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(54) **Cryogenic cooling apparatus**

(57) The present invention provides a cryogenic cooling apparatus (1; 10; 30) that is suitable for cooling a rotating cryogenic component such as a HTS winding or a LTS winding. The apparatus (1; 10; 30) comprises: a sealable vessel (2; 12) containing a cryogenic fluid (3; 13) within which the cryogenic component may be located; a conduction element (4; 14) having a first end and a second end, the conduction element (4; 14) located through a wall of the vessel (2; 12) such that the first end is located within the vessel (2; 12) for immersion in the cryogenic fluid (3; 13) and the second end is outside the vessel (2; 12) ; and a cooling machine (7; 17), such as a cold head, located external to the vessel (2; 12) and connected to the second end of the conduction element (4; 14). The apparatus (1; 10; 30) is advantageous as it allows the cooling of a rotating cryogenic component by immersion in a cryogenic fluid (3; 13) wherein the cryogenic fluid (3; 13) may be completely contained in the sealable vessel (2; 12). The present invention also provides a method of cooling a cryogenic fluid in a sealable vessel (2; 12) using the apparatus (1; 10; 30) of the present invention. The method comprises the steps of immersing the first end of the conduction element (4; 14) in the cryogenic fluid (3; 13); and operating the cooling machine (7; 17) to cool the second end of the conduction element (4; 14) to cool the conduction element (4; 14).

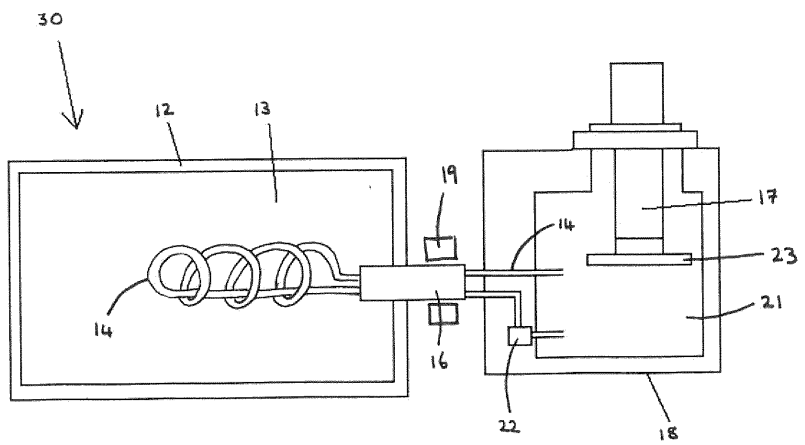

Figure 4

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Description

Background

[0001] The most thermally efficient method of cryogenically cooling a component that needs to be operated at a cryogenic temperature is by totally immersing the component within a cryogenic cooling medium. The cryogenic cooling medium may be any suitable gaseous or liquid cryogen. Examples of components that need to be operated at a cryogenic temperature include low temperature superconducting components and high temperature superconducting components.

[0002] In order to immerse a component within a cryogenic cooling medium, many cryogenic cooling apparatus generally comprise a sealable vessel for containing a cryogenic fluid and within which the component may be located. The shape and size of any specific sealable vessel is dependent upon the shape and size of the component that is cooled within the vessel.

[0003] The sealable vessels are generally thermally shielded in order to minimise heating of the cryogenic fluid and the component located therein. The composition of the thermal shielding is dependent upon the size and shape of the vessel and the temperature of the cryogenic fluid contained within the vessel. The thermal shielding may comprise several layers and may include the following components: a layer of multi-layer insulation wrapped around the outer surface of the vessel; a thermal screen surrounding the vessel; an intermediate vessel spaced from and enclosing the sealable vessel wherein the intermediate vessel contains a further volume of cryogenic fluid; an outer vacuum vessel enclosure containing the vessel and any thermal screen or intermediate vessel. In this manner heating of the sealable vessel containing the cryogenic component can be minimised. This minimises the amount of cooling that is required to maintain the cryogenic fluid at the appropriate temperature.

[0004] Despite thermal shielding of a sealable vessel, some cooling is required to maintain a cryogenic fluid at the appropriate temperature. This is normally done by circulating the cryogenic fluid about a cooling circuit. A normal cooling circuit will include a cold head that is located remotely to the vessel and that is used to remove heat from the cryogenic fluid. Unfortunately, the circulation of cryogenic fluid can be technically difficult. For example, if the sealable vessel and cryogenic component located therein is rotated during use the circulation system would also be required to have a rotating portion and a stationary portion. The rotating portion will have to rotate with the sealable vessel and the stationary portion will have to remain stationary with the cold head. This situation often occurs in superconducting rotating machines such as motors or generators wherein the cryogenic component is one or more HTS or LTS windings. As a results, the cooling of such components can be very difficult to adequately engineer.

[0005] In light of the above, there is a need for an improved cooling apparatus for cooling cryogenic component by immersion in cryogenic fluid. Preferably, the improved cooling apparatus should be suitable for use in rotating machines wherein the cryogenic component is one or more HTS or LTS windings.

Summary of Invention

[0006] The present invention provides a cryogenic cooling apparatus comprising:

- a sealable vessel for containing a cryogenic fluid within which a cryogenic component may be located and immersed in the fluid;
- a conduction element having a first end and a second end, the conduction element located through a wall of the vessel such that the first end is located within the vessel for immersion in the cryogenic fluid and the second end is outside the vessel; and
- a cooling machine located external to the vessel and connected to the second end of the conduction element.

[0007] The apparatus of the present invention is advantageous in that it allows the cooling of a cryogenic fluid within a sealable vessel without the need to circulate that fluid. Instead, when in use the conduction element has a first end located within the cryogenic fluid and acts to conduct heat away from the cryogenic fluid to the second end, which is located outside of the sealable vessel and is not immersed in the cryogenic fluid. The cooling machine acts to take heat away from the second end of the conduction element and ensure that heat is conducted through the conduction element away from the cryogenic fluid. In this manner complicated fluid circulation can be avoided. The present invention is particularly suitable for rotating machines where the circulation of cryogenic fluid is technically very difficult or impossible.

[0008] The apparatus of the invention may operate with any cryogenic fluid. However, in many embodiments of the invention it may be preferable that the cryogenic fluid is helium.

[0009] In some embodiments of the present invention it may be preferable that the conduction element is substantially solid. Having a solid conduction element can be advantageous as it can maximise the thermal conductivity of the element compared to a hollow conduction element or a conduction element formed in any other way.

[0010] As will be readily appreciated, the shape of a solid conduction element can be engineered to optimise the thermal conduction of heat from the cryogenic fluid. For example, it may be preferable to maximise the surface area of the conduction element that is contact with the cryogenic fluid with respect to the volume of the conduction element. One way of doing this is to give the at least the first end of the conduction element a finned shape. One example of a finned shape is a substantially cylindrical element that has radially extending fins that are evenly circumferentially spaced around a central axis. The number and size of the fins may be optimised by the skilled person on the basis of the relevant design concerns including, but not limited to, the size of the apparatus. A second example of a finned shape is a substantially cylindrical element that has radially extending fins that are spaced along a central axis of the conduction element. Again, the number, size and spacing of the fins may be optimised by the skilled person on the basis of the relevant design concerns including, but not limited to, the size of the apparatus and the first end of the conduction element.

[0011] A solid conduction element may be formed of any suitable material. A material will be suitable if it can withstand the mechanical stresses upon it at the cryogenic temperatures at which it will operate and if it has a thermal conductivity that is high enough to conduct sufficient heat from the cryogenic fluid. An example of a material that will be generally suitable for most applications of the present invention is copper. Other similar materials and any alternatives to copper that the skilled person would be aware of may also be used. It is anticipated that in most embodiments of the present invention the skilled person will be readily able to select a material suitable for forming a conduction element.

[0012] As an alternative to a solid conduction element, the conduction element may be conduit, such as a pipe, and it may carry a cooling medium in order to facilitate the transfer of heat from the cryogenic fluid to the cooling machine. This conduit may be formed to circulate a cooling medium in order to cool the cryogenic fluid. This may be done in any manner that is apparent to a person skilled in the art. For example, the cooling medium may be circulated around a loop that includes the cryogenic fluid and the cooling machine. Circulation can be done in a single stage or in two or more stages. In particular, a cooling medium may be circulated in a single uninterrupted loop around an apparatus according to the present invention. Alternatively, a cooling medium may be circulated about two or more distinct loops. Two or more distinct loops may be preferred when the sealable vessel is rotated during use. In these situations one or more loops may be substantially located in the sealable vessel such that they are rotated with the sealable vessel and a one or more loops may be located externally, in a non-rotating part of the apparatus. The rotating and non-rotating loops may be in thermal contact with one another by means of a rotating coupling.

[0013] The cooling medium may be any suitable cryogenic fluid that can be used for cooling. For example, the cooling medium may be helium, in liquid and/or gas form. Other suitable cooling mediums will be readily apparent to a person skilled in the art. The cooling medium in any loop may operate either in a single phase (i.e. gas or liquid) or may operate as a dual phase (i.e. gas and liquid) cooling medium.

[0014] If the conduction element is a conduit that circulates a cooling medium the conduction element may be any suitable shape. The length and shape of the conduction element may be optimised to maximise thermal transfer at the first end and/or the second end of the conduction element. For example, either the first end or the second end of the conduit may be coiled or otherwise similarly shaped in order to increase the length of conduit that is at the first end or the second end. Alternatively or additionally, either the first end or the second end of the conduit may be a relatively straight conduit in order to reduce the length of conduit relative to the other of the first end or the second end. It is to be understood that the skilled person would be able to optimise the length and design of the first end and the second end of a conduit for any specific apparatus according to the present invention. In particular, the relative length of the first end of the conduit and the second end of the conduit may be able to be determined based on the thermal requirements of the apparatus.

[0015] If the conduction element does circulate a cooling medium it may circulate the cooling medium around a closed loop or an open loop. That is, the conduction element may form a closed loop about which a cooling medium is circulated and within which the cooling medium is contained. This may be generally preferred for single phase operation because in such situations the cooling medium will remain at a substantially constant volume and/or pressure. If the conduction element does form a closed loop it may be preferable that the second end of the conduction element is in contact with the cooling machine via a suitable heat exchanger that is formed substantially at the second end of the conduction element.

[0016] Alternatively, the conduction element may be open at the second end and be in fluid communication with a suitable fluid reservoir. This may be generally preferred for dual phase operation where the phase, volume and pressure of the cooling medium will vary as it is circulated around the conduction element. If the conduction element is open at the second end and in fluid communication with a fluid reservoir then the conduction element need not be in direct thermal contact with the cooling machine but may be in thermal contact with it via the fluid reservoir. For example, there may be a condensing plate of the cooling machine located in the fluid reservoir for cooling the cooling medium. Such a condensing plate need not be in direct contact with the conduction element.

[0017] A cooling medium may be circulated around a suitable conduction element in any manner that is apparent to the person skilled in the art. An example of a suitable means for circulating helium around a suitable conduction element is a helium fan.

[0018] The cooling machine of the present invention may be any machine that is suitable for cooling either a solid conduction element or a cooling medium circulated within a conduction element, as discussed above. For example, a cooling machine of the present invention may comprise one or more cold heads or any other suitable cooling device.

[0019] If the cooling machine of the present invention does comprise one or more cold heads or other cooling devices then one or more of those cold heads or other cooling devices may be located within a vacuum chamber. One or more cold heads or other cooling devices can be located within a single vacuum chamber. There may be a plurality of vacuum chambers, each containing one or more cold heads or other cooling devices. Alternatively, there may be only a single vacuum chamber, containing all of the cold heads or other cooling devices.

[0020] The apparatus of the present invention may form part of a rotating machine. That is, a rotating machine may comprise the apparatus of the present invention. In such apparatus it is generally preferable that a rotating cryogenic component of the machine will be contained within the sealable vessel and cooled by the cryogenic fluid contained therein. The sealable vessel will preferably be rotated with, and at the same speed as, the rotating component. The cooling machine will be held stationary relative to the sealable vessel and the rotating component. The conduction element may be rotated at the same speed as the sealable vessel or it may be held stationary relative to the sealable vessel or it may be rotated at a different speed to the sealable vessel. Examples of cryogenic components include, but are not limited to, HTS and LTS windings.

[0021] If the sealable vessel is rotated in use it may be preferable that the conduction element is mounted along the rotational axis of the sealable vessel. This is advantageous as it allows the simplest mounting of the conduction vessel through a wall of the sealable vessel. If the conduction element is not rotated at the same speed as the sealable vessel it may be mounted through the wall of the sealable vessel by means of a suitable rotating coupling formed in the wall of the sealable vessel. Holding the conduction element stationary relative to the sealable vessel may be preferred as it may allow a better thermal link between the second end of the conduction element and the cooling machine. Generally, if the conduction element is rotated, either at the same speed as the sealable vessel or at any other speed, the thermal link between the second end of the conduction element and the (stationary) cooling machine will not be as efficient.

[0022] Nevertheless, it may be advantageous to rotate the conduction element as this can promote better mixing of the cryogenic fluid within the sealable vessel and thereby provide better cooling of the cryogenic fluid. That is, by rotating the conduction element relative to the sealable vessel, the first end of the conduction element may agitate and stir the cryogenic fluid within the sealable vessel. If the conduction element is intended to do this, the first end of the conduction element may be designed appropriately. For example, the first end of the conduction element may be specifically shaped or have fins to allow it to better mix the cryogenic fluid. The conduction element may be mounted to rotate using a suitable gearing mechanism or any other suitable mechanism.

[0023] In particularly advantageous embodiments of the present invention the conduction element may be mounted to be able to be rotated and to be able to held stationary. This may be advantageous as the conduction element may be rotated to mix the cryogenic fluid within the sealable vessel during initial cooling of the cryogenic fluid when the apparatus is being started, prior to use of the cryogenic component, or when warming the cryogenic fluid, after use of the cryogenic component. During operation and use of the cryogenic component the conduction element may be held stationary in order to improve thermal linkage between the conduction element and the cooling machine. One way of achieving this is to mount the conduction element within a rotating coupling that is controlled by a suitable gearing mechanism. The gearing mechanism may be locked off when it is desired to keep the conduction element stationary and can be suitably controlled when it is desired to rotate the conduction element.

[0024] Any or all cryogenic vessels and/or vaccum vessels that form a part of an apparatus according to the present invention may include pressure relief devices.

[0025] The present invention also provides a method of cooling a cryogenic fluid in a sealed vessel using an apparatus according to the present invention. The apparatus may have any of the features discussed above or as discussed in the description of the specific embodiments of the apparatus shown in the Figures. It is to be understood that the skilled person will be able to readily appreciate which of the features are suitable for use with any particular method feature of the present invention and which of the features are essential for any particular method step to function satisfactorily. Furthermore, the method of the present invention may comprise the step of operating any of the features discussed above in any manner that is discussed above or below or that would otherwise be apparent to the person skilled in the art.

[0026] The method comprises the steps of: immersing the first end of the conduction element in the cryogenic fluid; and operating the cooling machine to cool the second end of the conduction element to cool the conduction element. The conduction element will generally be mounted in the apparatus such that the first end of the conduction element is immersed in the cryogenic fluid when the sealable vessel is filled with the cryogenic fluid. By operating the cooling machine to cool the second end of the conduction element the cryogenic fluid in the sealable vessel will be indirectly cooled by the cooling machine via thermal conduction along the conduction element.

[0027] As discussed above, the conduction element may either be stationary or may be rotated relative to the sealable vessel when the method of the present invention is being operated. This may be achieved in any of the manners discussed elsewhere in this application.

[0028] As well as maintaining a cryogenic component, such as a HTS or LTS winding, within the sealable vessel at a suitable operating temperature, the method of the present invention may also be used to lower the temperature of the cryogenic component when an apparatus of the present invention is initially used and/or to raise the temperature of the cryogenic component after it has been used. Generally, this can be done in any way apparent to a person skilled in the art. However, in some circumstances additional method steps may be advantageous or even necessary. For example, as the conduction element is used to cool the cryogenic fluid within the sealable vessel the cryogenic fluid will contract lowering the pressure within the vessel. In order to maintain the pressure of the cryogenic fluid it may be necessary for the method of the present invention to further comprise the step of backfilling the sealable vessel with cryogenic fluid in order to maintain the pressure within the sealable vessel. Any backfilling may be done on demand due to the measured pressure within the sealable vessel and may not be necessary when the cryogenic component is being operated at a constant temperature and pressure.

[0029] Further additional steps may be used to speed up the initial cooling of the cryogenic fluid with the sealable vessel and to warm up the cryogenic fluid after use of the cryogenic component within the sealable vessel. For example, if the second end of the conduction element is housed in a vacuum vessel then the pressure in the vacuum vessel may be increased to warm up the second end of the conduction element. Furthermore, a heater may be attached to the second end of the conduction element and may be operated to transmit heat to the cryogenic fluid if and when it is necessary to do so. If the conduction element is suitably formed, rotating the conduction element relative to the sealable vessel can agitate the cryogenic fluid in order to speed up cooling or heating of the cryogenic fluid and the method of the present invention can further comprise this step.

[0030] If the apparatus of the present invention comprises a cooling machine that is substantially contained within a vacuum vessel, a method according to the present invention of operating that apparatus may comprise the step of evacuating the vessel during cooling of the cryogenic component and the cryogenic fluid within the sealable vessel. Preferably this will be done before the cryogenic component is operated and the vacuum vessel will remain evacuated during operation of the cryogenic component.

[0031] As discussed above, the conduction element may be a solid element or it may be a conduit about which a cooling medium is circulate. If the conduction element is a conduit then the method of the present invention may further comprise the step of circulating a cooling medium about the conduction element. As discussed above, this circulation may be single phase or dual phase and the conduit may be a closed loop or an open loop.

[0032] Further features of the apparatus and method of the present invention and further embodiments of the apparatus of the present invention will be apparent from the specific embodiments that are illustrated in the Figures and are discussed below.

<u>Drawings</u>

[0033]

Figure 1 is a schematic drawing of an apparatus according to a first embodiment of the present invention;

Figure 2 is a schematic drawing of an apparatus according to a second embodiment of the present invention;

Figure 3 is a schematic drawing of an apparatus according to a third embodiment of the present invention; and

Figure 4 is a schematic drawing of an apparatus according to a fourth embodiment of the present invention.

[0034] Four embodiments of apparatus (1; 10; 30) according to the present invention are shown in the Figures. These embodiments illustrate various alternative features that can be incorporated into apparatus according to the present invention. The alternative features can be incorporated into any suitable embodiment of the present invention; it may not be essential for an apparatus to have all of the features of the embodiments shown in the Figures in order to incorporate any particular one of these alternative features. Additionally or alternatively, additional features, not shown in the Figures may be incorporated into an apparatus (1; 10; 30) according to the present invention. It is to be understood that the skilled person would understand which of the alternative features of the illustrated embodiments can be incorporated into any specific apparatus according to the present invention and which additional features, such as those discussed above, may be incorporated.

[0035] A first embodiment of an apparatus 1 according to the present invention is shown in Figure 1. The apparatus comprises a sealable superinsulated helium vessel 2. The vessel 2 contains helium gas 3, which during operation of the apparatus is maintained at a temperature of about 30K and a pressure of about 1 bar (1kPa). A HTS winding is cooled by the apparatus 1 and is located within the vessel 2 but has been omitted from the Figure in order to make the details of the apparatus clear. The helium gas 3 is maintained at a temperature of 30k by the first end of a solid conduction element 4, which is in direct contact with the coolant. The solid conduction element 4 is substantially cylindrical and has radially extending fins 5 that are equally spaced along a longitudinal axis of the conduction element. The fins 5 act to maximise the surface area of the conduction element 4 that is in contact with the helium gas 3. The solid conduction element 4 is substantially formed of copper.

[0036] In operation the sealable vessel 2 is rotated. The conduction element 4 is mounted along the rotational axis of the sealable vessel 2 and but is held stationary relative to the sealable vessel during operation of the apparatus. The conduction element 4 extends from the sealable vessel into a vacuum vessel 8 containing a cold head 7. The vacuum vessel 8 is also held stationary during operation of the apparatus 1. The vacuum vessel 8 is connected to the sealable vessel 2 by a coupling 6 through which the conduction element 4 extends. A second end of the conduction element 4 is cooled by the cold head 7. The cold head 7, with which the conduction element 4 is in direct thermal contact, has its own supply of compressed helium gas (not shown) to provide cooling to the head, as is standard practice in the art. Both the sealable vessel 2 and the vacuum vessel 8 are fitted with suitable pressure relief devices (not shown).

[0037] In some embodiments of the apparatus 1 the conduction element 4 may be stationary and the sealable vessel 2 may be rotated around the conduction element 4, as shown in the embodiment of Figure 1. This may be preferred as it allows the best thermal link between the conduction element 4 and the cold head 7. In alternative embodiments, the conduction element 4 may be rotated with the sealable vessel 2 and the conduction element may be thermally connected to the cold head 7 by means of an appropriate coupling. This may reduce the efficiency of the thermal link between the conduction element 4 and the cold head 7 but may make the construction of the apparatus 1 simpler and provide other benefits, as discussed above. This is shown in the second embodiment of an apparatus according to the present invention, as shown in Figure 2.

[0038] The apparatus 1 of Figure 2 is substantially the same as the first embodiment of the apparatus 1 of Figure 1. As a result, the same reference numerals have been used to indicate equivalent features in each embodiment. The only difference between the first embodiment and the second embodiment is that the coupling 6 is a rotating coupling and the solid conduction element 4 is geared at the rotating coupling 6 by means of suitable gearing mechanism 9. The rotating coupling 6 and gearing mechanism 9 allow the conduction element 4 to be rotated relative to the sealable vessel 2 and the vacuum vessel 8. The first end of the conduction element 4 can be rotated at the same speed as, or at a different speed to, the sealable vessel 2. This can allow for advantageous operation of the apparatus 1.

[0039] In particular, having a first end of the conduction element 4 that can be rotated at the same speed as, or at a different speed to, the sealable vessel 2 can allow the helium gas 3 to be cooled more quickly when the apparatus 1 is initially used. This is because rotating the conduction element 4 at different speeds relative to the sealable vessel 2 can mix the helium gas 3 within the sealable vessel 2. As will be readily appreciated by the skilled person, in order to maximise the mixing of the helium gas 3 and thereby the rate of cooling the rate of rotation of the first end of the conduction element 4 and the sealable vessel 2 may be appropriately controlled. Similarly, the design of the fins 5 can be altered to maximise the mixing of the helium gas. This can be done in any manner apparent to a person skilled in the art. For example, helical fins may be used in place of the cylindrical fins 5 shown in Figures 1 or 2. Any other suitable fin shape or size may also be used.

[0040] An apparatus 10 according to a third embodiment of the present invention is shown in Figure 3. The apparatus 10 comprises a sealable superinsulated helium vessel 12. The vessel 12 contains helium gas 13, which during operation of the apparatus 10 is maintained at a temperature of about 30K and a pressure of about 1 bar (1kPa). A HTS winding is cooled by the apparatus 10 and is located within the vessel 12 but has been omitted from the Figure in order to make the details of the apparatus clear. The helium gas 13 is maintained at a temperature of 30k by the first end of a coiled helium tube conduction element 14, which is in direct contact with the coolant. The helium tube conduction element 14 is formed of copper (although it could be formed of any other suitable high thermal conductivity material or stainless steel). The helium tube conduction element 14 is formed of smooth copper piping, However, in the same manner as the solid conduction element 4 of the first and second embodiments, the piping could be finned in order to maximise heat transfer. In particular, the piping could be finned to maximise the surface area of the conduction element 14 that is in contact with the helium gas 13.

[0041] The first end of the conduction element 14 is formed of coiled piping in order to maximise the length of piping that is in contact with the helium gas 13 and consequently increase the thermal transfer between the helium gas 13 and the first end of the conduction element 14. The shape of the first end of the conduction element 14 is purely schematic. It is to be understood that the specific design of the conduction element 14 will be able to optimised by a person skilled in the art based on the size, shape and cooling requirements of any specific embodiment of the invention. The conduction element 14 shown in Figure 3 is purely schematic and its size and shape are not to be taken as representative.

[0042] The first end of the conduction element 14 is substantially positioned along the rotational axis of the sealable vessel 12 such and exits the sealable vessel via a rotating coupling 16. A second end of the conduction element 14 is positioned within a vacuum vessel 18 and is connected via a heat exchanger 20 to a standard cold head 17. The cold head 17 has its own supply of compressed helium gas (not shown) to provide cooling to the cold head. Although, the embodiment of Figure 3 has only a single cold head 17 it is to be understood that multiple cold heads can be incorporated into the apparatus 10 if more cooling power is required. The heat exchanger 20 comprises a fan for circulating helium gas about the conduction element 14.

[0043] During operation of the apparatus 10, the conduction element 14 circulates helium gas at approximately 30K and at a pressure of about 20 bar, although other temperatures and pressures could be used. The helium gas within the conduction element 14 is circulated using the helium fan located within the heat exchanger 20.

[0044] In the same manner as the apparatus 1 of the second embodiment, the solid conduction element 14 is geared at the rotating coupling 16 by means of suitable gearing 19. The gearing 19 allows the first end of the conduction element 14 to be rotated relative to the second end of the conduction element. The first end of the conduction element 14 can be rotated at the same speed as, or at a different speed to, the sealable vessel 12. This can allow for advantageous operation of the apparatus 10. Alternative embodiments may not include gearing 19 and the conduction element 14 may remain stationary during operation of the apparatus 10, in the same manner as the apparatus 1 of the first embodiment that is shown in Figure 1.

[0045] A fourth embodiment of an apparatus 30 according to the present invention is shown in Figure 4. The apparatus 30 is substantially the same as the apparatus 10 of the third embodiment, shown in Figure 3. Therefore, where appropriate, the same reference numerals have been used to indicate equivalent features. The apparatus 30 differs from the third embodiment 10 in that the conduction element 14 circulates helium in a dual phase system, rather than simply circulating helium gas. As a result and as shown in the Figure, there are structural differences between the fourth embodiment 30 and the third embodiment 10.

[0046] The second end of the conduction element 14 is open and is in fluid communication with a liquid helium reservoir 21 formed within the vacuum vessel 18. A helium fan 22 is mounted on the conduction element 14 adjacent the second end of the conduction element to circulate the helium around the conduction element. Rather than being in direct thermal contact with the conduction element 14, the cold head 17 has a condensing cold plate 23 that is in thermal contact with the liquid helium reservoir 21.

[0047] During normal operation of the apparatus 30, the helium within the reservoir 21 is circulated about the conduction element 14 and is maintained at a temperature of approximately 4K and a pressure of 1 bar (1kPa). During circulation through the conduction element 14, when cooling the helium gas 13, the helium liquid will boil and become helium gas. The helium gas will then be returned to the reservoir 21 by the action of the fan 22. The helium gas returned to the reservoir 21 will be at some temperature above 4K. It will then be cooled by contact with the condensing cold plate 23 and be returned to a liquid form. During circulation of helium around the conduction element 14, the pressure within the conduction element 14 will remain at about 1bar.

[0048] As for the apparatus 10 of the third embodiment, the conduction element 14 of the fourth embodiment 30 may be held stationary or may be rotated at the same speed as, or at a different speed to, the sealable vessel 12. This can be done by mounting the conduction element 14 appropriately and/or using an appropriate gearing mechanism 19. It is to be understood that the skilled person would be capable of forming the conduction element 14, a gearing mechanism 19 and the apparatus 30 in a manner that would allow this. Similarly, the conduction element 14 may be formed of simple piping (as shown in the Figure) or the piping may be finned, as discussed above.

Claims

1. A cryogenic cooling apparatus (1; 10; 30) comprising:

   a sealable vessel (2; 12) containing a cryogenic fluid (3; 13) within which a cryogenic component may be located;
   a conduction element (4; 14) having a first end and a second end, the conduction element (4; 14) located through a wall of the vessel (2; 12) such that the first end is located within the vessel (2; 12) for immersion in the cryogenic fluid (3; 13) and the second end is outside the vessel (2; 12); and
   a cooling machine (7; 17) located external to the vessel (2; 12) and connected to the second end of the conduction element (4; 14).

2. An apparatus (1; 10; 30) according to claim 1, wherein the cryogenic fluid (3; 13) is helium

3. An apparatus (1) according to claim 1 or claim 2, wherein the conduction element (4) is substantially solid.

4. An apparatus (1) according to claim 3, wherein the conduction element (4) has a finned shape.

5. An apparatus (1) according to claim 3 or claim 4, wherein the conduction element (4) is formed of copper.

6. An apparatus (10; 30) according to claim 1 or claim 2, wherein the conduction element (14) is a pipe.

7. An apparatus (10; 30) according to claim 6, wherein the conduction element carries a cooling gas.

6. An apparatus (1; 10; 30) according to any preceding claim, wherein the cooling machine (7; 17) comprises at least one cold head.

7. An apparatus (1; 10; 30) according to claim 6, wherein the at least one cold head (7; 17) is located within a vacuum chamber (8; 18).

8. An apparatus (1; 10; 30) according to claim 6 or claim 7, wherein the cooling machine (7; 17) comprises a plurality of cold heads.

9. A method of cooling a cryogenic fluid in a sealable vessel (2; 12) using a cryogenic cooling apparatus (1; 10; 30); the apparatus (1; 10; 30) comprising:

a sealable vessel (2; 12) containing a cryogenic fluid (3; 13) within which a cryogenic component may be located;
a conduction element (4; 14) having a first end and a second end, the conduction element (4; 14) located through a wall of the vessel (2; 12) such that the first end is located within the vessel (2; 12) for immersion in the cryogenic fluid and the second end is outside the vessel (2; 12); and
a cooling machine (7:17) located external to the vessel (2; 12) and connected to
the second end of the conduction element (4; 14);

the method comprising:

immersing the first end of the conduction element (4; 14) in the cryogenic fluid (3; 13); and
operating the cooling machine (7; 17) to cool the second end of the conduction element (4; 14) to cool the conduction element (4; 14).

10. A method according to claim 9, comprising the additional step of rotating the sealable vessel (2; 12) and any cryogenic component located therein whilst holding the conduction element (4; 14) and the cooling machine (7; 17) stationary.

11. A method according to claim 9, comprising the additional step of rotating the sealable vessel (2; 12) and any cryogenic component located therein at a first speed whilst rotating the conduction element (4; 14) at a second speed and holding the cooling machine (7; 17) stationary.

12. A method according to any of claims 9 to 11, comprising the step of backfilling the sealable vessel (2; 12) in order to maintain the pressure within the sealable vessel (2; 12).

13. A method according to any of claims 9 to 12, wherein the cooling machine (7; 17) is substantially contained in a vacuum vessel (8; 18) and during cooling the vacuum vessel (7; 17) is evacuated.

14. A method according to any preceding claim, further comprising the step of circulating a cooling medium about the conduction element (14).

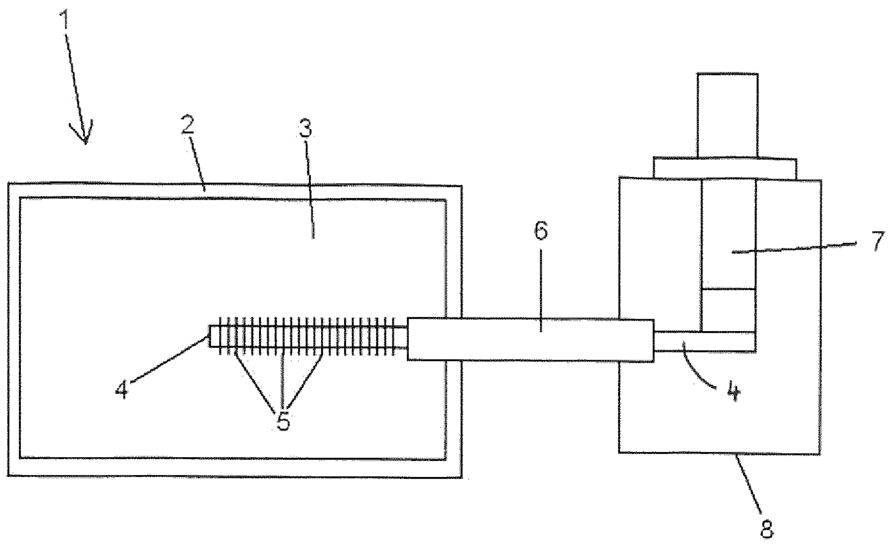

Figure 1

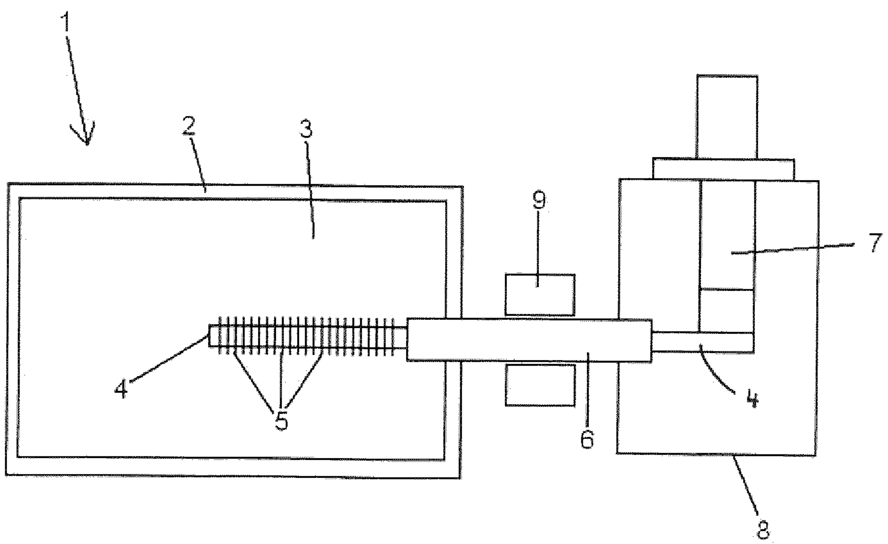

Figure 2

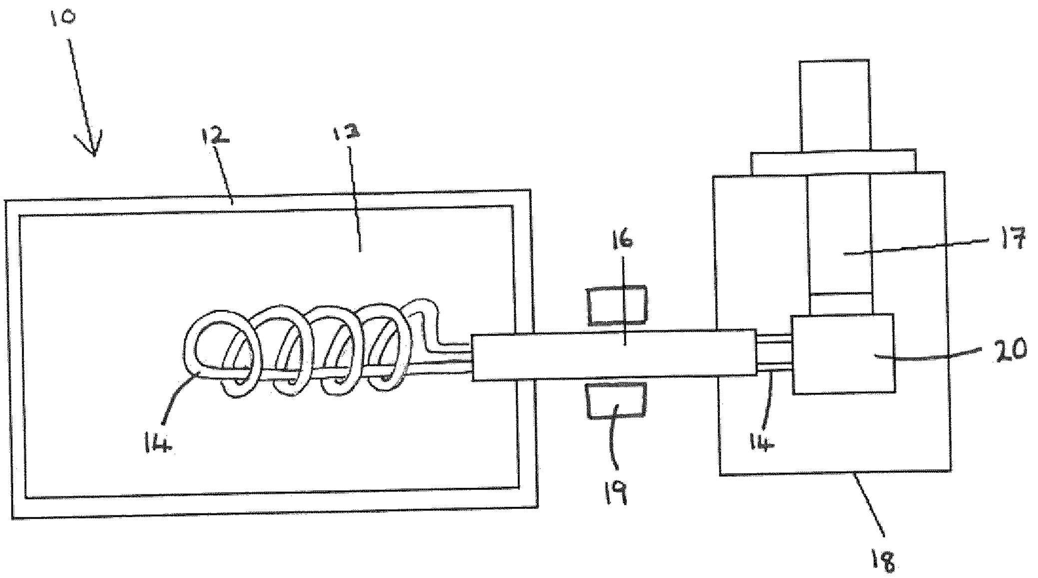

Figure 3

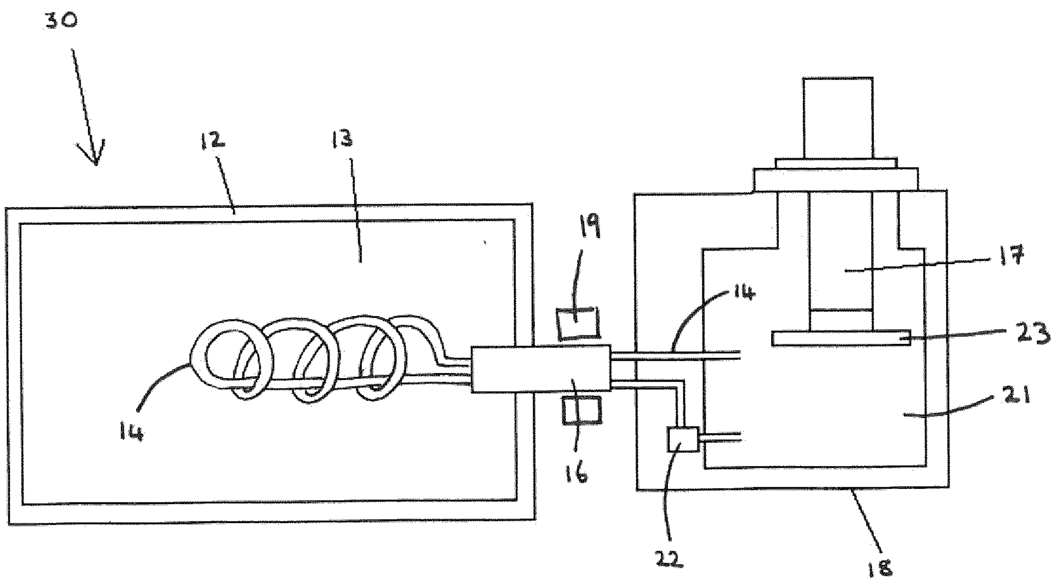

Figure 4

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EUROPEAN SEARCH REPORT

Application Number
EP 13 19 1259

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	WO 2009/134569 A2 (AMERICAN SUPERCONDUCTOR CORP [US]; YUAN JIE [US]; MAGUIRE JAMES [US]) 5 November 2009 (2009-11-05) * paragraphs [0041] - [0052]; figure 3 *	1-3, 6-11, 14-16	INV. F25D19/00
X	US 4 745 760 A (PORTER WARREN W [US]) 24 May 1988 (1988-05-24) * column 3, line 64 - column 5, line 46; figures 1,6 * * column 6, lines 15-63 *	1-3, 5-11, 14-16	
X	JP 2003 111745 A (HITACHI MEDICAL CORP) 15 April 2003 (2003-04-15) * paragraphs [0013] - [0014]; figures 2,3,5 *	1-3,5, 8-11,14, 15	
X	US 2006/237548 A1 (HARTNEY NICHOLAS A [US] ET AL) 26 October 2006 (2006-10-26) * paragraphs [0002], [0017], [0026]; figure 2 *	1-5,9, 11,14-16	
X	US 2010/058790 A1 (JUNG JE HEON [KR] ET AL) 11 March 2010 (2010-03-11) * paragraphs [0025] - [0034]; figures 1-3 *	1,3,6,7, 11-13	

TECHNICAL FIELDS SEARCHED (IPC)

F25D
F25B
A61F
H01L
F28D

The present search report has been drawn up for all claims

3

Place of search	Date of completion of the search	Examiner
The Hague	26 August 2014	Léandre, Arnaud

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons
& : member of the same patent family, corresponding document

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Application Number
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CLAIMS INCURRING FEES

The present European patent application comprised at the time of filing claims for which payment was due.

☐ Only part of the claims have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due and for those claims for which claims fees have been paid, namely claim(s):

☐ No claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due.

LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

see sheet B

☒ All further search fees have been paid within the fixed time limit. The present European search report has been drawn up for all claims.

☐ As all searchable claims could be searched without effort justifying an additional fee, the Search Division did not invite payment of any additional fee.

☐ Only part of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the inventions in respect of which search fees have been paid, namely claims:

☐ None of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims, namely claims:

☐ The present supplementary European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims (Rule 164 (1) EPC).

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LACK OF UNITY OF INVENTION SHEET B

Application Number
EP 13 19 1259

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

1. claims: 1-11, 14-16

A cryogenic cooling apparatus with a conduction element having one end immersed in the cryogenic fluid contained in a vessel where a component may be cooled, and the other end connected to a cooling machine which is external to the vessel.

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2. claims: 12, 13

A method of cooling a cryogenic fluid in a sealable vessel using cryogenic cooling apparatus with a conduction element having one end immersed in the cryogenic fluid contained in a vessel where a component may be cooled, and the other end connected to a cooling machine which is external to the vessel, and comprising the step of rotating the sealable vessel and any cryogenic component located therein whilst holding the conduction element and the cooling machine stationary.

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 13 19 1259

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
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26-08-2014

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82