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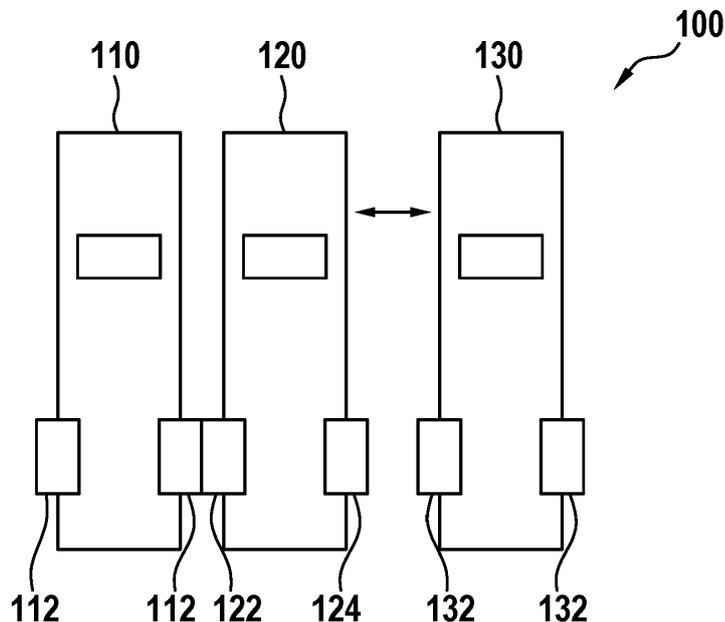
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(54) **CRYOGENIC MODULE FOR USE IN A MODULAR CRYOGENIC INFRASTRUCTURE AND MODULAR CRYOGENIC INFRASTRUCTURE**

(57) The present disclosure relates to a cryogenic module (120) for use in a modular cryogenic infrastructure (100, 200, 300, 400, 500), comprising at least one first interface (122) at an exterior of the cryogenic module (120), the at least one first interface (122) configured to detachably connect the cryogenic module (120) to a pre-cooling module (110) of the cryogenic infrastructure (100,

200, 300, 400, 500); and at least one second interface (124) at the exterior of the cryogenic module (120), the at least one second interface (124) configured to detachably connect the cryogenic module (120) to an operations module (130) having operable equipment to be cooled by the cryogenic module (120).

Fig. 2



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Description

FIELD

[0001] The present disclosure relates to a cryogenic module for use in a modular cryogenic infrastructure, a modular cryogenic infrastructure, and a method of operating a modular cryogenic infrastructure. More particularly, the present disclosure relates to operating equipment, particularly electronics, inside an operations module under defined thermal conditions, e.g., at ultra-low temperatures in the sub-Kelvin or milli-Kelvin range.

BACKGROUND

[0002] A cryostat is generally used to achieve and maintain low temperatures. Low temperatures may be achieved by using, for example, a cryogenic fluid bath such as liquid helium. However, the cooling medium, such as liquid helium, continuously evaporates due to external and/or internal heat input in the cryostat and therefore needs to be refilled regularly. This requires considerable time and resources, whereby the operating costs of such cryostats are high.

[0003] To overcome the above drawbacks, cryogen-free cryostats have been developed. Cryogen-free cryostats may employ a cryogen-free closed cycle system, such a pulse tube cryocooler. Modern pulse tube cryocoolers can achieve temperatures down to 1.2K. To achieve sub-Kelvin temperatures, a magnetic cooling stage can be used in addition to the cryogen-free closed cycle system. The magnetic cooling stage may be an adiabatic demagnetization refrigerator (ADR), which can achieve temperatures down to a few milli-Kelvin. ADR is based on the magneto-caloric effect. When a medium is magnetized, its magnetic moments get aligned and the heat of magnetization is released. Vice versa, if the medium is demagnetized its temperature drops.

[0004] Cryostats have been used almost exclusively in scientific applications where power consumption, ease of use, uptime, and maintainability are valued much lower than performance, particularly cooling power and base temperature. With the proliferation of new commercial electronic hardware that requires cryostats to achieve operating conditions, these previously marginalized features will be critical to making new technologies scalable beyond the scientific laboratory.

[0005] In view of the above, new cryogenic modules, cryogenic infrastructures, and methods of operating such cryogenic modules and cryogenic infrastructures that overcome at least some of the problems in the art are beneficial.

SUMMARY

[0006] It is an object of the present disclosure to provide a cryogenic module for use in a modular cryogenic infrastructure, a modular cryogenic infrastructure, and a

method of operating a modular cryogenic infrastructure that enable efficient operation of equipment, such as electronics, at low temperatures. Another object of the present disclosure is to provide a scalable cryogenic infrastructure, and to reduce downtime and/or power consumption of the cryogenic infrastructure.

[0007] According to an independent aspect of the present disclosure, a cryogenic module for use in a modular cryogenic infrastructure is provided. The cryogenic module includes at least one first interface at an exterior of the cryogenic module, the at least one first interface configured to detachably connect the cryogenic module to a pre-cooling module; and at least one second interface at the exterior of the cryogenic module, the at least one second interface configured to detachably connect the cryogenic module to an operations module having operable equipment to be cooled by the cryogenic module.

[0008] The at least one operations module can be configured to operate the equipment for or during intended use (e.g., commercial use) and not for testing as in laboratories. The at least one operations module can include or accommodate any operable equipment, such as electronics, optics, or a combination thereof. Depending on the type of equipment, the at least one operations module can also be referred to as electronics module or optics module.

[0009] The cryogenic module can also be referred to as a "cryostat". A cryostat is generally used to achieve and maintain low temperatures in the low-Kelvin and/or sub-Kelvin range.

[0010] According to some embodiments, which can be combined with other embodiments described herein, the cryogenic module is connectable to the pre-cooling module while the pre-cooling module is in a first operational state.

[0011] Preferably, the first operational state of the pre-cooling module is selected from the group including, or consisting of, an on-state and idle state of the pre-cooling module.

[0012] Preferably, a second operational state of the pre-cooling module is an off-state of the pre-cooling module.

[0013] According to some embodiments, which can be combined with other embodiments described herein, the cryogenic module is detachable from the pre-cooling module while the pre-cooling module is in the first operational state.

[0014] According to some embodiments, which can be combined with other embodiments described herein, the cryogenic module is connectable to the operations module while the cryogenic module is in a first operational state.

[0015] Preferably, the first operational state of the cryogenic module can be that an operating temperature of the cryogenic module corresponds to a temperature lower than room temperature, e.g., between 1.5 and 10K, such as 4K. In some embodiments, the operating temperature of the cryogenic module can be a temperature provided

by the pre-cooling module.

[0016] Additionally, or alternatively, the first operational state of the cryogenic module is selected from the group including, or consisting of, an on-state and idle state of the cryogenic module. In some embodiments, the idle state of the cryogenic module can correspond to an operating temperature between 1.5 and 10K, such as 4K, which may be a temperature provided by the pre-cooling module. The on-state may correspond to a temperature lower than that, such as 1K or below.

[0017] Additionally, or alternatively, in the first operational state such as the idle state, the cryogenic module does not actively generate cooling power to maintain low temperatures, i.e., the means such as the pulse tube cryocooler or the magnetic cooling stage are not operated to generate cooling power. Additionally, in the first operational state such as the idle state, the cryogenic module may transfer cooling power from the pre-cooling module to the operations module ("passive cooling power"). In this case, the cryogenic module can only transfer part of the cooling power from the pre-cooling module to the operations module and use the remaining part of the cooling power to cool one or more internal thermal components thereof, such as heat shields.

[0018] Preferably, a second operational state of the cryogenic module is an off-state of the cryogenic module.

[0019] Preferably, in the second operational state of the cryogenic module, the cryogenic module does not actively generate cooling power and/or does not receive cooling power from another module and/or does not passively transfer cooling power to another module.

[0020] According to some embodiments, which can be combined with other embodiments described herein, the cryogenic module is detachable from the operations module while the cryogenic module is in the first operational state.

[0021] The terms "connectable" and "detachable" mean a releasable mechanical connection between the modules. For example, the modules can be connected to each other by positioning the modules, e.g., side by side or above each other, in a certain relative position and closing/fastening attachment means such as clamps and/or screws. Furthermore, the modules can be detached or disconnected from each other by opening/releasing the attachment means. Accordingly, "detachable" means that the modules can be separated without damaging the modules.

[0022] The connection between the modules may be any direct or indirect connection suitable for the connected modules to interact thermally and optionally electronically and/or optically and/or fluidly (e.g., a vacuum connection). For example, the connection may be a substantially vacuum-tight connection, e.g., using bellows, vacuum seals, rigid tubing, flexible tubing, O-rings, and the like.

[0023] The term "on-state" as used throughout the present disclosure refers to one of multiple operational states of the modules. In the on-state, the pre-cooling

module or the cryogenic module may actively generate cooling power by operating means such as a pulse tube cryocooler or a magnetic cooling stage to maintain low temperatures. Furthermore, in the on-state, the operations module, particularly the electronics inside the operations module, is operated or switched on.

[0024] In the off-state, the pre-cooling module or the cryogenic module does not actively generate cooling power to maintain low temperatures, i.e., the means such as the pulse tube cryocooler or the magnetic cooling stage are not operated to generate cooling power. Furthermore, in the off-state, the operations module, particularly the electronics inside the operations module, is not operated or is switched off.

[0025] The term "idle state" as used throughout the present disclosure refers to an intermediate state between the on-state and the off-state.

[0026] Additionally, or alternatively, the idle state can be a state of the respective module in which the module is ready and/or pre-configured for actual operation in the on-state.

[0027] Additionally, or alternatively, in the idle state, the pre-cooling module and/or the cryogenic module may not actively generate cooling power, but at least some of its components may be operated or switched on so that the module is ready for operation in the on-state. Furthermore, in the idle state, the operations module, particularly the electronics inside the operations module, is ready for operation in the on-state.

[0028] Additionally, or alternatively, the module may be fully switched on and/or operational in the on-state, partially switched on and/or operational in the idle-state, and fully switched off and/or inoperable in the off-state.

[0029] Additionally, or alternatively, the idle state can be that an operating temperature of the module corresponds to a temperature lower than room temperature, e.g., between 1.5 and 10K, such as 4K. In some embodiments, the operating temperature of the module can be a temperature provided by the pre-cooling module. In the on-state, the operating temperature may be lower than that, such as 1K or below.

[0030] According to some embodiments, which can be combined with other embodiments described herein, the pre-cooling module includes an interface arrangement compatible with the at least one first interface of the cryogenic module.

[0031] According to some embodiments, which can be combined with other embodiments described herein, the operations module includes an interface arrangement compatible with the at least one second interface of the cryogenic module.

[0032] According to some embodiments, which can be combined with other embodiments described herein, the at least one first interface of the cryogenic module includes at least one first thermal interface. The pre-cooling module may have a (first) thermal interface arrangement compatible with the at least one first thermal interface of the cryogenic module.

[0033] Preferably, the at least one first thermal interface is configured to be cooled by the pre-cooling module to a first temperature when the pre-cooling module is in the on-state, particularly via the (first) thermal interface arrangement.

[0034] Preferably, the first temperature is 1K or above, or 4K or above. For example, the first temperature can be in a range between 1K and 100K, or in a range between 1K and 50K, or in a range between 4K and 100K, or in a range between 4K and 50K. In an exemplary embodiment, the first temperature can be about 4K or about 1.2K.

[0035] According to some embodiments, which can be combined with other embodiments described herein, the at least one first interface includes at least one first electrical interface. The pre-cooling module may have a (first) electrical interface arrangement compatible with the at least one first electrical interface of the cryogenic module. The electrical connection between the cryogenic module and the pre-cooling module may be configured for data communication, such as related to the operation and/or control of the cryogenic module and the pre-cooling module.

[0036] According to some embodiments, which can be combined with other embodiments described herein, the at least one first interface of the cryogenic module includes at least one first optical interface. The pre-cooling module may have a (first) optical interface arrangement compatible with the at least one first optical interface of the pre-cooling module. The optical connection between the cryogenic module and the pre-cooling module may be configured for data communication, such as related to the operation and/or control of the cryogenic module and the pre-cooling module.

[0037] According to some embodiments, which can be combined with other embodiments described herein, the at least one second interface of the cryogenic module includes at least one second thermal interface. The operations module may have a (second) thermal interface arrangement compatible with the at least one second thermal interface of the cryogenic module.

[0038] Preferably, the at least one second thermal interface is configured to be cooled by a cooling mechanism of the cryogenic module to a second temperature, particularly when the cryogenic module is in the on-state.

[0039] Preferably, the second temperature is lower than the first temperature.

[0040] Preferably, the second temperature is 4K or below, or 1K or below. For example, the second temperature can be in a range between 1K and 4K, or in a range between 100mK and 4K, or in a range between 2mK and 1K.

[0041] According to some embodiments, which can be combined with other embodiments described herein, the at least one second interface includes at least one second electrical interface. The operations module may have a (second) electrical interface arrangement compatible with the at least one second electrical interface of

the cryogenic module. The electrical connection between the cryogenic module and the operations module may be configured for data communication, such as related to the operation and/or control of the cryogenic module and the operations module.

[0042] According to some embodiments, which can be combined with other embodiments described herein, the at least one second interface of the cryogenic module includes at least one second optical interface. The operations module may have a (second) optical interface arrangement compatible with the at least one second optical interface of the cryogenic module. The optical connection between the cryogenic module and the operations module may be configured for data communication, such as related to the operation and/or control of the cryogenic module and the operations module.

[0043] According to some embodiments, which can be combined with other embodiments described herein, the at least one second interface of the cryogenic module is a plurality of second interfaces. Accordingly, the cryogenic module can be connectable to multiple other modules via the second interfaces, such as other cryogenic modules and/or multiple operations modules.

[0044] According to some embodiments, which can be combined with other embodiments described herein, the cryogenic module is connectable to the operations module while being connected to the pre-cooling module. In other words, the operations module is connectable to the cryogenic module while the cryogenic module is already connected to the pre-cooling module.

[0045] According to some embodiments, which can be combined with other embodiments described herein, the cryogenic module is detachable from the operations module while being connected to the pre-cooling module. In other words, the operations module is detachable from the cryogenic module while the cryogenic module is still connected to the pre-cooling module.

[0046] According to some embodiments, which can be combined with other embodiments described herein, the cryogenic module is connectable to the operations module while the operations module is in a second operational state.

[0047] Preferably, the second operational state of the operations module is an off-state of the operations module. A first operational state of the operations module may be selected from the group including, or consisting of, an idle state and an on-state.

[0048] According to some embodiments, which can be combined with other embodiments described herein, the cryogenic module is detachable from the operations module while the operations module is in the second operational state. In other words, the operations module is detachable from the cryogenic module while the operations module is in the off-state.

[0049] According to some embodiments, which can be combined with other embodiments described herein, the cryogenic module is connectable to the pre-cooling module while being connected to the operations module. In

other words, the pre-cooling module is connectable to the cryogenic module while the cryogenic module is already connected to the operations module.

[0050] According to some embodiments, which can be combined with other embodiments described herein, the cryogenic module is detachable from the pre-cooling module while being connected to the operations module. In other words, the pre-cooling module is detachable from the cryogenic module while the operations module is still connected to the cryogenic module.

[0051] According to some embodiments, which can be combined with other embodiments described herein, the cryogenic module is connectable to the pre-cooling module while being in the second operational state, i.e., the off-state.

[0052] According to some embodiments, which can be combined with other embodiments described herein, the cryogenic module is detachable from the pre-cooling module while being in the second operational state, i.e., the off-state.

[0053] According to some embodiments, which can be combined with other embodiments described herein, the cryogenic module includes a heater arrangement at the at least one first interface and/or at least one second interface configured to heat the at least one first interface and/or at least one second interface. For example, if an operations module is disconnected from the cryogenic module, the load reduction can be compensated using the heater arrangement, stabilizing operation of the cryogenic module.

[0054] According to another independent aspect of the present disclosure, a modular cryogenic infrastructure is provided. The modular cryogenic infrastructure includes at least one cryogenic module; a pre-cooling module; and at least one operations module. The cryogenic module may be the cryogenic module described above.

[0055] According to some embodiments, which can be combined with other embodiments described herein, the modular cryogenic infrastructure is scalable.

[0056] According to some embodiments, which can be combined with other embodiments described herein, multiple cryogenic modules are connectable (or connected) in parallel to the pre-cooling module. In particular, multiple cryogenic modules can be connectable (or connected) to the same pre-cooling module.

[0057] Preferably, the pre-cooling module has a plurality of (first) thermal interface arrangements, with one cryogenic module connectable to each of the thermal interface arrangements.

[0058] Optionally, the pre-cooling module has a plurality of (first) electrical interface arrangements, with one cryogenic module connectable to each of the electrical interface arrangements. Additionally, or alternatively, the pre-cooling module has a plurality of (first) optical interface arrangements, with one cryogenic module connectable to each of the optical interface arrangements.

[0059] Preferably, the multiple cryogenic modules are connectable (or connected) to the pre-cooling module at

the same time.

[0060] Preferably, the pre-cooling module is configured to simultaneously supply cooling power to the multiple cryogenic modules.

5 **[0061]** According to some embodiments, which can be combined with other embodiments described herein, at least two operations modules are connectable (or connected) to each other via respective interfaces, such as thermal and/or electrical and/or optical interfaces.

10 **[0062]** According to some embodiments, which can be combined with other embodiments described herein, the at least two operations modules include a first operations module and a second operations module, wherein the first operations module is connectable (or connected) to the second operations module.

15 **[0063]** Preferably, the first operations module of the at least two operations modules is connectable (or connected) to a first cryogenic module.

20 **[0064]** In some embodiments, the second operations module is connectable (or connected) to a second cryogenic module.

25 **[0065]** In other embodiments, the second operations module of the at least two operations modules is connectable (or connected) to the first operations module while being not connected to a cryogenic module. In particular, the second operations module is not connectable (or connected) to any cryogenic module. For example, the pre-cooling module, the first cryogenic module, the first operations module and the second operations module may be connectable (or connected) in series. In this case, cooling power may be provided to the second operations module by the first cryogenic module via the first operations module.

30 **[0066]** According to some embodiments, which can be combined with other embodiments described herein, the at least one operations module is, or includes, a quantum technology module, particularly a quantum computing module, a quantum communications module, a quantum sensing module, an optics module, or a combination thereof.

35 **[0067]** According to some embodiments, which can be combined with other embodiments described herein, the at least one cryogenic module is, or includes, an adiabatic demagnetization refrigeration module.

40 **[0068]** According to some embodiments, which can be combined with other embodiments described herein, the pre-cooling module is, or includes, a centralized pre-cooling module.

45 **[0069]** According to some embodiments, which can be combined with other embodiments described herein, the pre-cooling module is, or includes, a Turbo-Brayton cooling module.

[0070] Preferably, the pre-cooling module is part of a commercial setup, such as a data center.

50 **[0071]** According to some embodiments, which can be combined with other embodiments described herein, the modular cryogenic infrastructure is, or is included in, a data center.

[0072] According to some embodiments, which can be combined with other embodiments described herein, the modular cryogenic infrastructure is, or is included in, a commercial setup.

[0073] According to some embodiments, which can be combined with other embodiments described herein, the modular cryogenic infrastructure includes a user interface.

[0074] Preferably, the user interface includes at least one display unit and at least one input unit, such as a keyboard. In some embodiments, the user interface includes a touch screen.

[0075] Preferably, the user interface is configured to allow a user to control operation of the modular cryogenic infrastructure.

[0076] Preferably, the user interface is configured to inform and/or guide a user during a module connecting process and/or a module disconnecting process.

[0077] Preferably, the user interface may be configured to guide the user through the individual steps of the module connecting process and/or module disconnecting process.

[0078] Preferably, the user interface may be configured to receive user input about process steps completed by the user, such as attaching screws and/or clamps. Upon receiving the user input, the user interface may inform the user of the next step(s) of the module connecting process and/or module disconnecting process.

[0079] According to another independent aspect of the present disclosure, a pre-cooling module for use in a modular cryogenic infrastructure is provided. The modular cryogenic infrastructure may be the modular cryogenic infrastructure of the embodiments of the present disclosure.

[0080] According to some embodiments, which can be combined with other embodiments described herein, the pre-cooling module includes an interface arrangement at an exterior of the pre-cooling module, the interface arrangement configured to detachably connect the pre-cooling module to one or more cryogenic modules and/or one or more operations modules of the cryogenic infrastructure, wherein the pre-cooling module is connectable to the one or more cryogenic modules and/or the one or more operations modules and/or detachable from the one or more cryogenic modules and/or the one or more operations modules while the pre-cooling module is in a first operational state.

[0081] Preferably, the first operational state of the pre-cooling module is selected from the group including, or consisting of, an on-state and idle state of the pre-cooling module.

[0082] According to some embodiments, which can be combined with other embodiments described herein, the pre-cooling module includes a heater arrangement at the (thermal) interface arrangement configured to heat the (thermal) interface arrangement. For example, if a cryogenic module is disconnected from the pre-cooling module, the load reduction can be compensated using the

heater arrangement, stabilizing operation of the pre-cooling module.

[0083] According to another independent aspect of the present disclosure, an operations module for use in a modular cryogenic infrastructure is provided. The modular cryogenic infrastructure may be the modular cryogenic infrastructure of the embodiments of the present disclosure.

[0084] According to some embodiments, which can be combined with other embodiments described herein, the operations module includes an interface arrangement at an exterior of the operations module, the interface arrangement configured to detachably connect the operations module to a pre-cooling module of the cryogenic infrastructure, wherein the operations module is connectable to the pre-cooling module and/or detachable from the pre-cooling module while the pre-cooling module is in a first operational state.

[0085] Preferably, the first operational state of the pre-cooling module is selected from the group including, or consisting of, an on-state and idle state of the pre-cooling module.

[0086] According to another independent aspect of the present disclosure, a method of operating a modular cryogenic infrastructure is provided. The method may use the modular cryogenic infrastructure of the embodiments of the present disclosure.

[0087] According to some embodiments, which can be combined with other embodiments described herein, the method includes connecting the cryogenic module to the pre-cooling module while the pre-cooling module is in a first operational state.

[0088] Preferably, the first operational state of the pre-cooling module is selected from the group including, or consisting of, an on-state and idle state of the pre-cooling module.

[0089] According to some embodiments, which can be combined with other embodiments described herein, the method includes detaching the cryogenic module from the pre-cooling module while the pre-cooling module is in the first operational state.

[0090] According to some embodiments, which can be combined with other embodiments described herein, the method includes connecting the cryogenic module to the operations module while the cryogenic module is in a first operational state.

[0091] Preferably, the first operational state of the cryogenic module is selected from the group including, or consisting of, an on-state and idle state of the cryogenic module.

[0092] According to some embodiments, which can be combined with other embodiments described herein, the method includes detaching the cryogenic module from the operations module while the cryogenic module is in the first operational state.

[0093] According to another independent aspect of the present disclosure, a cryogenic infrastructure is provided. The cryogenic infrastructure includes a pre-cool-

ing module, an operations module connectable to the pre-cooling module; and one or more cryogenic modules connectable to the operations module.

[0094] The cryogenic infrastructure may be the modular cryogenic infrastructure described throughout this document. Additionally, or alternatively, the pre-cooling module may be the pre-cooling module described throughout this document. Additionally, or alternatively, the operations module may be the operations module described throughout this document. Additionally, or alternatively, the cryogenic module may be the cryogenic module described throughout this document.

[0095] According to some embodiments, which can be combined with other embodiments described herein, the pre-cooling module may be a single pre-cooling module.

[0096] According to some embodiments, which can be combined with other embodiments described herein, the operations module may be a single operations module.

[0097] According to some embodiments, which can be combined with other embodiments described herein, the operations module has operable equipment to be cooled by the cryogenic module.

[0098] According to some embodiments, which can be combined with other embodiments described herein, the operations module is configured to provide a thermal path between the pre-cooling module and the one or more cryogenic modules to provide pre-cooling to the one or more cryogenic modules. Accordingly, the one or more cryogenic modules may provide cooling power to the operations module to cool the operable equipment (e.g., 1K or below), and may receive pre-cooling power (e.g., 4K) from the pre-cooling module via the same operations module. In other words, there may be a two-way thermal path between the operations module and the one or more cryogenic modules. The two-way thermal path may be implemented using, for example, nested thermal interfaces.

[0099] According to some embodiments, which can be combined with other embodiments described herein, the operations module is configured to cool one or more internal thermal components thereof using the pre-cooling power received from the pre-cooling module. Accordingly, the pre-cooling power may be used not only by the one or more cryogenic modules but may also be used by the operations module to cool the one or more internal thermal components thereof, such as thermal shields.

[0100] Preferably, the operations module may transfer cooling power from the pre-cooling module to the one or more cryogenic modules ("passive cooling power"). For example, the operations module can only transfer part of the cooling power from the pre-cooling module to the one or more cryogenic modules and use the remaining part of the cooling power to cool one or more internal thermal components thereof, such as heat shields.

[0101] Further aspects, benefits, and features of the present disclosure are apparent from the claims, the description, and the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0102] So that the manner in which the above recited features of the present disclosure can be understood in detail, a more particular description of the disclosure, briefly summarized above, may be had by reference to embodiments. The accompanying drawings relate to embodiments of the disclosure and are described in the following:

FIG. 1 shows a schematic view of a modular cryogenic infrastructure in an assembled state according to the embodiments of the present disclosure;

FIG. 2 shows a schematic view of a modular cryogenic infrastructure in a disassembled state according to the embodiments of the present disclosure;

FIG. 3 shows a schematic view of a modular cryogenic infrastructure in a disassembled state according to further embodiments of the present disclosure;

FIG. 4 shows a schematic view of a modular cryogenic infrastructure according to embodiments of the present disclosure;

FIG. 5 shows a schematic view of a modular cryogenic infrastructure according to further embodiments of the present disclosure;

FIG. 6 shows a schematic view of a modular cryogenic infrastructure according to further embodiments of the present disclosure; and

FIG. 7 shows a schematic view of a modular cryogenic infrastructure according to further embodiments of the present disclosure.

DETAILED DESCRIPTION OF EMBODIMENTS

[0103] Reference will now be made in detail to the various embodiments of the disclosure, one or more examples of which are illustrated in the figures. Within the following description of the drawings, the same reference numbers refer to same components. Generally, only the differences with respect to individual embodiments are described. Each example is provided by way of explanation of the disclosure and is not meant as a limitation of the disclosure. Further, features illustrated or described as part of one embodiment can be used on or in conjunction with other embodiments to yield yet a further embodiment. It is intended that the description includes such modifications and variations.

[0104] Cryostats have been used almost exclusively in scientific applications where power consumption, ease of

use, uptime, and maintainability are valued much lower than performance, particularly cooling power and base temperature. With the proliferation of new commercial electronic hardware that requires cryostats to achieve operating conditions, these previously marginalized features will be critical to making new technologies scalable beyond the scientific laboratory.

[0105] The embodiments of the present disclosure overcome the above drawbacks by providing a modular cryogenic infrastructure having a centralized pre-cooling mechanism and independently operable modules. This allows the cryogenic infrastructure to be both flexible and scalable beyond the scientific laboratory, making it suitable for large facilities such as data centers. In addition, the modularity does not require complete shutdown of the cryogenic infrastructure for maintenance, repair, and addition of more cryogenic and/or operations modules.

[0106] FIG. 1 shows a schematic view of a modular cryogenic infrastructure 100 in an assembled state according to the embodiments of the present disclosure. FIG. 2 shows a schematic view of the modular cryogenic infrastructure 100 in a partly disassembled state. FIG. 3 shows a schematic view of the modular cryogenic infrastructure 100 in another partly disassembled state.

[0107] The modular cryogenic infrastructure 100 can be used to operate equipment, such as quantum technology, under defined thermal conditions, e.g., at ultra-low temperatures in the sub-Kelvin or milli-Kelvin range.

[0108] According to some non-limiting embodiments of the present disclosure, the modular cryogenic infrastructure 100 is, or is included in, a commercial setup, such as a data center.

[0109] The modular cryogenic infrastructure 100 includes a pre-cooling module 110, at least one cryogenic module 120, and at least one operations module 130.

[0110] The pre-cooling module 110 may be a centralized pre-cooling module, such as a Turbo-Brayton cooling module. The single centralized pre-cooling module, such as the such as a Turbo-Brayton cooling module, can be implemented on an industrial scale, reducing power consumption.

[0111] The at least one cryogenic module 120 may be an adiabatic demagnetization refrigeration (ADR) module. In some embodiments, the adiabatic demagnetization refrigeration (ADR) module can achieve and maintain low temperatures in the low-Kelvin and/or sub-Kelvin range using the magneto-caloric effect.

[0112] The operations module 130 has operable equipment, such as electronics and/or optics, to be cooled by the cryogenic module 120. The at least one operations module 130 may be a quantum technology module, such as a quantum computing module, a quantum communications module and/or a quantum sensing module. In particular, the at least one operations module 130 can be configured to operate the quantum technology for intended use (e.g., commercial use) and not for testing as in laboratories. In other words, the operable electronics to be cooled by the cryogenic module 120 may be

quantum electronics, such as a quantum computer.

[0113] The individual modules 120, 130 may take the shape of 19" racks and provide interfaces between these racks to facilitate connection and disconnection of individual modules without interfering with the operation of the previous module(s). These interfaces may allow interfacing of individual vacuums, temperatures, and/or electrical signals.

[0114] In the example of FIG. 1, the pre-cooling module 110, the cryogenic module 120, and the operations module 130 are each in a first operational state, such as an on-state or idle state. A second operational state of the pre-cooling module 110, the cryogenic module 120, and the operations module 130 may be an off-state.

[0115] The term "on-state" as used throughout the present disclosure refers to an actual operating state of the respective module. Similarly, the term "off-state" as used throughout the present disclosure refers to a non-operating state of the respective module. For example, in the on-state, the pre-cooling module 110 may actively generate cooling power by operating for instance a Turbo-Brayton mechanism. In the off-state, the pre-cooling module 110 may not operate for instance the Turbo-Brayton mechanism to generate cooling power. The idle state is an intermediate state between the on-state and the off-state in which the module is ready for actual operation.

[0116] The cryogenic module 120 includes at least one first interface 122 at an exterior of the cryogenic module 120, the at least one first interface 122 configured to detachably connect the cryogenic module 120 to the pre-cooling module 110; and at least one second interface 124 at the exterior of the cryogenic module 120, the at least one second interface 124 configured to detachably connect the cryogenic module 120 to the operations module 130 having operable equipment to be cooled by the cryogenic module 120.

[0117] The pre-cooling module 110 includes an interface arrangement 112 compatible with the at least one first interface 122 of the cryogenic module 120.

[0118] In some embodiments, the at least one first interface 122 of the cryogenic module 120 may include at least one first thermal interface, and the interface arrangement 112 of the pre-cooling module 110 may have a thermal interface arrangement compatible with the at least one first thermal interface of the cryogenic module 120.

[0119] The at least one first thermal interface of the cryogenic module 120 may be configured to be cooled by the pre-cooling module 110 to a first temperature when the pre-cooling module 110 is in the on-state. In some embodiments, the first temperature can be 1K or above, or 4K or above. For example, the first temperature can be in a range between 1K and 100K, or in a range between 1K and 50K, or in a range between 4K and 100K, or in a range between 4K and 50K. In an exemplary embodiment, the first temperature can be about 4K or about 1.2K.

[0120] In some embodiments, the at least one first interface 122 of the cryogenic module 120 may include at least one first electrical interface, and the interface arrangement 112 of the pre-cooling module 110 may have an electrical interface arrangement compatible with the at least one first electrical interface of the cryogenic module 120. The electrical connection between the cryogenic module 120 and the pre-cooling module 110 may be configured for data communication, such as related to the operation and/or control of the cryogenic module 120 and the pre-cooling module 110.

[0121] In some embodiments, the at least one first interface 122 of the cryogenic module 120 may include at least one first optical interface, and the interface arrangement 112 of the pre-cooling module 110 may have an optical interface arrangement compatible with the at least one first optical interface of the cryogenic module 120. The optical connection between the cryogenic module 120 and the pre-cooling module 110 may be configured for data communication, such as related to the operation and/or control of the cryogenic module 120 and the pre-cooling module 110.

[0122] The operations module 130 includes an interface arrangement 132 compatible with the at least one second interface 124 of the cryogenic module 120.

[0123] In some embodiments, the at least one second interface 124 of the cryogenic module 120 may include at least one second thermal interface, and the interface arrangement 132 of the operations module 130 may have a thermal interface arrangement compatible with the at least one second thermal interface of the cryogenic module 120.

[0124] The at least one second thermal interface of the cryogenic module 120 may be configured to be cooled by a cooling mechanism of the cryogenic module 120 to a second temperature lower than the first temperature when the cryogenic module 120 is in the on-state. The second temperature may be 4K or below, or 1K or below. For example, the second temperature can be in a range between 1K and 4K, or in a range between 100mK and 4K, or in a range between 100mK and 1K.

[0125] In some embodiments, the at least one second interface 124 of the cryogenic module 120 may include at least one second electrical interface, and the interface arrangement 132 of the operations module 130 may have an electrical interface arrangement compatible with the at least one second electrical interface of the cryogenic module 120. The electrical connection between the cryogenic module 120 and the operations module 130 may be configured for data communication, such as related to the operation and/or control of the cryogenic module 120 and the operations module 130.

[0126] In some embodiments, the at least one second interface 124 of the cryogenic module 120 may include at least one second optical interface, and the interface arrangement 132 of the operations module 130 may have an optical interface arrangement compatible with the at least one second optical interface of the cryogenic mod-

ule 120. The optical connection between the cryogenic module 120 and the operations module 130 may be configured for data communication, such as related to the operation and/or control of the cryogenic module 120 and the operations module 130.

[0127] As shown in the example of FIG. 2, in some embodiments, the cryogenic module 120 and the operations module 130 can be connected to each other while the cryogenic module 120 is in the first operational state, such as the on-state or idle state, and optionally while the pre-cooling module 110 is in the first operational state, such as the on-state or idle state, and/or the operations module 130 is in the second operational state which is the off-state. In addition, the cryogenic module 120 and the operations module 130 can be separated from each other while the cryogenic module 120 is in the first operational state, and optionally while the pre-cooling module 110 is in the first operational state and/or the operations module 130 is in the second operational state.

[0128] Additionally, or alternatively, the cryogenic module 120 and the operations module 130 can be connected to each other while the cryogenic module 120 is already connected to the pre-cooling module 110. In addition, the cryogenic module 120 and the operations module 130 can be separated from each other while the cryogenic module 120 is still connected to the pre-cooling module 110.

[0129] As shown in the example of FIG. 3, in some embodiments, the cryogenic module 120 and the pre-cooling module 110 can be connected to each other while the pre-cooling module 110 is in the first operational state, such as the on-state or idle state, and optionally while the cryogenic module 120 is in the second operational state (off-state) and/or the operations module 130 is in the second operational state (off-state). In addition, the cryogenic module 120 and the pre-cooling module 110 can be separated from each other while the pre-cooling module 110 is in the first operational state (on-state or idle state), and optionally while the cryogenic module 120 is in the off-state and/or the operations module 130 is in the second operational state (off-state).

[0130] Additionally, or alternatively, the cryogenic module 120 and the pre-cooling module 110 can be connected to each other while the cryogenic module 120 is already connected to the operations module 130. In addition, the cryogenic module 120 and the pre-cooling module 110 can be separated from each other while the cryogenic module 120 is still connected to the operations module 130.

[0131] In view of the above, there is a releasable mechanical connection between the modules 110, 120 and 130. For example, the modules 110, 120 and 130 can be connected to each other by positioning the modules 110, 120 and 130 side by side and/or above each other in a certain relative position and optionally closing/fastening attachment means such as clamps and/or screws. Furthermore, the modules 110, 120 and 130 can be separated from each other by opening/releasing the

attachment means. Accordingly, "detachable" means that the modules 110, 120 and 130 can be separated without damaging the modules 110, 120 and 130.

[0132] The connection between the modules 110, 120 and 130 may be any direct or indirect connection suitable for the connected modules to interact thermally and optionally electronically and/or optically.

[0133] In some embodiments, the connection may be a substantially vacuum-tight connection.

[0134] Optionally, one or more vacuum locks can be provided to maintain a vacuum in one or more areas of the modular cryogenic infrastructure during adding and/or removing modules. For example, the one or more vacuum locks can be configured to maintain a vacuum in modules which are in the first operational state, such as the on-state or idle state. Optionally, the one or more vacuum locks can be configured to maintain a vacuum in modules which are in the second operational state, i.e., the off-state.

[0135] Optionally, the vacuum itself may be used to secure the connection between the modules. Optionally, fastening means can be used to secure the connection between the modules, such as a plug-connection using male and female plugs, a screw connection, a Bayonet lock, a latch connection, and the like.

[0136] Optionally, stabilizing means can be provided to stabilize an assembling process of two modules. For example, a pneumatic device and/or a guiding device can be used so that surfaces are slowly brought together when a vacuum is generated.

[0137] Optionally, first certain parts of the modules may be brought together to thermally and optionally electrically connect the modules, and then a vacuum may be generated in at least one of the modules and/or the fastening means may be fastened to securely connect the modules and prevent vacuum leaks.

[0138] Optionally, electrical confirmation means, such as one or more pins, can be provided at the modules. If the electrical connection (and thus the thermal connection) between the modules is correctly established, a current flowing through the one or more pins may indicate the connection. For example, the one or more pins can be provided at the electric interface.

[0139] In some embodiments, the connection may include a flexible tube, such as a bellows tube. The flexible tube provides flexibility such that the relative position between the modules can vary in a certain range. The thermal interface can be arranged inside the flexible tube. Optionally, the electrical interface and/or optical interface can be arranged inside the flexible tube. In this case, the electrical interface and/or optical interface can be thermalized. Alternatively, the electrical interface and/or optical interface can be arranged outside the flexible tube. In this case, the electrical interface and/or optical interface may not be thermalized. This is particularly useful if no (pre-)cooling of the electrical interface and/or optical interface is required.

[0140] Optionally, one or more thermal shields and/or

spacer means to separate different components and/or temperature regimes from each other can be arranged inside the flexible tube. For example, a milli-Kelvin bus, a 4K shield, a 40K shield, and a vacuum vessel can be arranged in this order from the inside out, with spaces in between so that no contact occurs. A stabilizing connection, such as the spacer means, between these "layers" can have a low thermal conductivity (e.g., due to a small diameter) to minimize thermal interaction between different temperature regimes.

[0141] Optionally, three or more flexible tubes can be connected to each other e.g. at an intersection or crossing device. For example, a first flexible tube may be connected to the pre-cooling module and the intersection or crossing device, and two or more second flexible tubes can be connected to the intersection or crossing device and corresponding two or more cryogenic modules. A similar connection can be provided between one or more cryogenic modules and one or more operations modules.

[0142] In other embodiments, the connection may include a rigid tube. The thermal interface can be arranged inside the rigid tube. Optionally, the electrical interface and/or optical interface can be arranged inside the rigid tube. In this case, the electrical interface and/or optical interface can be thermalized. Alternatively, the electrical interface and/or optical interface can be arranged outside the rigid tube. In this case, the electrical interface and/or optical interface may not be thermalized. This is particularly useful if no (pre-)cooling of the electrical interface and/or optical interface is required.

[0143] Optionally, one or more thermal shields and/or spacer means to separate different components and/or temperature regimes from each other can be arranged inside the rigid tube. For example, a milli-Kelvin bus, a 4K shield, a 40K shield, and a vacuum vessel can be arranged in this order from the inside out, with spaces in between so that no contact occurs. A stabilizing connection, such as the spacer means, between these "layers" can have a low thermal conductivity (e.g., due to a small diameter) to minimize thermal interaction between different temperature regimes. Due to the rigidity of the tube, the spaces between the "layers" can be small, which allows a compact design to be achieved.

[0144] Optionally, three or more rigid tubes can be connected to each other e.g. at an intersection or crossing device. For example, a first rigid tube may be connected to the pre-cooling module and the intersection or crossing device, and two or more second rigid tubes can be connected to the intersection or crossing device and corresponding two or more cryogenic modules. A similar connection can be provided between one or more cryogenic modules and one or more operations modules.

[0145] FIG. 4 shows a schematic view of a modular cryogenic infrastructure 200 according to embodiments of the present disclosure. The cryogenic infrastructure 200 is similar to the cryogenic infrastructure shown in FIGs. 1 to 3, and therefore a description of similar or identical aspects is not repeated.

[0146] The cryogenic infrastructure 200 is scalable. The term "scalable" means that multiple cryogenic modules and/or multiple operations modules can be connected to each other and/or to the single pre-cooling module 110 in various ways. To this end, the modules 110, 120 and 130 may each have multiple interfaces for connecting the modules 110, 120 and 130.

[0147] FIG. 5 shows a schematic view of a modular cryogenic infrastructure 300 according to further embodiments of the present disclosure. The cryogenic infrastructure 300 is similar to the cryogenic infrastructures shown in FIGs. 1 to 4, and therefore a description of similar or identical aspects is not repeated.

[0148] In some embodiments, the pre-cooling module 110 has a plurality of interface arrangements 112, with one cryogenic module 120a, 120b connectable to each of the interface arrangements 112.

[0149] As shown in FIG. 5, multiple cryogenic modules 120a, 120b can be connected in parallel to the single pre-cooling module 110. Preferably, the multiple cryogenic modules 120a, 120b are connected to the pre-cooling module 110 at the same time and are simultaneously supplied with cooling power from the pre-cooling module 110.

[0150] In addition, multiple operations modules 130a, 130b can be provided, wherein each operations module 130a, 130b can be connected to a respective cryogenic module 120a, 120b. In the example of FIG. 5, a first operations module 130a is connected to a first cryogenic module 120a, and a second operations module 130b is connected to a second cryogenic module 120b.

[0151] Although two cryogenic modules and two operations modules are shown in the example of FIG. 5, it is to be understood that the present disclosure is not limited thereto, and that a different number of cryogenic modules and operations modules may be simultaneously connected to the pre-cooling module and/or to each other. In particular, the number of cryogenic modules and the number of operations modules simultaneously connected to the pre-cooling module and/or to each other may be the same or different.

[0152] In some embodiments, the number of cryogenic modules can be two or more, five or more, 10 or more, 20 or more, 50 or more, or 100 or more.

[0153] Additionally, or alternatively, the number of operations modules can be two or more, five or more, 10 or more, 20 or more, 50 or more, or 100 or more.

[0154] FIG. 6 shows a schematic view of a modular cryogenic infrastructure 400 according to further embodiments of the present disclosure. The cryogenic infrastructure 400 is similar to the cryogenic infrastructures shown in FIGs. 1 to 5, and therefore a description of similar or identical aspects is not repeated.

[0155] In some embodiments, at least two adjacent operations modules 130a, 130b are connected to each other via respective interfaces 132, such as thermal interfaces and/or electrical interfaces and/or optical interfaces.

[0156] The connection between the at least two operations modules 130a, 130b may be configured for thermal transfer between the at least two operations modules 130a, 130b. Additionally, or alternatively, the connection between the at least two operations modules 130a, 130b may be configured for data communication, such as related to the operation and/or control of the at least two operations modules 130a, 130b.

[0157] In the example of FIG. 6, the at least two operations modules include a first operations module 130a and a second operations module 130b, wherein the first operations module 130a is connected to the second operations module 130b. The first operations module 130a is connected to the first cryogenic module 120a and the second operations module 130b is connected to the second cryogenic module 120b.

[0158] FIG. 7 shows a schematic view of a modular cryogenic infrastructure 500 according to further embodiments of the present disclosure. The cryogenic infrastructure 500 is similar to the cryogenic infrastructures shown in FIGs. 1 to 6, and therefore a description of similar or identical aspects is not repeated.

[0159] In the example of FIG. 7, the second operations module 130b is connected to the first operations module 130a while being not connected to a cryogenic module. In particular, the second operations module 130b may not be connected to any cryogenic module. For example, the pre-cooling module 110, the cryogenic module 120, the first operations module 130a and the second operations module 130b may be connected in series. In this case, cooling power may be provided to the second operations module 130b by the cryogenic module 120 via the first operations module 130a and the respective interfaces 124 and 132.

[0160] In view of the above, the embodiments of the present disclosure provide a modular cryogenic infrastructure having a centralized pre-cooling mechanism and independently operable modules. This allows the cryogenic infrastructure to be both flexible and scalable beyond the scientific laboratory, making it suitable for large facilities such as data centers. In addition, the modularity does not require complete shutdown of the cryogenic infrastructure for maintenance, repair, and addition of more cryogenic and/or operations modules.

[0161] While the foregoing is directed to embodiments of the disclosure, other and further embodiments of the disclosure may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

Claims

1. Cryogenic module (120) for use in a modular cryogenic infrastructure (100, 200, 300, 400, 500), comprising:

at least one first interface (122) at an exterior of

the cryogenic module (120), the at least one first interface (122) configured to detachably connect the cryogenic module (120) to a pre-cooling module (110) of the cryogenic infrastructure (100, 200, 300, 400, 500); and

at least one second interface (124) at the exterior of the cryogenic module (120), the at least one second interface (124) configured to detachably connect the cryogenic module (120) to an operations module (130) having operable equipment to be cooled by the cryogenic module (120),

wherein:

- the cryogenic module (120) is connectable to the pre-cooling module (110) and/or detachable from the pre-cooling module (110) while the pre-cooling module (110) is in a first operational state, wherein the first operational state of the pre-cooling module (110) is an on-state or idle state of the pre-cooling module (110), and/or

- the cryogenic module (120) is connectable to the operations module (130) and/or detachable from the operations module (130) while the cryogenic module (120) is in a first operational state, wherein the first operational state of the cryogenic module (120) is an on-state or idle state of the cryogenic module (120).

2. Cryogenic module (120) of claim 1, wherein:

- the at least one first interface (122) includes at least one first thermal interface and/or at least one first electrical interface and/or at least one first optical interface; and/or

- the at least one second interface (124) includes at least one second thermal interface and/or at least one second electrical interface and/or at least one second optical interface.

3. Cryogenic module (120) of claim 1 or 2, wherein:

- the cryogenic module (120) is connectable to the operations module (130) and/or detachable from the operations module (130) while being connected to the pre-cooling module (110); and/or

- the cryogenic module (120) is connectable to the operations module (130) and/or detachable from the operations module (130) while the operations module (130) is in a second operational state, wherein the second operational state of the cryogenic module (120) is an off-state.

4. Cryogenic module (120) of any one of claims 1 to 3, wherein:

- the cryogenic module (120) is connectable to the pre-cooling module (110) and/or detachable from the pre-cooling module (110) while being connected to the operations module (130); and/or

- the cryogenic module (120) is connectable to the pre-cooling module (110) and/or detachable from the pre-cooling module (110) while being in the second operational state, wherein the second operational state of the cryogenic module (120) is the off-state.

5. Modular cryogenic infrastructure (100, 200, 300, 400, 500), comprising:

at least one cryogenic module (120) according to any one of claims 1 to 4;
a pre-cooling module (110); and
at least one operations module (130).

6. Modular cryogenic infrastructure (300, 400) of claim 5, wherein multiple cryogenic modules (120a, 120b) are connectable in parallel to the pre-cooling module (110).

7. Modular cryogenic infrastructure (300, 400, 500) of claim 5 or 6, wherein at least two operations modules (130a, 130b) are connectable to each other via respective interfaces.

8. Modular cryogenic infrastructure (400) of claim 7, wherein:

- a first operations module (130a) of the at least two operations modules (130a, 130b) is connectable to a first cryogenic module (120a), a second operations module (130b) of the at least two operations modules (130a, 130b) is connectable to a second cryogenic module (120b), and wherein the first operations module (130a) is connectable to the second operations module (130b), or

- a first operations module (130a) of the at least two operations modules (130a, 130b) is connectable to a first cryogenic module (120a), and wherein a second operations module (130b) of the at least two operations modules (130a, 130b) is connectable to the first operations module (130a) while being not connected to a cryogenic module.

9. Modular cryogenic infrastructure (100, 200, 300, 400, 500) of any one of claims 5 to 8, wherein the at least one operations module (130) is, or includes, a quantum technology module, particularly a quantum computing module, a quantum communications module, a quantum sensing module, an optics module, or a combination thereof.

10. Modular cryogenic infrastructure (100, 200, 300, 400, 500) of any one of claims 5 to 9, wherein the at least one cryogenic module (120) is, or includes, an adiabatic demagnetization refrigeration module. 5
11. Modular cryogenic infrastructure (100, 200, 300, 400, 500) of any one of claims 5 to 10, wherein the pre-cooling module (110) is, or includes, a centralized pre-cooling module and/or a Turbo-Brayton cooling module. 10
12. Pre-cooling module (110) for use in a modular cryogenic infrastructure (100, 200, 300, 400, 500), comprising:
 an interface arrangement (112) at an exterior of the pre-cooling module (110), the interface arrangement (112) configured to detachably connect the pre-cooling module (110) to one or more cryogenic modules (120) and/or one or more operations modules (130) of the cryogenic infrastructure (100, 200, 300, 400, 500), wherein the pre-cooling module (110) is connectable to the one or more cryogenic modules (120) and/or the one or more operations modules (130) and/or detachable from the one or more cryogenic modules (120) and/or the one or more operations modules (130) while the pre-cooling module (110) is in a first operational state, wherein the first operational state of the pre-cooling module (110) is an on-state or idle state. 15
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13. Operations module (130) for use in a modular cryogenic infrastructure (100, 200, 300, 400, 500), comprising:
 an interface arrangement (132) at an exterior of the operations module (130), the interface arrangement (132) configured to detachably connect the operations module (130) to a pre-cooling module (110) of the cryogenic infrastructure (100, 200, 300, 400, 500), wherein the operations module (130) is connectable to the pre-cooling module (110) and/or detachable from the pre-cooling module (110) while the pre-cooling module (110) is in a first operational state, wherein the first operational state of the pre-cooling module (110) is an on-state or idle state. 35
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14. Method of operating a modular cryogenic infrastructure (100, 200, 300, 400, 500) of any one of claims 5 to 11, comprising:
 connecting the cryogenic module (120) to the pre-cooling module (110) while the pre-cooling module (110) is in a first operational state, wherein the first operational state of the pre-cooling module (110) is an on-state or idle state; and/or 50
 55
 detaching the cryogenic module (120) from the pre-cooling module (110) while the pre-cooling module (110) is in the first operational state;
- and/or
 connecting the cryogenic module (120) to the operations module (130) while the cryogenic module (120) is in a first operational state, wherein the first operational state of the cryogenic module (120) is an on-state or idle state; and/or
 detaching the cryogenic module (120) from the operations module (130) while the cryogenic module (130) is in the first operational state.
15. Cryogenic infrastructure, comprising:
 a pre-cooling module;
 an operations module connectable to the pre-cooling module; and
 one or more cryogenic modules connectable to the operations module,
 wherein the operations module has operable equipment to be cooled by the cryogenic module, and wherein the operations module is configured to provide a thermal path between the pre-cooling module and the one or more cryogenic modules to provide pre-cooling to the one or more cryogenic modules. 24

Fig. 1

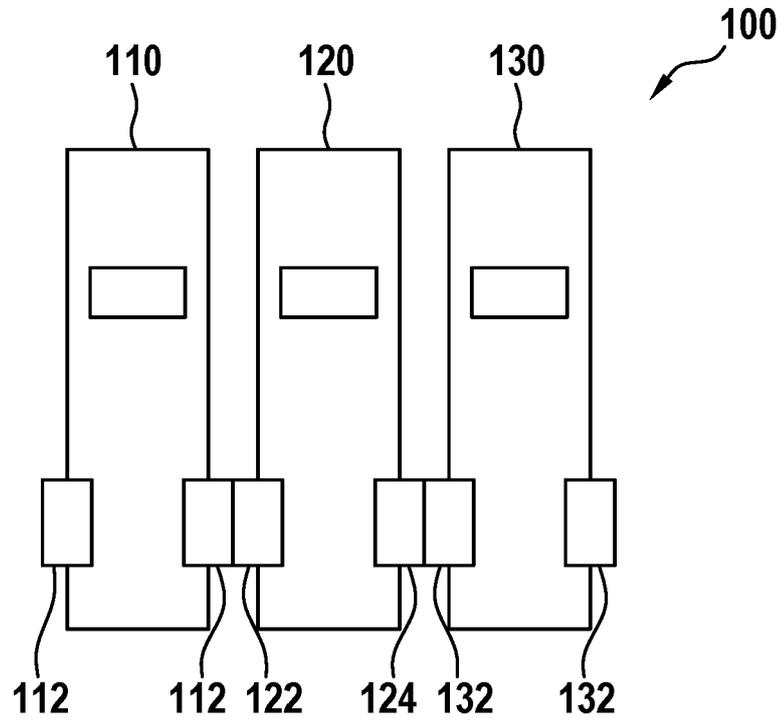


Fig. 2

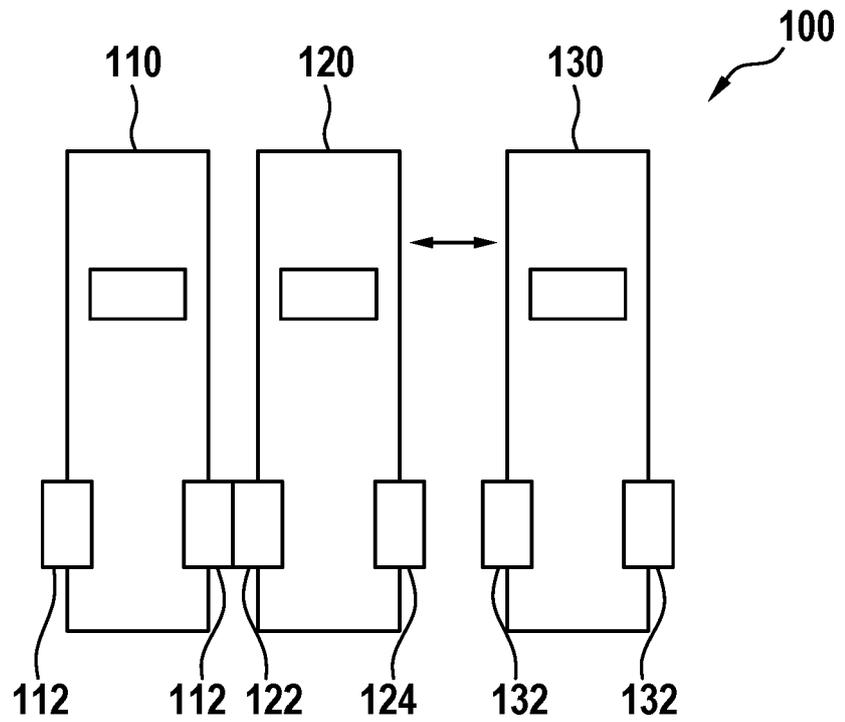


Fig. 3

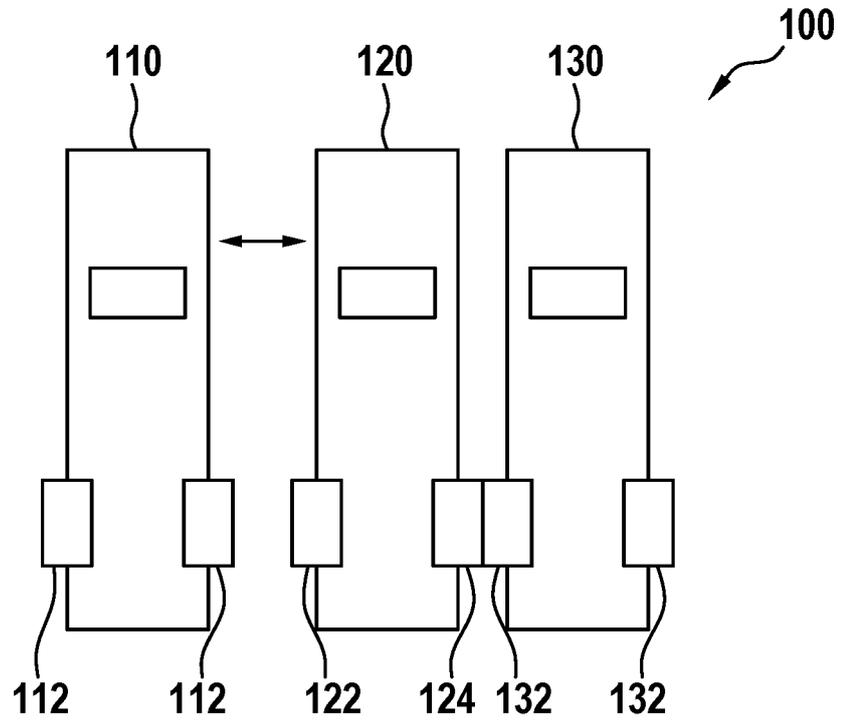


Fig. 4

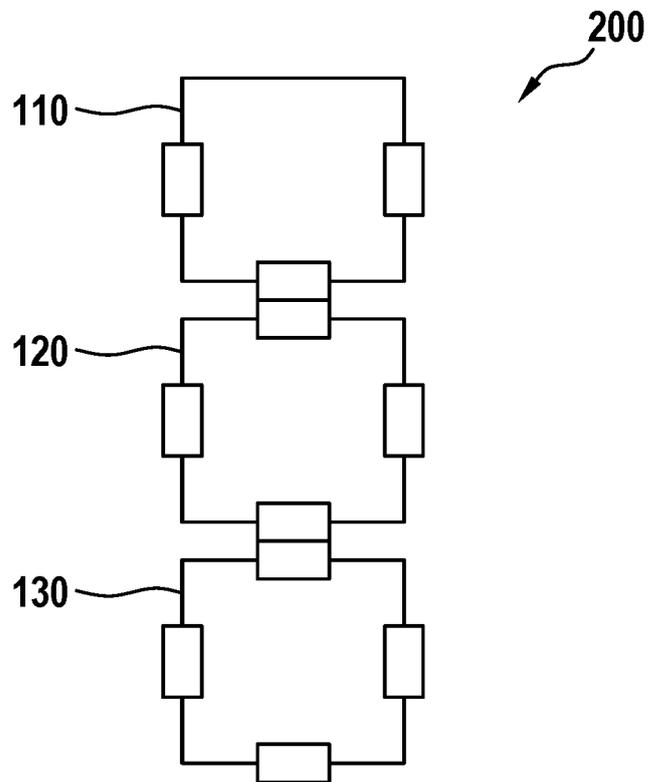


Fig. 5

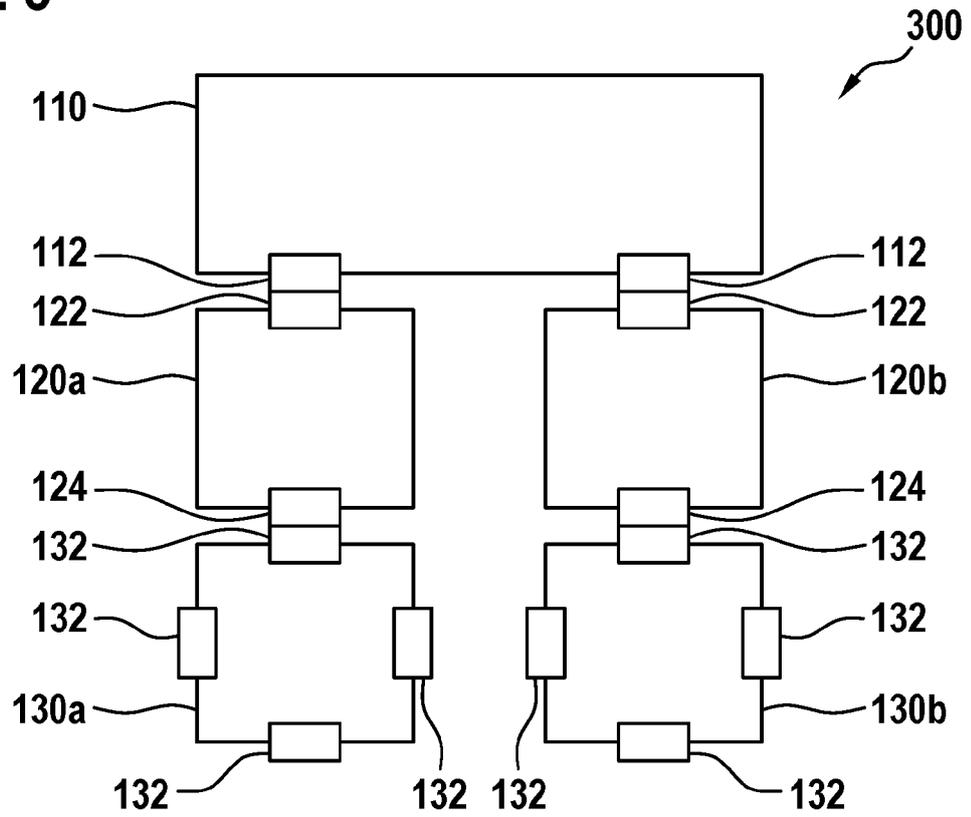


Fig. 6

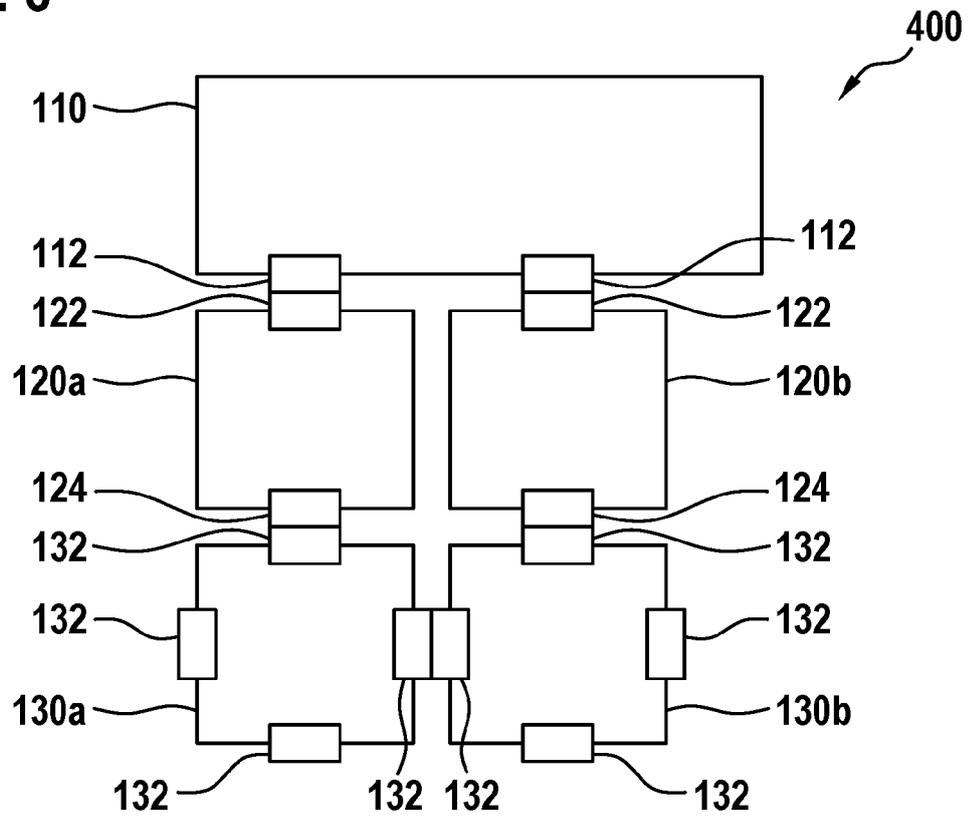
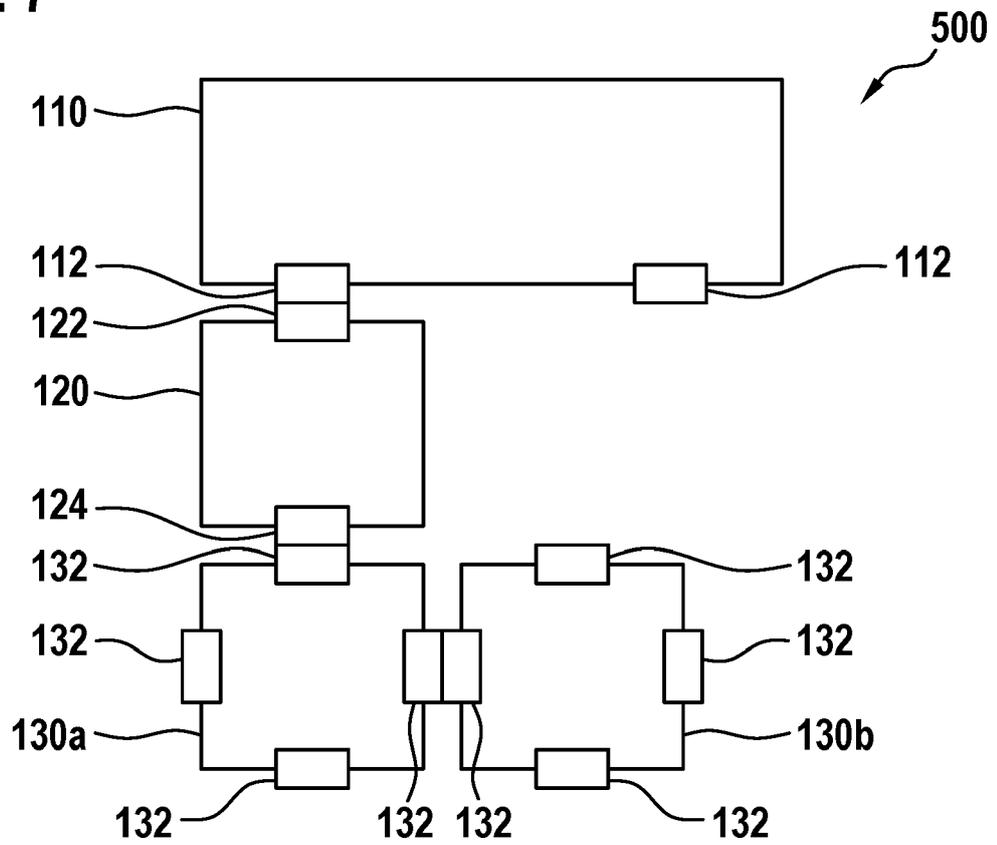


Fig. 7





PARTIAL EUROPEAN SEARCH REPORT

Application Number

under Rule 62a and/or 63 of the European Patent Convention.
This report shall be considered, for the purposes of subsequent proceedings, as the European search report

EP 23 19 1209

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	US 4 986 077 A (SAHO NORIHIDE [JP] ET AL) 22 January 1991 (1991-01-22) * abstract; figures 1,6 * * column 3, line 65 - column 4, line 14 * * column 6, line 22 - line 41 * -----	1-11, 14	INV. F25D19/00 F25D29/00 ADD. F25B9/10
X	US 2023/090979 A1 (MATTHEWS ANTHONY [GB] ET AL) 23 March 2023 (2023-03-23) * Abstract, figures 1-4 and paragraphs [0053]-[0073] * -----	1-8, 10, 14	
X	US 9 234 691 B2 (BLACK RANDALL [US]; MARTIEN DINESH [US] ET AL.) 12 January 2016 (2016-01-12) * Abstract, figures 1-3 and column 6, line 1 - column 7, line 20 * -----	1-8, 10, 14	
X	US 5 381 666 A (SAHO NORIHIDE [JP] ET AL) 17 January 1995 (1995-01-17) * Abstract, figures 1-4 and columns 6, 9 and 11 * -----	1-8, 10, 14	
X	EP 4 184 081 A1 (BLUEFORS OY [FI]) 24 May 2023 (2023-05-24) * the whole document * -----	1-11, 14	

TECHNICAL FIELDS SEARCHED (IPC)

F25D
F25B

INCOMPLETE SEARCH

The Search Division considers that the present application, or one or more of its claims, does/do not comply with the EPC so that only a partial search (R.62a, 63) has been carried out.

Claims searched completely :

Claims searched incompletely :

Claims not searched :

Reason for the limitation of the search:

see sheet C

EPO FORM 1503 03.82 (P04E07)

Place of search The Hague	Date of completion of the search 13 February 2024	Examiner Bejaoui, Amin
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CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
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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



**INCOMPLETE SEARCH
SHEET C**

Application Number

EP 23 19 1209

5

Claim(s) completely searchable:

1-11, 14

10

Claim(s) not searched:

12, 13, 15

Reason for the limitation of the search:

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The search has been restricted to the subject-matter indicated by the applicant in his letter of 07-02-2024 filed in reply to the invitation pursuant to Rule 62a(1) EPC.

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