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(54) **COOLING SYSTEM FOR A POWER MODULE**

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(57) **ABSTRACT**

A cooling system for a power module (or some other power electronics device) is described, the cooling system having a closed flow path for circulating a cooling fluid, the flow path having a pressure that is reduced to below atmospheric pressure. The cooling fluid is circulated along the flow path to provide cooling of the power module. The flow path is delimited from the exterior environment by a space provided between the flow path and the exterior environment, said space being sealed off from the cooling flow path, and said space being sealed off towards the exterior environment. The flow path has a pressure below atmospheric pressure and the space between the flow path and the exterior environment is evacuated and typically has a pressure lower than the pressure in the flow path.

(21) Appl. No.: **14/007,801**

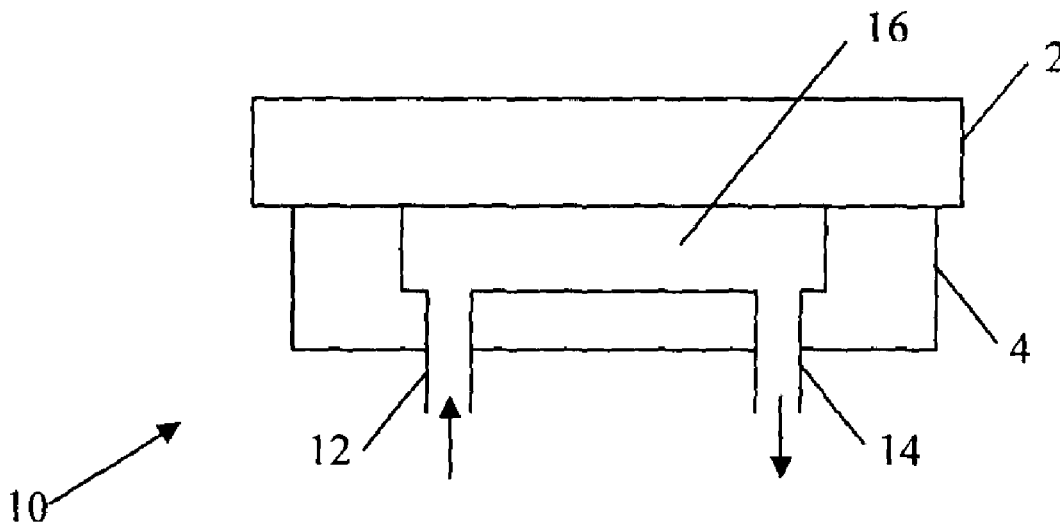
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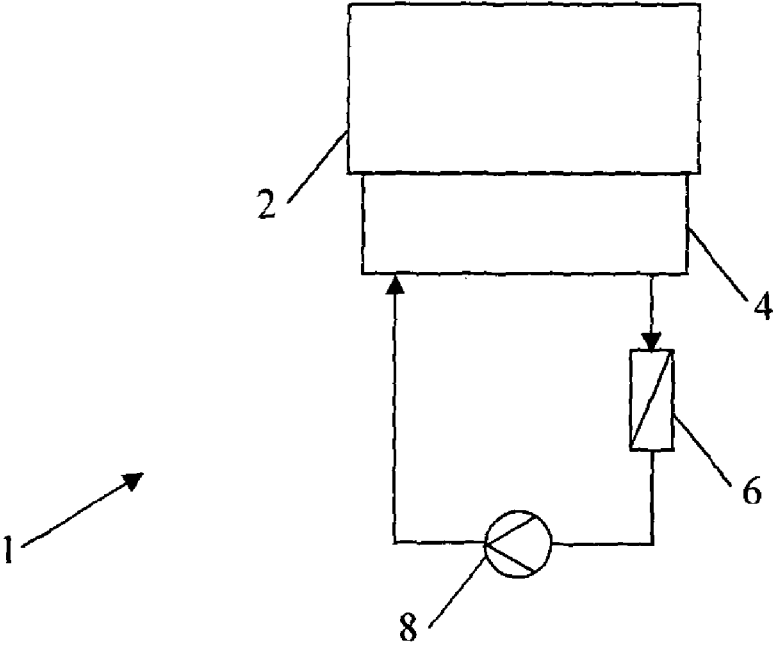


Fig. 1

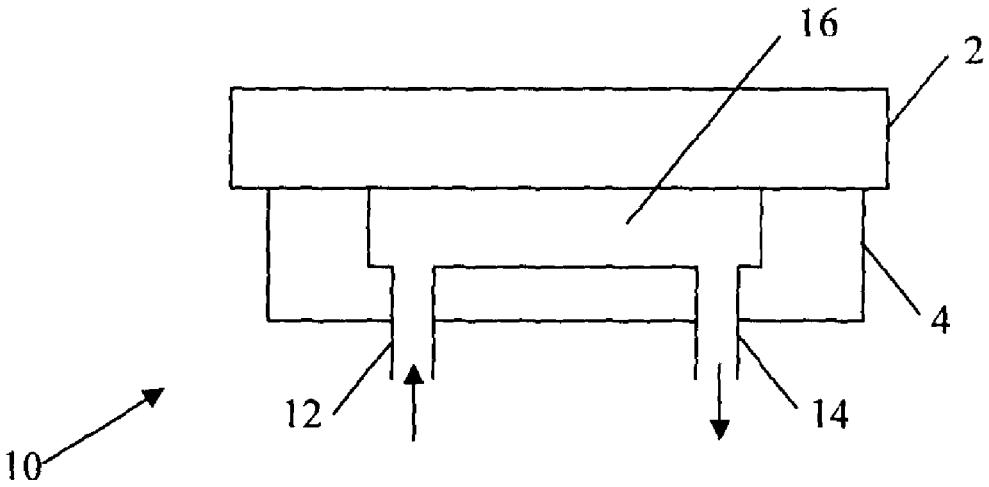


Fig. 2

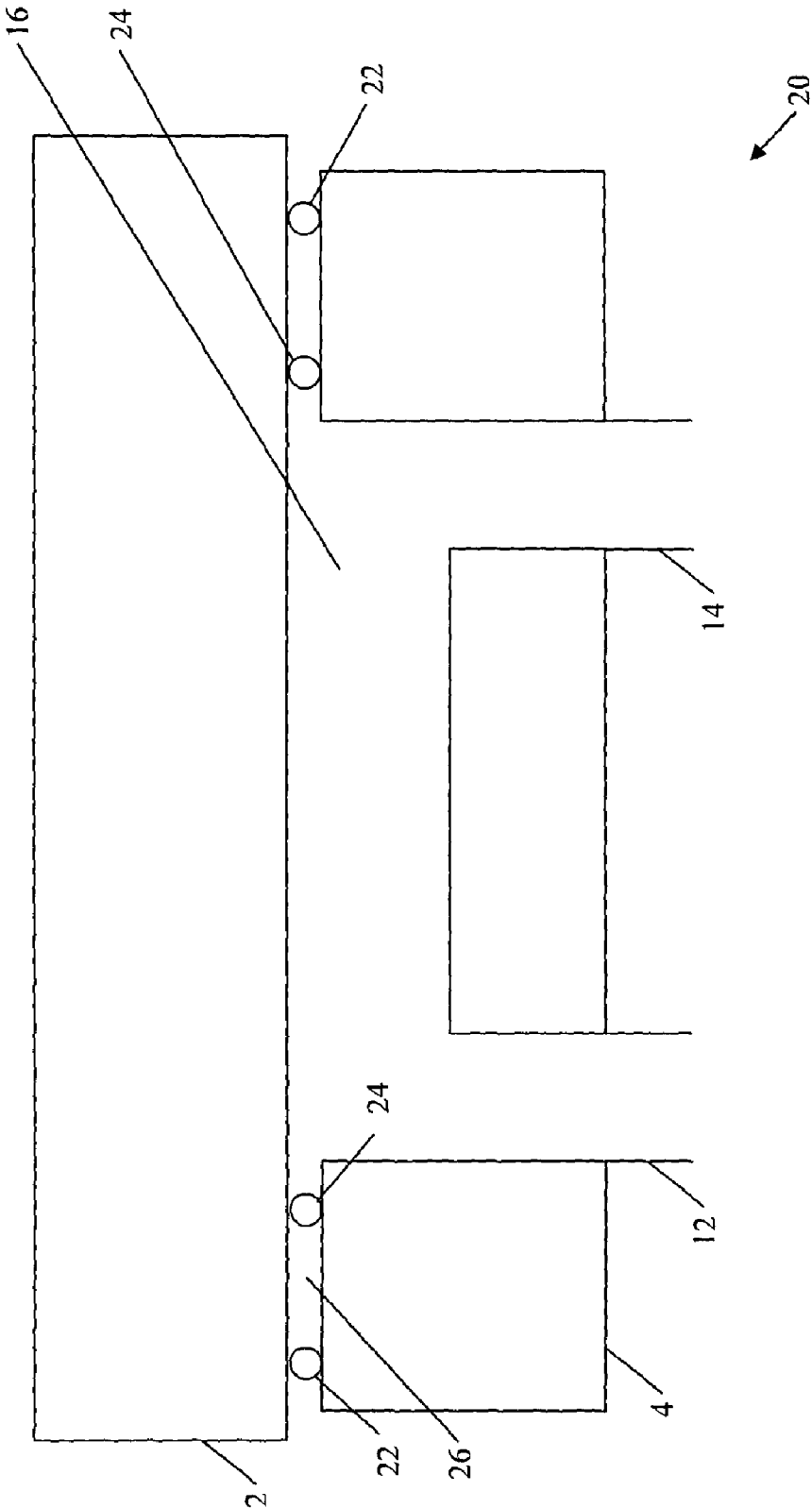
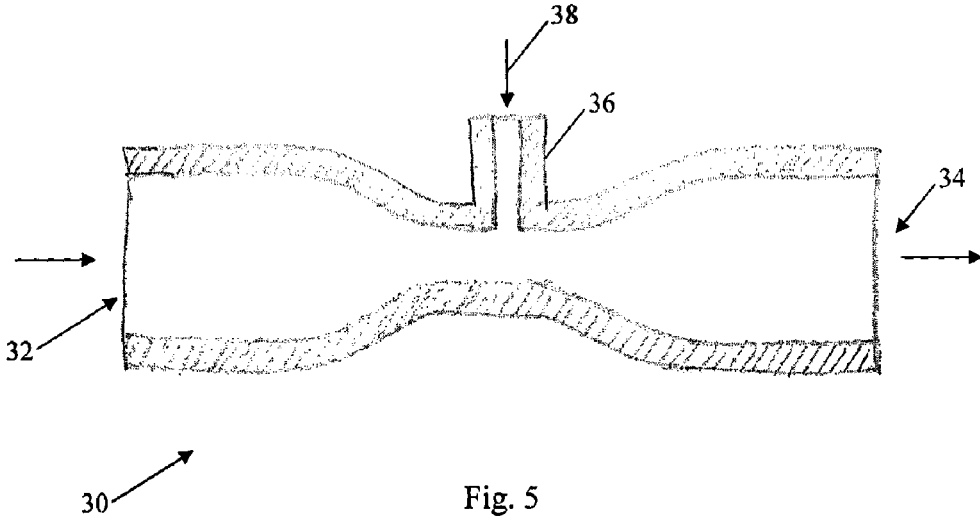
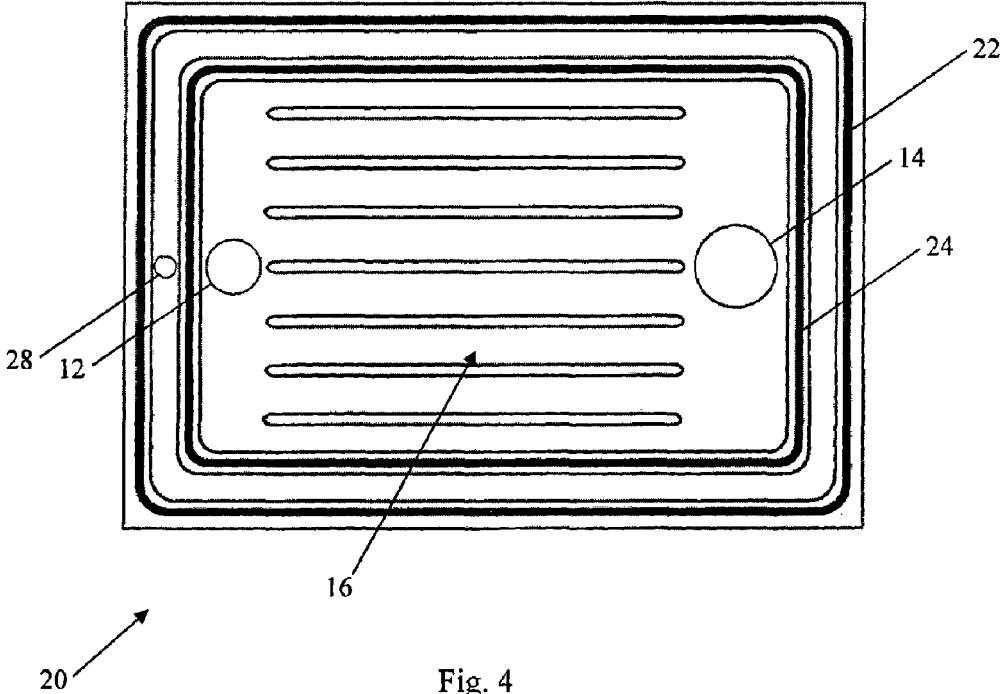


Fig. 3



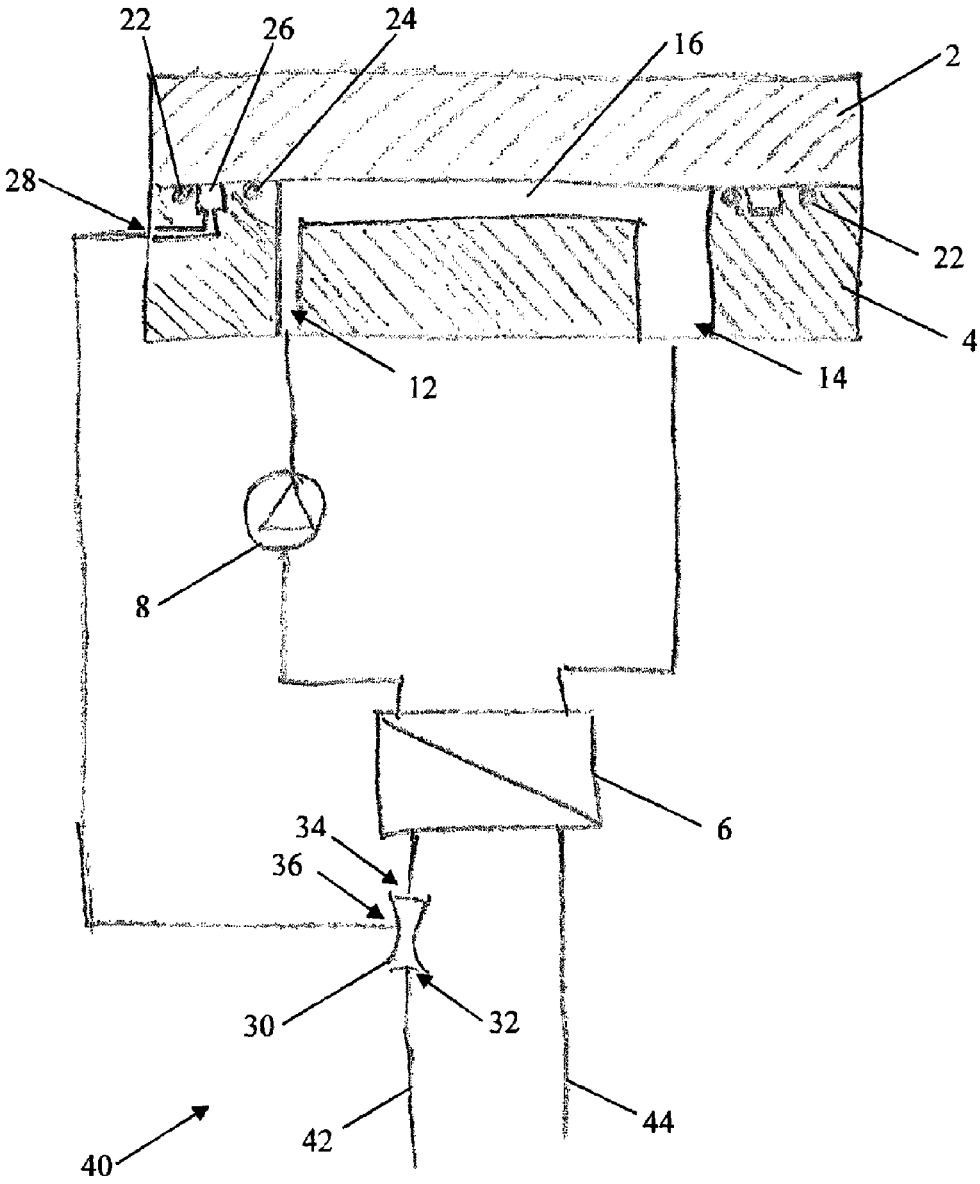


Fig. 6

COOLING SYSTEM FOR A POWER MODULE

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application is entitled to the benefit of and incorporates by reference subject matter disclosed in International Patent Application No. PCT/DK2012/000032 filed on Apr. 2, 2012, Danish Patent Application No. PA 2011 00253 filed Apr. 4, 2011 and U.S. Patent Application 61/482,398 filed May 4, 2011.

FIELD OF THE INVENTION

[0002] The invention relates to a cooling system for a power converting module or some other power electronics device. The invention also relates to a power converting module such as a frequency converter. The invention furthermore relates to a method for operating a cooling system for a power converting module or some other power electronics device.

BACKGROUND OF THE INVENTION

[0003] The cooling of heat emitting components, particularly electronic components such as semiconductor power modules, it is often done by bringing the heat-emitting component into contact with a base plate. Such a base plate is cooled, perhaps by the flow of air across a finned heat sink or by internal cavities in the base plate itself which conduct a coolant.

[0004] It is an advantage to keep the heat conducting path as short as possible and free of interfaces with a high thermal resistance, such as the presence of thermal interfaces such as thermal grease. To avoid the use of such a thermal interface, it is known to introduce the liquid coolant directly onto the surface of the heat-emitting component by means of a fluid distribution element, for example, which causes the coolant to circulate along the surface to be cooled.

[0005] Such an embodiment has the problem that a seal must be present between the distributor system and the surface to be cooled, in order to prevent fluid leaking out. Such leakage is undesirable since the release of conductive fluids, such as water (a commonly used coolant), can cause havoc in an electronic environment. A better seal could be provided by gluing, soldering or otherwise permanently fixing the distributor to the element to be cooled. This, however, is not an optimum solution because it prevents the replacement of a failed electronic component, or the easy cleaning of the fluid distributor.

SUMMARY OF THE INVENTION

[0006] An object of the invention may be to provide better and/or simpler cooling performance of a cooling system for cooling power modules and other power electronics devices. An object of the invention may alternatively or additionally be to provide power modules and other power electronics devices having a better and/or a simpler cooling system.

[0007] In accordance with the first-mentioned object of the invention, the present invention provides a cooling system for a power electronics device (such as a power module), the cooling system comprising: a closed flow path for circulating a cooling fluid (said cooling fluid typically being based on water); means (e.g. a pump) for circulating the fluid along the flow path to provide cooling of the power electronics device; and a condenser, wherein: said cooling fluid is passed to the condenser after having passed the power electronics device

and the cooling fluid is passed to the power electronics device after having passed the condenser; the flow path has a pressure that is reduced to below a pressure prevailing in an exterior environment (the pressure prevailing in the exterior environment typically being atmospheric pressure); and the flow path is delimited from the exterior environment by a space provided between the flow path and the exterior environment, said space being sealed off from the flow path, said space being sealed off from the exterior environment, and said space being (at least partially) evacuated.

[0008] The present invention also provides a method of using a cooling system to cool a power electronics device (such as a power module), the method comprising: passing a cooling fluid around a closed flow path from the power electronics device to a condenser of the cooling system and from the condenser to the power electronics device, wherein the flow path has a pressure that is reduced to below a pressure prevailing in an exterior environment (typically atmospheric pressure); and partially evacuating a space that is provided between the flow path and the exterior environment. In many forms of the invention, the step of partially evacuating the space may result in the space having a pressure below the pressure of both the flow path and the exterior environment. The step of partially evacuating the said space may comprise using a pump (such as an injector pump).

[0009] Thus, a cooling system for a power module or some other power electronics device and a method of using such a cooling system for cooling a power module or some other power electronics device are described, the cooling system having a closed flow path for circulating a cooling fluid, the flow path having a pressure that is reduced to below atmospheric pressure. The cooling fluid is circulated along the flow path to provide cooling of the power electronics device. The flow path is delimited from the exterior environment by a space provided between the flow path and the exterior environment, said space being sealed off from the cooling flow path, and said space being sealed off towards the exterior environment. The flow path has a pressure below atmospheric pressure and the space between the flow path and the exterior environment is evacuated and typically has a pressure lower than the pressure in the flow path.

[0010] In use, the cooling fluid at least partially evaporates in the flow path when close to the power electronics device, thereby removing heat from the power electronics device. The cooling fluid is then condensed by the condenser before being returned to the area in the vicinity of the power electronics device to be evaporated again. Energy is removed from the system by the condenser.

[0011] The cooling fluid is typically based on water. Using water as refrigerant in a pumped two-phase system solves a number of problems associated with normal 2-phase cooling such as low pressure, and the pressure of the cooling fluid being lower than atmospheric pressure eliminates any deformation problems normally associated with 2-phase cooling. Also, serviceability becomes simpler, and there is no spillage of environmentally unfriendly refrigerants. Exchange of power modules becomes possible for a service technician. Furthermore, water is very environmentally friendly, and water is not flammable, not toxic, has no ozone depletion problems (ODP) or global warming problems (GWP).

[0012] The space may be sealed off both from the exterior environment and from the flow path for the cooling fluid by at least two gaskets, both of said gaskets preferably being made

from an elastomeric gasket, and at least one, possibly both, of said gasket being permeable to air.

[0013] Utilising a double gasket, one on each side of the space, i.e., one gasket towards the exterior environment and one gasket towards the closed flow path for the cooling fluid, and maintaining a vacuum (or at least a partial vacuum) in the space by evacuating the space between the two gaskets has the advantage of enabling the use of standard gasket materials like rubber and other elastomers despite the fact that the one or both of the gaskets may be permeable to air.

[0014] The space may have a pressure below the pressure of both the flow path and the exterior environment. By way of example, the space may have a pressure of the order of 10-50 mbar and the flow path may have a pressure of the order of 200 mbar. The exterior environment is typically at atmospheric pressure (of the order of 1000 mbar). Of course, other pressures are possible in alternative implementations of the invention.

[0015] Maintaining a partial vacuum in the space by evacuating the space has the advantage of any leakage from the flow path of the cooling fluid being a leakage to the evacuated space, and not being a leakage to the exterior environment. Moreover, any leakage from the exterior environment will be into the evacuated space. Thereby, any leakage will have no or only limited damaging effect towards maintaining vacuum in the flow path.

[0016] A pump may be provided for reducing the pressure in the said space. In some forms of the invention, the pump is an injector pump. The injector pump may make use of the movement of a secondary fluid to generate a partial vacuum used for reducing the pressure in the said space. The secondary fluid may also be used for cooling the cooling fluid in the closed flow path described above. The secondary cooling fluid may be water. The secondary cooling fluid may be pre-heated by the cooling system for use in another application. By way of example, the secondary cooling fluid may be a fluid (such as water) used in a heating system so that pre-heating the fluid not only assists in removing heat from the power electronics device being cooled but is also usefully used in the heating system.

[0017] In use, the cooling fluid may have a certain pressure and the flow path may be provided with means for controlling the pressure of the cooling fluid for maintaining a certain pressure of the cooling fluid.

[0018] In some forms of the invention, the power electronics device comprises a base plate, wherein the flow path is configured to cool the said base plate. However, this is not the only possible arrangement. For example, the flow path may comprise a section that extends inside the power electronics device as such, the cooling fluid thereby cooling the power module from inside the power electronics device. Alternatively, or in addition, the flow path may have a section that extends along the power electronics device as such, the cooling fluid thereby cooling the power electronics device from an outer boundary of the power electronics device.

[0019] The flow path may have a section comprising heat pipes, the cooling fluid at least partly cooling the power electronics device by evaporation of the cooling fluid in the heat pipes.

[0020] The flow path may have a section extending along dielectric cooling channels, the cooling fluid at least partly cooling the power electronics device by evaporation of the cooling fluid in the dielectric cooling channels.

[0021] The power electronics device may be embedded in the cooling system so that a section of the flow path extends along the power electronics device, the cooling fluid thereby cooling the power electronics device from an outer boundary of the power electronics device.

[0022] The flow rate of the cooling fluid may be controlled so that a liquid fraction of the cooling fluid is only partly evaporated when the cooling liquid is passed along the flow path near the power electronics device (e.g. in the base plate, if provided), resulting in a mixture of a liquid phase and a gas phase of the cooling fluid.

[0023] The flow path may have a section extending along an expansion vessel, a fluid connection being established between the flow path and the expansion chamber, with the proviso that the cooling liquid expands due to evaporation, the cooling fluid being capable of at least partly filling the expansion chamber with gas of an evaporated cooling fluid.

[0024] The flow path may comprise micro channels having an average cross-sectional area between 1 mm² and 100 mm². The flow path may comprise micro-channels having an average cross-sectional area between 1 mm² and 25 mm². Of course, other dimensions are possible in alternative embodiments of the invention.

[0025] In some forms of the invention, the cooling fluid may include an anti-freezing agent selected from an additive unmixed or an additive mixed with the water, for lowering the freezing temperature of the cooling fluid. The anti-freezing agent may be a salt. Lowering the freezing temperature of the cooling fluid results in the power module being capable of continued functioning at temperatures below the freezing temperature of water.

[0026] The cooling system may comprise a reservoir capable of accommodating a gas constituent of the cooling fluid, said reservoir being void of cooling fluid if no gas constituent of the cooling liquid is present in the cooling system. The reservoir may, for example, be positioned at an upper level, preferably at a top, of the cooling system when the cooling system is in operation. The reservoir may be provided with a bulge provided between the cooling fluid and a reservoir cavity void of cooling fluid. A reservoir for containing possible gas of the cooling fluid has the advantage of the cooling fluid or at least part of the cooling fluid being capable of evaporating without the pressure increasing within the cooling system, due to possible evaporation of all or part of the cooling fluid, resulting in damage to the cooling system as such. Also, a reservoir for containing gas of the cooling fluid provides an increased possibility for the cooling system functioning as a thermo siphon. Especially because the cooling system contains water, pressure losses must be limited because the degree of evaporation is very sensitive to any pressure loss.

[0027] In accordance with the second-mentioned object of the invention, the present invention provides a power module (such as a frequency converter) having a cooling system as set out above. The cooling system typically forms an integrated part of the power module.

[0028] Thus, the present invention provides a power module (such as a frequency converter) comprising a cooling system (typically forming an integrated part of the power module), wherein the cooling system comprises: a closed flow path for circulating a cooling fluid (said cooling fluid typically being based on water); means (e.g. a pump) for circulating the fluid along the flow path to provide cooling of the power module; and a condenser, wherein: said cooling

fluid is passed to the condenser after having passed the power module and the cooling fluid is passed to the power module after having passed the condenser; the flow path has a pressure that is reduced to below a pressure prevailing in an exterior environment; and the flow path is delimited from the exterior environment by a space provided between the flow path and the exterior environment, said space being sealed off from the cooling flow path, said space being sealed off from the exterior environment, and said space being evacuated.

[0029] The power module may have a plurality of heat dissipating components, at least some of the heat dissipating components comprising an evaporator situated inside the heat dissipating components.

[0030] The cooling system of the power module may have a pump for pumping the cooling liquid along the flow path.

[0031] The cooling system of the power module may be being orientated for functioning as a thermo siphon.

[0032] In some forms of the invention, the cooling system is configured so that the power electronics device (e.g. a power module such as a frequency converter) is provided such that an operator of the power module only needs to connect cooling water to an inlet and an outlet of the cooling system. The operator can choose any kind of water, i.e., non-saline or saline water, without considering whether the cooling system is capable of utilising the water for cooling the power module. This cooling water is used to cool the cooling fluid that is circulated around the closed flow path of the cooling system. This cooling water (sometimes referred to as a secondary cooling fluid) can also be used in the injector pump of some embodiments of the invention in order to reduce the pressure in the space between the flow path and the exterior environment.

[0033] The first mentioned object and/or the second mentioned object of the invention may be obtained by a method for operating a cooling system according to the invention, said method comprising the step of controlling the flow rate of the cooling fluid, so that a liquid fraction of the cooling fluid is only partly evaporated when the cooling liquid is passed along the flow path in the base plate, resulting in a mixture of liquid of the cooling fluid and gas of the cooling fluid when the cooling fluid is leaving the flow path of the base plate.

[0034] Using a self circulating, or a pumped or a vapour compression or a combination of these to cool the power module by phase transition, but controlling the flow rate of the cooling fluid, so that the cooling fluid is only partly evaporated has the advantage of optimal heat transfer and/or substantially unified temperature across the surface of the power module being cooled.

BRIEF DESCRIPTION OF THE DRAWINGS

[0035] The invention will hereafter be described with reference to the drawings, where

[0036] FIGS. 1-6 are highly schematic sketches showing specific embodiments of a part of a cooling system. In particular:

[0037] FIG. 1 is a block diagram of a cooling system in accordance with an aspect of the present invention;

[0038] FIG. 2 shows a cross-section of cooling system in accordance with an aspect of the present invention;

[0039] FIG. 3 is an expanded view of a cooling system in accordance with an aspect of the present invention;

[0040] FIG. 4 is a plan view of the cooling mechanism of FIG. 3;

[0041] FIG. 5 shows an injector pump that may be used in some embodiments of the present invention; and

[0042] FIG. 6 is a block diagram of a cooling system incorporating an injector pump in accordance with an aspect of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0043] FIG. 1 is a block diagram of a cooling system, indicated generally by the reference numeral 1, in accordance with an aspect of the present invention. The cooling system 1 comprises an object to be cooled 2, a distributor 4, a condenser 6 and a pump 8. The object to be cooled 2 is a power electronics device, such as a power module.

[0044] Cooling fluid is directed from the pump 8 to an inlet of the distributor 4. That cooling fluid is at least partially evaporated within the distributor 4, thereby removing heat from the object 2. The evaporated cooling fluid leaves the distributor 4 at an outlet and is directed to a condenser 6. The condenser 6 returns the cooling fluid to its liquid state and the liquid cooling fluid is pumped back to the inlet of the distributor 4 by the pump 8.

[0045] In this way, heat is removed from the object 2 by means of the vaporisation (or the partial vaporisation) of the cooling fluid. Energy is removed from the cooling fluid by the condenser 6. Such a two-phase cooling mechanism is able to remove more heat from the object 2 than a typical one-phase liquid cooling system.

[0046] FIG. 2 shows a cross-section of a part of the cooling system, indicated generally by the reference numeral 10, in accordance with an aspect of the present invention. The cooling system 10 includes the object to be cooled 2 and the distributor 4 of the cooling system 1 described above. The distributor 4 is shown in more detail, as described further below.

[0047] As shown in the cooling system 10, the distributor 4 includes an inlet 12, an outlet 14 and a channel 16. In use, cooling fluid arrives (in liquid form) at the inlet 12 and is directed to the channel 16. In the channel, the liquid is at least partially vaporised, thereby removing heat from the object to be cooled 2. The fluid exits the channel via the outlet 14. From the outlet 14, the at least partially vaporised fluid is directed to the condenser 6 (not shown in FIG. 2) where the fluid is condensed. The condensed fluid is then directed back to the inlet 14 by the pump 8 (not shown in FIG. 2).

[0048] The cooling fluid is typically water. Using water has many advantages, such as the ease of servicing and the fact that water is relatively environmentally friendly when compared with other possible refrigerants. A problem with the use of water is that the channel 16 must be maintained at a pressure lower than atmospheric pressure. The leakage of air from outside the cooling system 10 into the channel results in an increasing of the pressure in the channel and a reduction in the effectiveness of the cooling system 10. Leakage of cooling fluid from the channel 16 is also a potential problem.

[0049] FIG. 3 is an expanded view of a cooling system, indicated generally by the reference numeral 20, in accordance with an aspect of the present invention. The cooling system 10 includes the object to be cooled 2 and the distributor 4 described above. The system 20 also includes a sealing mechanism between the object to be cooled 2 and the distributor 4, as described further below.

[0050] As shown in FIG. 3, the cooling system 20 is provided with a space 26 situated between an external environment and the channel 16. The space 26 is delimited from the

external environment by a first gasket 22 and is delimited from the channel 16 by a second gasket 24. The space 26 is evacuated so that the pressure inside the space is lower than the pressure of the external environment. By way of example, the space 26 may have a pressure of the order of 10-50 mbar and the channel 16 may have a pressure of the order of 200 mbar. The exterior environment is typically at atmospheric pressure (of the order of 1000 mbar). Of course, other pressures are possible and are within the scope of the present invention.

[0051] Thus, any leakage between the external environment and the flow path results in any gas from the outside being accumulated in the space and not entering the flow path. The result of any gas from the outside being accumulated in the space and not entering the flow path is obtained even if the gaskets are made of a material permeable to gas such as rubber or another elastomeric material. Thereby, standard gaskets may be utilised.

[0052] Similarly, any leakage of cooling fluid from the flow path results in that cooling fluid being accumulated in the space and not exiting to the exterior environment.

[0053] Thus, FIG. 3 shows the provision of a double sealing gasket, in which two parallel gaskets are used between the flow path of the cooling fluid and the exterior environment. This provides a space between the two gaskets, which space can be evacuated, or at least be subjected to a reduced pressure. Such an embodiment requires the provision of a reduced pressure by a kind of vacuum system, said system capable of reducing the pressure between the two gaskets.

[0054] FIG. 4 is a plan view of the cooling mechanism 20. As shown in FIG. 4, the cooling mechanism includes the inlet 12, outlet 14, channel 16, first gasket 22 and second gasket 24 described above. The cooling mechanism also includes a vacuum outlet 28 that is provided to enable the evacuation of the space 26 between the gaskets. The distributor housing may be formed by injection moulding using a plastic compound.

[0055] In one embodiment of the invention, space 26 between the two gaskets of the cooling mechanism 20 is reduced using an injector pump (although other vacuum pumps could be used in different embodiments of the invention). FIG. 5 shows an exemplary injector pump, indicated generally by the reference numeral 30. The injector pump comprises an inlet 32, an outlet 34 and a vacuum input 36. As shown in FIG. 4, the injector pump is a tube having a constricted centre waist. The vacuum input 36 is provided at the constricted part of the tube.

[0056] In use, the vacuum input 36 is connected to a volume to be evacuated. A liquid is then passed from the inlet 32 to the outlet 34 of the injector pump. The constriction in the tube causes a drop in pressure in the vicinity of the vacuum input 36 due to the well-known Venturi effect. This drop in pressure causes matter to be drawn into the injector pump through the vacuum input, as indicated schematically by the arrow 38.

[0057] In the event that the vacuum input is connected to an enclosed volume, then that enclosed volume is partially evacuated when liquid passes through the injector pump from the inlet 32 to the outlet 34. Thus, connecting the vacuum input 36 of the injector pump 30 to the vacuum outlet 28 of the cooling mechanism 20 enables the injector pump to be used to evacuate the space 26.

[0058] FIG. 6 is a block diagram of a cooling system, indicated generally by the reference numeral 40, incorporating an injector pump.

[0059] The system 40 comprises the object to be cooled 2 and the distributor 4. As described above, the distributor 4 includes an inlet 12, an outlet 14 and a channel 16. The inlet 12 is connected to the pump 8 (shown highly schematically in FIG. 6). The outlet 14 is connected to the condenser 6 (again, shown highly schematically in FIG. 6).

[0060] As described above with reference to FIG. 3, the distributor 4 includes a first gasket 22, a second gasket 24 and a space 26 between the gaskets. The space is in fluid communication with the vacuum outlet 28 of the distributor.

[0061] The cooling system 40 additionally comprises an injector pump 30. As described above, the injector pump has an inlet 32, an outlet 34 and a vacuum inlet 36. The vacuum inlet 36 of the inject pump is connected to the vacuum outlet 28 of the distributor in order to enable the injector pump to be used to reduce the pressure in the space 26. A check valve may be provided (not shown in FIG. 6) to ensure that fluid can flow from the space 26 to the inlet of the injector pump 30, but cannot flow from the injector pump to the space.

[0062] As described above, heat is removed from the object 2 by vaporising a cooling fluid in the channel 16. The cooling fluid is received as a liquid at the inlet 12 and exits the distributor, typically as a liquid/vapour mix, at the outlet 14. The liquid/vapour mix is condensed back into a liquid at the condenser 6.

[0063] In the cooling system 40, a secondary cooling liquid (typically water) is provided to the condenser 6. A secondary source of cooling liquid 42 is directed towards the condenser and heated liquid 44 is directed away from the condenser.

[0064] As shown in FIG. 6, the secondary cooling liquid is received at the inlet 32 of the injector pump and directed from the outlet 34 of the injector pump to the condenser 6. In this way, the secondary cooling liquid can be used by the injector pump to generate the pressure drop required to evacuate the space 26 in the distributor.

[0065] The dual use of the secondary cooling fluid provides an elegant and efficient manner for both removing energy from the condenser 6 and for operating the injector pump 30.

[0066] The secondary cooling fluid may be obtained from a variety of different sources. For example, the secondary cooling fluid may be water that is used in a heating system (such as a central heating system). This is particular advantageous since the secondary cooling fluid can be pre-heated by the cooling mechanism 20, thereby improving the efficiency of the heating system in which the secondary cooling fluid is used. In an alternative embodiment, the secondary cooling fluid may be obtained from a different source, such as a river. The secondary cooling fluid need not be provided in a closed loop.

[0067] FIGS. 1 to 3 show the object to be cooled 2 being wider than the distributor 4. This is not a requirement of the invention. The distributor could be larger than, smaller than or have similar dimensions to the object to be cooled.

[0068] The embodiments of the invention described above are provided by way of example only. The skilled person will be aware of many modifications, changes and substitutions that could be made without departing from the scope of the present invention. The claims of the present invention are intended to cover all such modifications, changes and substitutions as fall within the spirit and scope of the invention.

[0069] Although various embodiments of the present invention have been described and shown, the invention is not

restricted thereto, but may also be embodied in other ways within the scope of the subject-matter defined in the following claims.

What is claimed is:

1. A cooling system for a power electronics device, the cooling system comprising: a closed flow path for circulating a cooling fluid; means for circulating the fluid along the flow path to provide cooling of the power electronics device; and a condenser, wherein:

said cooling fluid is passed to the condenser after having passed the power electronics device and the cooling fluid is passed to the power electronics device after having passed the condenser;

the flow path has a pressure that is reduced to below a pressure prevailing in an exterior environment; and the flow path is delimited from the exterior environment by a space provided between the flow path and the exterior environment, said space being sealed off from the flow path, said space being sealed off from the exterior environment, and said space being at least partially evacuated.

2. The cooling system according to claim **1**, wherein said cooling fluid is based on water.

3. The cooling system according to claim **1**, wherein the space is sealed off from the exterior environment and is sealed off from the flow path by gaskets.

4. The cooling system according to claim **1**, wherein the space has a pressure below the pressure of both the flow path and the exterior environment.

5. The cooling system according to claim **1**, further comprising a pump for reducing the pressure in the said space.

6. The cooling system according to claim **5**, wherein said pump is an injector pump.

7. The cooling system according to claim **6**, further comprising the provision of a secondary cooling fluid used to operate the injector pump.

8. The cooling system according to claim **7**, wherein the secondary cooling fluid is used to cool the cooling fluid provided in the closed flow path.

9. A power module having a cooling system as claimed in claim **1**.

10. A method of using a cooling system to cool a power electronics device, the method comprising:

passing a cooling fluid around a closed flow path from the power electronics device to a condenser of the cooling system and from the condenser to the power electronics device, wherein the flow path has a pressure that is reduced to below a pressure prevailing in an exterior environment; and

partially evacuating a space that is provided between the flow path and the exterior environment.

11. The method according to claim **10**, wherein the step of partially evacuating the space results in the space having a pressure below the pressure of both the flow path and the exterior environment.

12. The method according to claim **10**, further comprising the step of partially evacuating the said space using an injector pump.

13. The method according to claim **12**, wherein a secondary cooling fluid is provided to operate the injector pump.

14. The method according to claim **13**, wherein the secondary cooling fluid is used to cool the cooling fluid provided in the closed flow path.

15. The method according to claim **10**, wherein the cooling fluid is water-based.

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