to claim 5, wherein the mounting means are arranged to mount the plurality of spray modules in parallel.

7. A spray cooling apparatus according to claim 5 or 6, further comprising a plurality of heat sensors for sensing heat emitted from a plurality of heat sources in the spaces between spray modules mounted in the spray chamber.
8. A spray cooling apparatus according to claim 7, wherein the controller means are operable to control spraying of specific heat sources by individual spray modules, based on the heat sensed by specific heat sensors.
9. A spray cooling apparatus according to claim 8, wherein the controller means is operable to start spraying of those heat sources, the heat sensor for which senses an amount of heat exceeding a first threshold.
10. A spray cooling apparatus according to claim 8 or 9, wherein the controller means is operable to stop spraying of those heat sources, the heat sensor for which senses an amount of heat below a second threshold.
11. A spray cooling apparatus according to claims 9 and 10, wherein the second threshold is lower than the first threshold.
12. A spray cooling apparatus according to any one of claims 7 to 11, wherein the heat sensors are temperature sensors.
13. A spray cooling apparatus according to any one of claims 5 to 12, further comprising:
a reservoir for receiving fluid from the fluid collecting surface and supplying said fluid to the plurality of spray modules mounted in the spray chambers.
14. A spray cooling apparatus according to any one of claims 5 to 13, further comprising a condenser for receiving fluid from the fluid collecting surface and for removing heat from said fluid.
15. A spray cooling apparatus according to claims 13 and 14, wherein the reservoir is operable to receive said fluid from said fluid collecting surface via said condenser.

16. A spray cooling apparatus according to any one of claims 5 to 15, further comprising a second fluid collecting surface for receiving and collecting fluid sprayed within the chamber from the plurality of spray modules, the second fluid collecting surface being an opposing internal surface of the spray chamber from the first fluid collecting surface.

17. A spray cooling apparatus according to claim 16, wherein the first and second fluid collecting surfaces both have a plurality of fluid collecting holes therein for draining fluid therethrough.

SPRAY COOLING METHOD AND APPARATUS

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ABSTRACT

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A spray module has a body and a cavity with a sliding plate within it. Incoming control signals move the sliding plate between an open position, in which holes in the plate align with holes in the body, to allow cooling spraying to occur, and a closed position, in which no spraying occurs. A plurality of these spray modules are removably mounted in parallel, one in front of the other, in a spray chamber. Each module has its body holes directed at one or more heat sources on a circuit board or some such, the circuit boards being placed between adjacent spray modules. Separate temperature sensors detect the temperatures of different heat sources. Based on these detected temperatures, a controller selectively sends signals to specific spray modules to spray those heat sources whose temperature is too high. Sprayed coolant from all the spray modules falls to the gravimetric bottom of the spray chamber in whichever orientation the chamber is in and is collected, condensed and sent back to the spray modules.

FIGURE 1