US 20140069116A1

(19) United States

(12) Patent Application Publication (10) Pub. No.: US 2014/0069116 A1

Durand (43) Pub. Date: Mar. 13, 2014

(54) CRYOGENIC COOLING DEVICE AND METHOD

(75) Inventor: **Fabien Durand**, Voreppe (FR)

(73) Assignee: **L'Air Liquide Societe Anonyme Pour L'Etude Et L'Exploitation Des Procedes Georges Claude**, Paris (FR)

(21) Appl. No.: **14/116,576**

(22) PCT Filed: **Apr. 20, 2012**

(86) PCT No.: **PCT/FR2012/050864**

§ 371 (c)(1), (2), (4) Date: **Nov. 8, 2013**

(30) **Foreign Application Priority Data**

May 9, 2011 (FR) 1153941

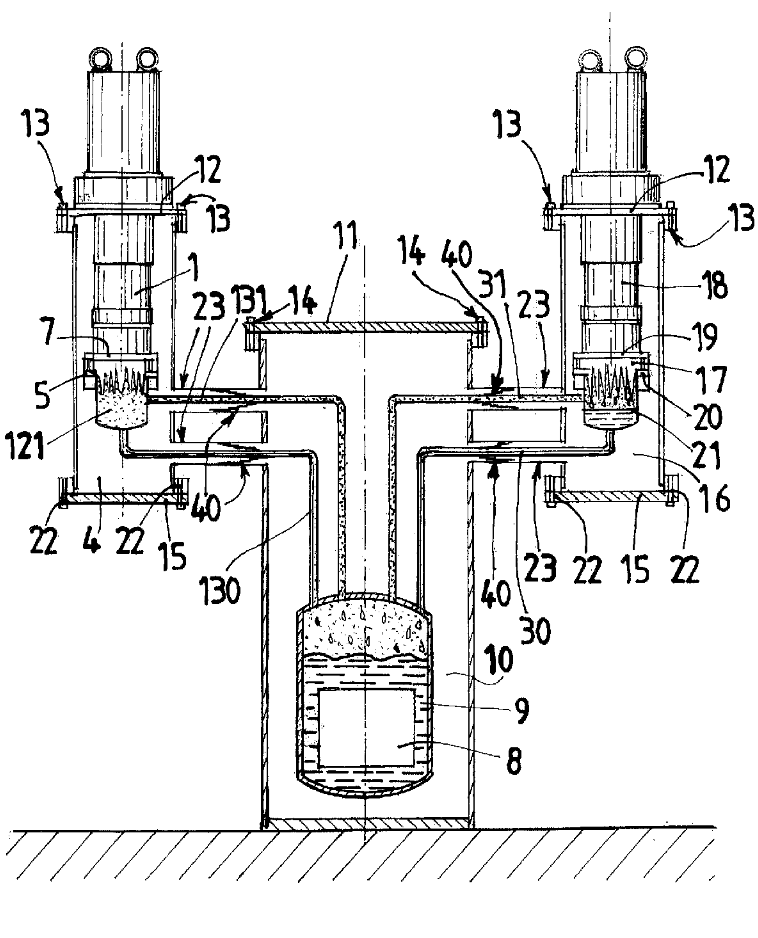
Publication Classification

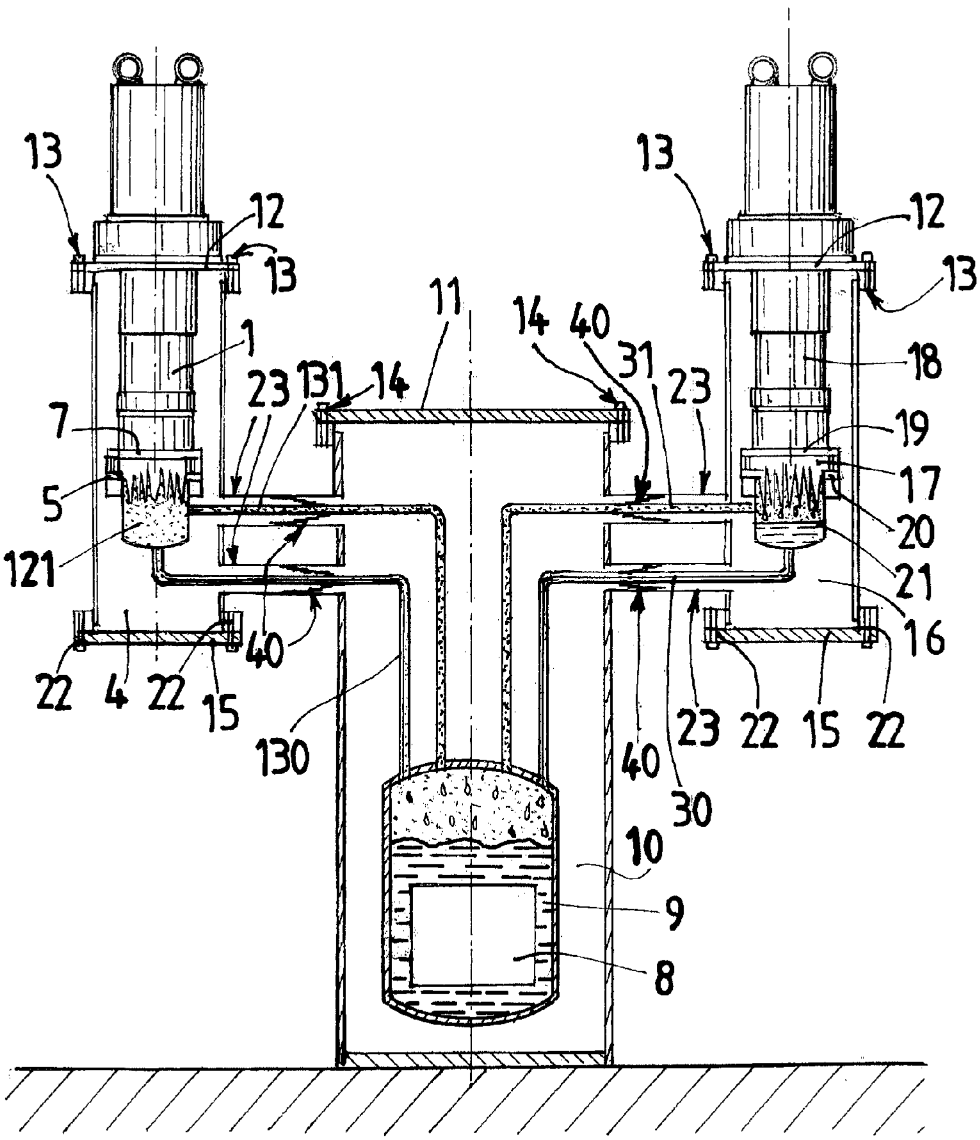
(51) **Int. Cl.**
F25B 9/14 (2006.01)

(52) **U.S. Cl.**
CPC *F25B 9/14* (2013.01)
USPC **62/6**

(57) **ABSTRACT**

Cryogenic cooling method and device comprising a main cryogenic cooler comprising a cold head positioned in a first chamber selectively placed under vacuum, a reservoir of working fluid placed in a second chamber selectively placed under vacuum, a member to be cooled being placed in the reservoir in heat exchange with the working fluid, the cold head of the main cryogenic cooler being thermally connected to a heat exchanger which is itself fluidically connected to the reservoir via pipes forming a first circulation loop for the working fluid, the pipes passing from the first to the second chamber, characterized in that the volumes selectively under vacuum of the first and second chambers are independent and in that the device comprises a secondary cryogenic cooler comprising a cold head placed in a third chamber selectively placed under vacuum, the cold head of the secondary cryogenic cooler being thermally connected to a heat exchanger which is itself fluidically connected to the reservoir via pipes forming a second circulation loop for the working fluid, and in that the volume selectively under vacuum of the third chamber is independent of the volumes selectively under vacuum of the first and second chambers.




13
12
13
1
7
23
131
14
11
14
40
31
23
13
12
13
18
19
17
5
20
121
21
16
40
22
4
22
15
130
40
23
22
15
22
30
10
9
8

CRYOGENIC COOLING DEVICE AND METHOD

[0001] The present invention relates to a cryogenic cooling device and method.

[0002] It should be noted that the work leading up to the present invention enjoyed funding from the European Union 7^{th} framework program FP/2007-2013 under grant No. 241285.

[0003] The invention relates more particularly to a cryogenic cooling device comprising a main cryocooler with a cold head arranged in a first chamber selectively placed under vacuum, a reservoir of working fluid arranged in a second chamber selectively placed under vacuum, a member that is to be cooled being arranged in the reservoir in a heat exchange relationship with the working fluid, the cold head of the main cryocooler being thermally connected to a heat exchanger, itself fluidically connected to the reservoir via pipes forming a first circulation loop for the working fluid, the pipes passing from the first to the second chamber.

[0004] Document US20090049862A1 describes a refrigeration device using a cryocooler to liquefy a working fluid, for example nitrogen. The liquefied working fluid is used in the conventional way to cool an application to a very low temperature, typically superconductor cables.

[0005] In sensitive electrical applications, this type of cooler has to be able to operate uninterrupted. However, the known solutions do not allow the refrigeration device to undergo maintenance or repair in a way that is simple and easy for an operator and minimizes the impact on the production of cold.

[0006] It is an object of the present invention to alleviate all or some of the abovementioned disadvantages of the prior art.

[0007] To this end, the device according to the invention, which in other respects is in accordance with the generic definition thereof given in the above preamble, is essentially characterized in that the volumes selectively under vacuum of the first and second chambers are independent and in that the device comprises a secondary cryocooler comprising a cold head arranged in a third chamber selectively placed under vacuum, the cold head of the secondary cryocooler being thermally connected to a heat exchanger, itself fluidically connected to the reservoir via pipes forming a second circulation loop for the working fluid, and in that the volume selectively under vacuum of the third chamber is independent of the volumes selectively under vacuum of the first and second chambers.

[0008] Furthermore, some embodiments of the invention may include one or more of the following features:

- **[0009]** out of the first and third chambers, at least one is sealed off by at least one selectively removable cap;
- **[0010]** at least one selectively removable cap is arranged in the lower part of the chamber such that it is adjacent to the cold head;
- **[0011]** at least one cap is mounted in a sealed fashion on the body of the chamber via fixing screws;
- **[0012]** the device comprises, around the pipes passing from the first to the second chamber, vacuum barriers which separate the volumes selectively under vacuum of the first and second chambers, the vacuum barriers being arranged in at least one tubular portion that connects the first and second chambers;
- **[0013]** the device comprises, around the pipes passing from the third to the second chamber, vacuum barriers which separate the volumes selectively under vacuum of the third and second chambers, the vacuum barriers being arranged in at least one tubular portion that connects the third and second chambers;
- **[0014]** the cold head of the cryocooler(s) is associated with a heat exchanger that acts as a condenser for the working fluid;
- **[0015]** the cold head of the main cryocooler is connected to the reservoir via two pipes the upstream ends of which are connected to a hermetic volume arranged under the cold head of the main cryocooler, the downstream ends of the pipes being connected to an upper end of the reservoir via a vertical or substantially vertical portion;
- **[0016]** the cold head of the secondary cryocooler is connected to the reservoir via two pipes the upstream ends of which are connected to a hermetic volume arranged under the cold head of the secondary cryocooler and the downstream ends of which are connected to an upper end of the reservoir via a vertical or substantially vertical portion;
- **[0017]** in the operating configuration, out of: the main cryocooler and the secondary cryocooler, at least one is arranged in a vertical configuration,
- **[0018]** the vacuum barriers comprise for example at least one of the following members: a system referred to as a “simple cone” system, a system referred to as a “double cone” system,
- **[0019]** a heater, for example an electric heater, is mounted on at least one heat exchanger of a cold head of a cryocooler,
- **[0020]** the chamber or chambers are placed under vacuum with respect to air at a pressure of between 10^{-3} and 10^{-6} mbar,
- **[0021]** the member that is to be cooled comprises a coil or electric cables which are superconductors,
- **[0022]** the device comprises several secondary cryocoolers,
- **[0023]** the secondary cryocooler or one of the secondary cryocoolers is in operation and contributes to the cooling of the member at the same time as the main cryocooler,
- **[0024]** the working fluid comprises or is made up of at least one out of: helium, hydrogen, neon, nitrogen, argon, oxygen, methane, krypton, xenon, CnHm, ammonium, a CFC, an HCFC, an HFC or any other fluid refrigerant,
- **[0025]** the fluid loop may use a buffer volume to limit the rise in pressure of the loop when the system is at ambient temperature.

[0026] The invention also relates to a method for cooling a member to a low temperature using a cryogenic cooling device having any one of the features above or below, in which the main cryocooler is used to cool the member, the first chamber and the second chamber being placed under vacuum, the secondary cryocooler being selectively switched off or on while the main cryocooler is in operation.

[0027] Moreover, some embodiments of the invention may comprise one or more of the following features:

- **[0028]** the main cryocooler is switched off and, at the same time as or in anticipation of this, the secondary cryocooler is started in order to cool the member, the third chamber being placed under vacuum or kept under vacuum,
- **[0029]** when a cryocooler is switched off, the cold head of the cryocooler switched off is heated up to an ambient temperature using at least one of the following steps: by

spontaneous natural heating, by commanded active heating, by forced circulation of gas at ambient temperature into the chamber of the cryocooler or around the exchangers via a coiled tube or any other device, by bringing the volume of the cryocooler chamber to atmospheric pressure,

[0030] the method comprises a step of repairing or maintaining one of the two cryocoolers while the other cryocooler is in operation and is cooling the member, the method comprising:

[0031] shutting down the cryocooler intended to undergo repair or maintenance or keeping it in the switched off state,

[0032] keeping the cryocooler intended to undergo repair or maintenance at ambient temperature or bringing it to ambient temperature,

[0033] opening the chamber containing the cryocooler intended to undergo repair or maintenance,

[0034] dismantling the cryocooler intended to undergo repair or maintenance so that it can be replaced or repaired without connected the hermetic volume to the atmosphere,

[0035] maintaining the vacuum within the chamber of the other cryocooler that is in operation and in the second chamber.

[0036] The invention may also relate to any alternative device or method comprising any combination of the features above or below.

[0037] Other particulars and advantages will become apparent on reading the following description, given with reference to the single FIGURE which is a schematic and partial view in cross section illustrating the structure and operation of a refrigeration device according to one possible embodiment of the invention.

[0038] With reference to the FIGURE, the cryogenic cooling device comprises a main cryocooler **18** comprising, in the conventional way, a cold head **19**. The main cryocooler **18** (and in particular the cold head **19**) is arranged in a first chamber **16** selectively placed under vacuum. The cold head **19** is equipped for example with a heat exchanger **17** to liquefy a working fluid. The exchanger **17** is, for example, screwed to the base of the cold head **19** using screws **20**.

[0039] Underneath the cold head **19** and the exchanger **17**, the main cryocooler **18** delimits a volume **21** for the liquefied working fluid, this volume being connected via two pipes, respectively an upper pipe **31** and a lower pipe **30**, to a storage reservoir **9** for the liquefied working fluid.

[0040] This liquefied working fluid storage reservoir **9** contains the member **8** that is to be cooled by (direct or indirect) exchange of heat with the liquefied working fluid.

[0041] The storage reservoir **9** is housed in a second chamber **10** selectively placed under vacuum independently of the first chamber **16**. What that means is that the pipes **30**, **31** pass from the first **16** to the second **10** chamber through tubular portions **23** that connect the first **16** and second **10** chambers.

[0042] The second chamber **10** rests, for example, on the ground via a base and is, for example, sealed off at the top by a removable cover **11** (removable for example using screws **14**).

[0043] The vacuums within the volumes of the first **16** and second **10** chambers are kept independent for example via one or more vacuum barriers **40** arranged respectively around the pipes **30**, **31** inside the tubular connecting portions **23**.

[0044] The vacuum barriers **40** may comprise any known system such as a double cone.

[0045] According to one advantageous feature, the device comprises a secondary cryocooler **1**, for example of the same type as the main cryocooler **18**. The secondary cryocooler **1** comprises a structure equivalent to the structure described hereinabove. What that means to say is that the cold head **7** of the secondary cryocooler **1** is arranged in a third chamber **4** selectively placed under vacuum. As before, the cold head **7** is equipped with a heat exchanger **2** for liquefying a working fluid. The exchanger **2** is screwed to the base of the cold head **7** using screws **5**.

[0046] Underneath the cold head **7** and the exchanger, the secondary cryocooler **1** delimits a volume **121** for the liquefied working fluid, this volume **121** being connected by two pipes, respectively an upper pipe **131** and a lower pipe **130**, to the same liquefied working fluid storage reservoir **9**.

[0047] As before, the second chamber **10** is selectively placed under vacuum independently of the third chamber **4**. The pipes **130**, **131** pass from the third **4** to the second **10** chamber through the tubular portions **23** that connect the third **4** and second **10** chambers.

[0048] The vacuums within the volumes of the third **4** and second **10** chambers are kept independent via one or more vacuum barriers **40** arranged respectively around the pipes **130**, **131**, inside the tubular connecting portions **23**.

[0049] In this way, the chambers **16**, **10** and **4** are isolated from one another by vacuum barriers **40** so that the various chambers can be placed under vacuum independently of one another.

[0050] Where the working fluid is nitrogen, the device can be used to keep the member **8** at a cryogenic temperature (for example of 100 K).

[0051] The member **8** to be kept at a cryogenic temperature may, for example, be a superconductor coil, a heat exchanger in a heat exchange relationship with another heat-transfer fluid, or any other suitable member.

[0052] In one possible operation, the member **8** that is to be cooled is immersed in a bath of liquid nitrogen at a temperature of 100K for example.

[0053] The heat generated by the member **8** evaporates some of the liquid nitrogen from the bath **9**. This gaseous nitrogen travels upward via the upper pipe **31** of the main cryocooler **18**. On arriving at the exchanger **17** of the main cryocooler **18**, the gaseous nitrogen is liquefied once again.

[0054] To do this, the exchanger **17** is kept at a temperature slightly below 100K by the cryocooler **18** which is in operation. The cold head **19** of the main cryocooler **18** extracts heat from the adjacent exchanger **17**. The liquid nitrogen drops under gravity into the volume **21** situated under the exchanger **17** and then travels downward via the lower pipe **30** as far as the bath in the reservoir **9**. This process takes place continuously in a working loop for the working fluid (nitrogen in this example).

[0055] A heater, for example an electric heater (not depicted) may be mounted on the heat exchanger **17** of the cold head **19** of the main cryocooler **18** to regulate the temperature thereof.

[0056] The secondary cryocooler **1** preferably has a structure and an operation identical to those of the main cryocooler **18**.

[0057] The secondary cryocooler **1** is preferably used as a reserve. When the main cryocooler **18** is in operation, the secondary cryocooler **1** is switched off and the temperature of its cold head **7** is close to ambient temperature. The working fluid contained in the exchanger **2**, the pipes **130**, **131** is in the gaseous state.

[0058] As a result of thermal stratification, the gas in the pipes **130**, **131** forms gaseous thermal plugs which limit transfers of heat between the secondary cryocooler **1** which is switched off and the reservoir **9**.

[0059] By contrast, should the main cryocooler **18** fail or be switched off (for example for the purposes of carrying out maintenance on the main cryocooler **18**), the secondary cryocooler **1** can be switched on, for example automatically.

[0060] After the main cryocooler **18** has been shut down, its cold head **19** and its exchanger **17** are warmed up to ambient temperature. This warming can be done either by waiting for them to warm up naturally, or by using an electric heater or by circulation of gas at ambient temperature, or by making the pressure in the first chamber **16** rise to atmospheric pressure.

[0061] The pressure in the first chamber **16** can be raised from the vacuum up to atmospheric pressure for example using a valve (not depicted) allowing selective communication between the interior volume of the chamber **16** and the exterior atmosphere.

[0062] The first **16** and the third **4** chambers are sealed off by at least one insulating and selectively removable cap **15** allowing direct access to the cryocooler, notably the cold head thereof.

[0063] For example, the first **16** and third **4** chambers are mechanically connected to the second chamber **10** and are raised up above the ground.

[0064] The removable cap **15** is, for example, positioned on the bottom part of each first **16** and third **4** chamber, so that it is adjacent to the cold head **19**, **7**.

[0065] Each cap **15** is, for example, mounted on the body of its chamber **16**, **4** via fixing screws **22** or any other suitable system.

[0066] Thus, to gain access to the main cryocooler **18**, the cap **15** is removed. The operator can then dismantle the exchanger **17**, for example by removing the fixing screws **20** on the cold head **19**. The flange **12** of the cryocooler **18** can then be disconnected from the chamber **16** (for example by removing the fixing screws **13**). The cryocooler can then be taken out for replacement or maintenance thereof.

[0067] A new cryocooler or the repaired cryocooler can then be refitted. The flange **12** is once again fixed to the chamber **16**. The fixing screws **20** which attach the exchanger **17** to the cold head **19** are refitted. The cap **15** is also put back into position.

[0068] A vacuum is once more created in the first chamber **16**, for example by means of a vacuum pump and via a valve (neither of these has been depicted).

[0069] The repaired or exchanged main cryocooler **18** can then be switched on if the secondary cryocooler **1**, which has now taken over the production of cold, malfunctions or requires maintenance.

[0070] The procedure for replacing or performing maintenance on the other cryocooler may be identical to the procedure described hereinabove.

[0071] The cryocoolers may for example operate on a Gifford MacMahon cycle. The cryocoolers **1**, **18** can be insulated using a superinsulator of the multilayer or monolayer type.

1-13. (canceled)

14. A cryogenic cooling device comprising a main cryocooler with a cold head arranged in a first chamber placed under vacuum, a reservoir of working fluid arranged in a second chamber placed under vacuum, a member that is to be cooled being arranged in the reservoir in a heat exchange relationship with the working fluid, and a secondary cryocooler comprising a cold head arranged in a third chamber placed under vacuum, wherein:

the cold head of the main cryocooler is thermally connected to a heat exchanger, itself fluidically connected to the reservoir via pipes forming a first circulation loop for the working fluid, the pipes passing from the first to the second chamber;

the volumes under vacuum of the first and second chambers are independent which means to say that the vacuums in the first and second chambers are independent;

the cold head of the secondary cryocooler is thermally connected to a heat exchanger, itself fluidically connected to the reservoir via pipes forming a second circulation loop for the working fluid; and

the volume under vacuum of the third chamber is independent of the volumes under vacuum of the first and second chambers which means to say that the vacuums of the first, second and third chambers are independent.

15. The device of claim **14**, wherein at least one of the first and third chambers is sealed off by at least one selectively removable cap.

16. The device of claim **15**, wherein at least one selectively removable cap is arranged in the lower part of the chamber such that it is adjacent to the cold head.

17. The device of claim **15**, wherein at least one cap is mounted in a sealed fashion on the body of the chamber via fixing screws.

18. The device of claim **14**, further comprising, around the pipes passing from the first to the second chamber, vacuum barriers which separate the volumes under vacuum of the first and second chambers, the vacuum barriers being arranged in at least one tubular portion that connects the first and second chambers.

19. The device of claim **14**, further comprising, around the pipes passing from the third to the second chamber, vacuum barriers which separate the volumes under vacuum of the third and second chambers, the vacuum barriers being arranged in at least one tubular portion that connects the third and second chambers.

20. The device of claim **14**, wherein the cold head of the cryocooler(s) is associated with a heat exchanger that acts as a condenser for the working fluid.

21. The device of claim **14**, wherein the cold head of the main cryocooler is connected to the reservoir via two pipes the upstream ends of which are connected to a hermetic volume arranged under the cold head of the main cryocooler, the downstream ends of the pipes being connected to an upper end of the reservoir via a vertical or substantially vertical portion.

22. The device of claim **14**, wherein the cold head of the secondary cryocooler is connected to the reservoir via two pipes the upstream ends of which are connected to a hermetic volume arranged under the cold head of the secondary cryocooler and the downstream ends of which are connected to an upper end of the reservoir via a vertical or substantially vertical portion.

23. A method for cooling a member to a low temperature using the cryogenic cooling device of claim **14**, wherein the main cryocooler is used to cool the member, the first chamber and the second chamber are placed under vacuum and the secondary cryocooler is selectively switched off or on while the main cryocooler is in operation.

24. The method of claim **23**, wherein the main cryocooler is switched off, and at the same time or before the main cryocooler is switched off, the secondary cryocooler is started in order to cool the member, the third chamber being placed under vacuum or kept under vacuum.

25. The method of claim **23**, wherein when a cryocooler is switched off, the cold head of the cryocooler switched off is heated up to an ambient temperature using at least one of the following steps:

spontaneous natural heating;

by commanded active heating;

by forced circulation of gas at ambient temperature into the chamber of the cryocooler or around the exchangers via a coiled tube or any other device; and

by bringing the volume of the cryocooler chamber to atmospheric pressure.

26. The method of claim **23**, further comprising a step of repairing or maintaining one of the two cryocoolers while the other cryocooler is in operation and is cooling the member, the method comprising:

shutting down the cryocooler intended to undergo repair or maintenance or keeping it in the switched off state;

keeping the cryocooler intended to undergo repair or maintenance at ambient temperature or bringing it to ambient temperature;

opening the chamber containing the cryocooler intended to undergo repair or maintenance;

dismantling the cryocooler intended to undergo repair or maintenance so that it can be replaced or repaired without connected the hermetic volume to the atmosphere; and

maintaining the vacuum within the chamber of the other cryocooler that is in operation and in the second chamber.

* * * * *