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(56) Documents Cited:
US 5235818 A1 **US 4763483 A**
US 20080104968 A1 **US 20050229620 A1**

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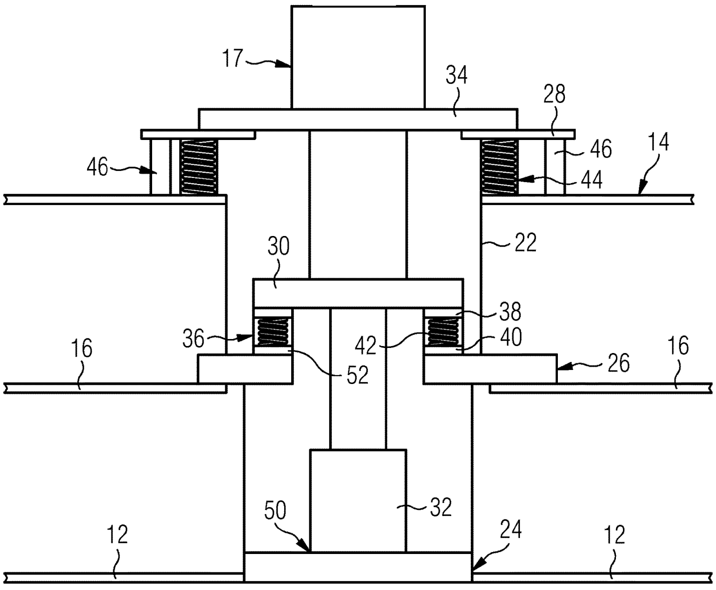
Other: **Online: WPI, EPODOC, TXTA**

(54) Title of the Invention: **Refrigerator de-coupling device**
Abstract Title: **A coupler for thermally coupling and decoupling a cryogenic refrigerator to and from cooled equipment**

(57) A coupler for thermally coupling and decoupling a cryogenic refrigerator 17 to and from cooled equipment 12 comprises a first and second intercept 24, 26 in thermal contact with the equipment to be cooled. A moveable flange 28 having a spring biasing means 44 is urged in a direction whereby each intercept is not in contact with the equipment to be cooled. At least one actuator 46 when active urges the flange with a force greater than the biasing means whereby each intercept contacts the equipment to be cooled. The refrigerator may be a two-stage refrigerator whereby each intercept comprises a first 30 and second 32 cooling stage mounted within an evacuated closed sock 22. The sock may be omitted (figs 4 – 6). The first stage may cool to a first temperature of 50K to 100K and second stage may cool to 4K. The biasing means may comprise a stainless steel bellows or a piston arrangement and seals the flange with a port of the outer vacuum container (OVC) 14. Resilient thermal link(s) 36 may provide a thermal contact between the first intercept and first cooling stage via upper 38 and lower 40 conductive plates with a spring 42 therebetween.

FIG 2



At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

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FIG 1

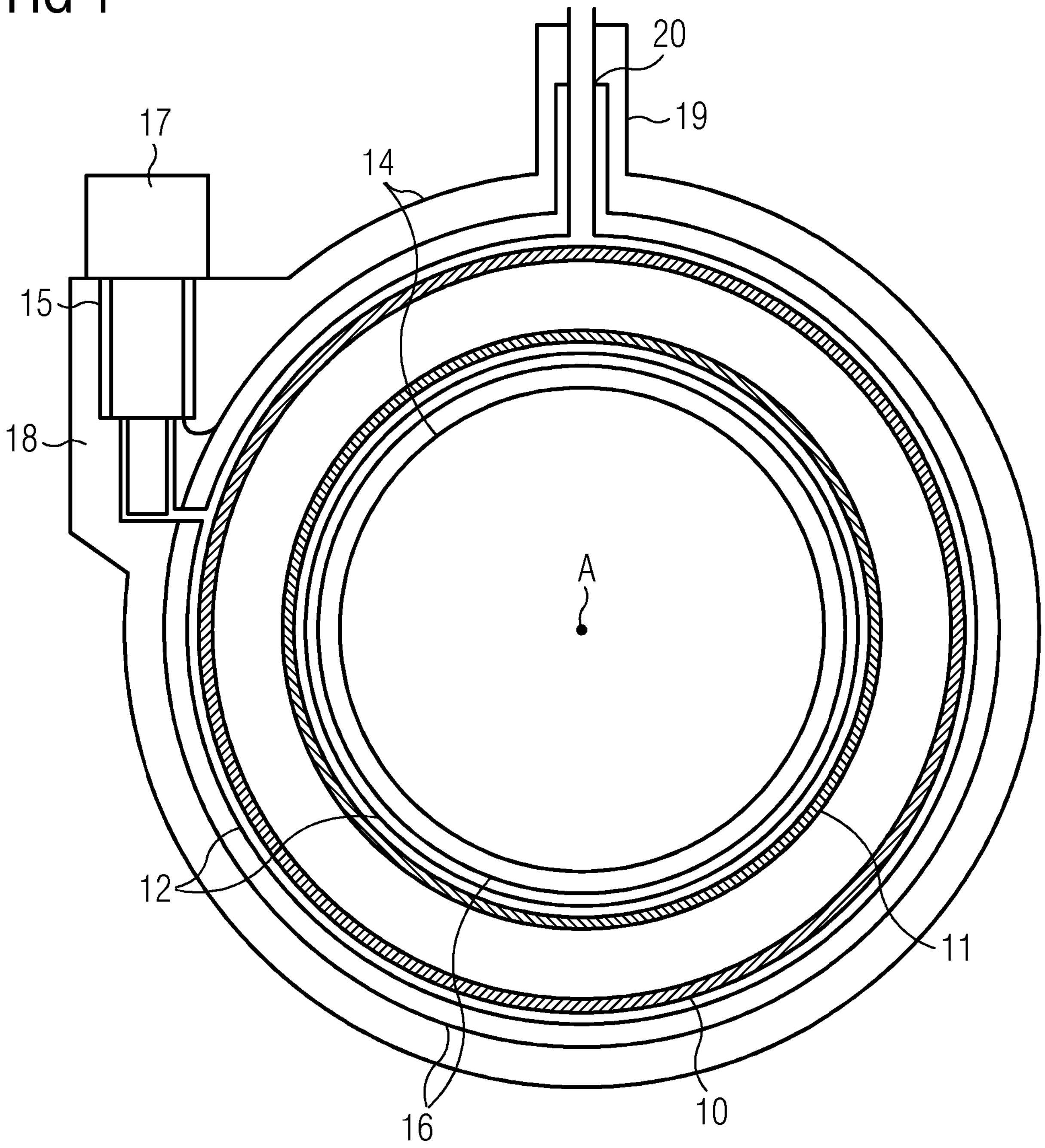

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FIG 2

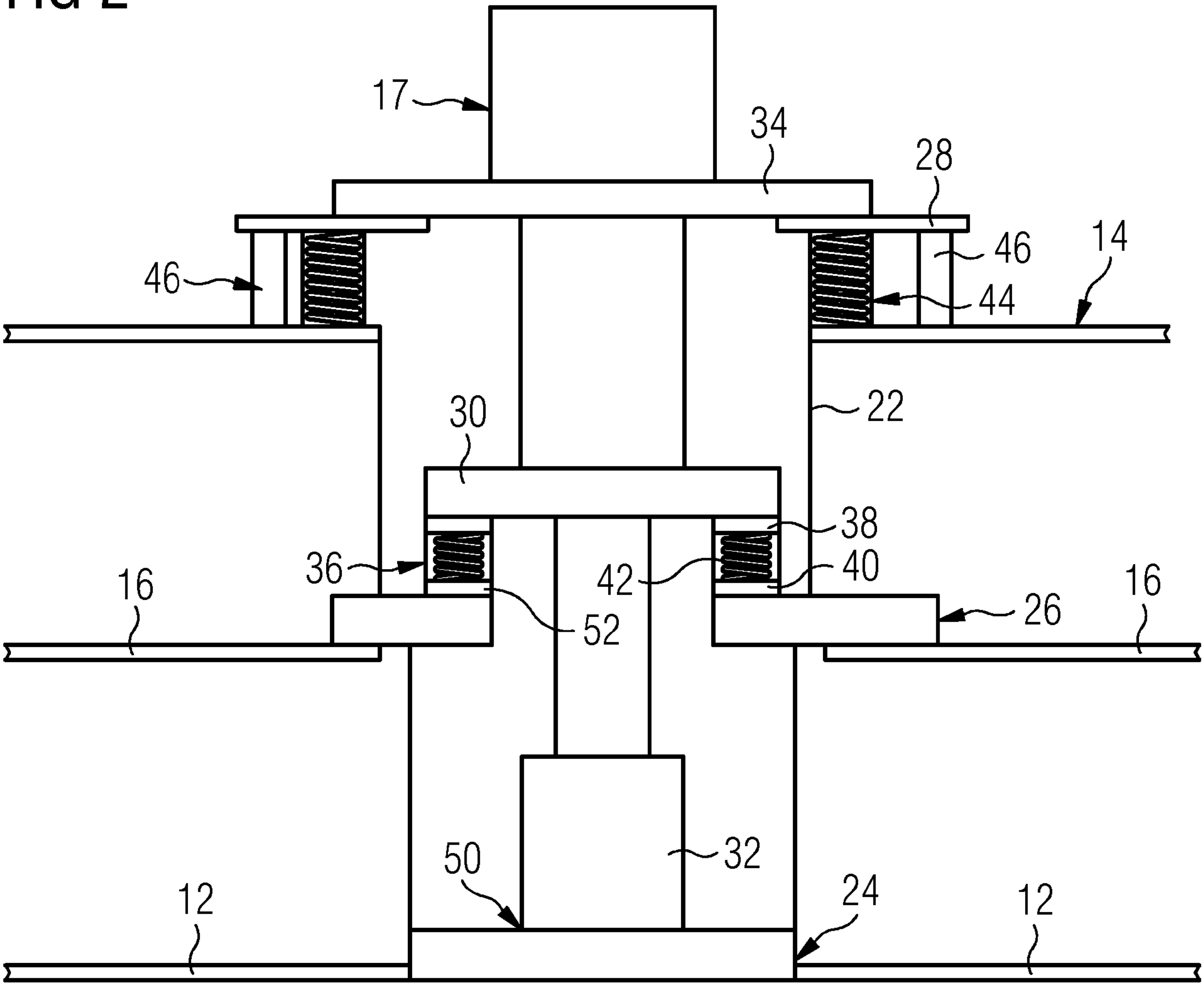

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FIG 3

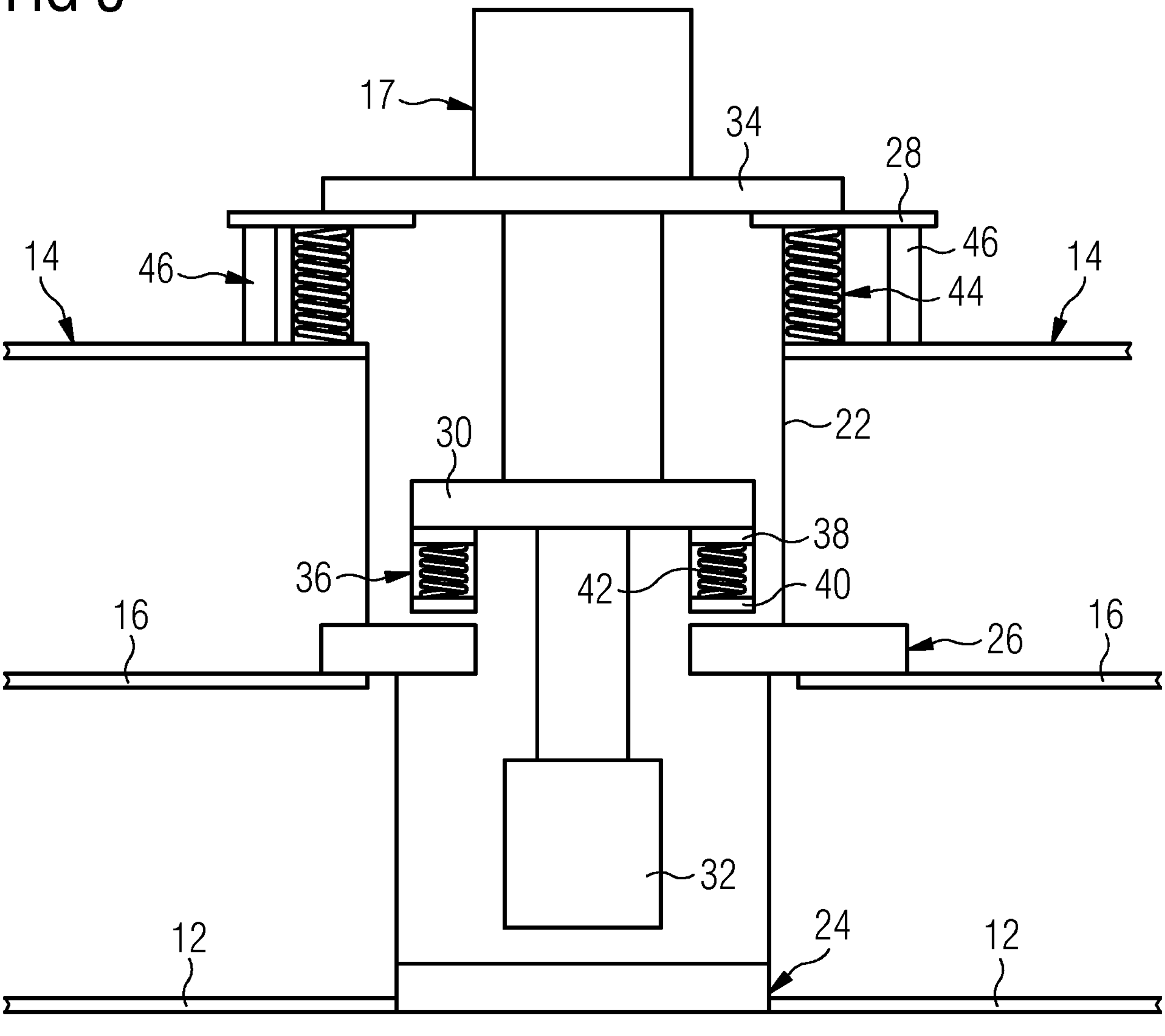

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FIG 4

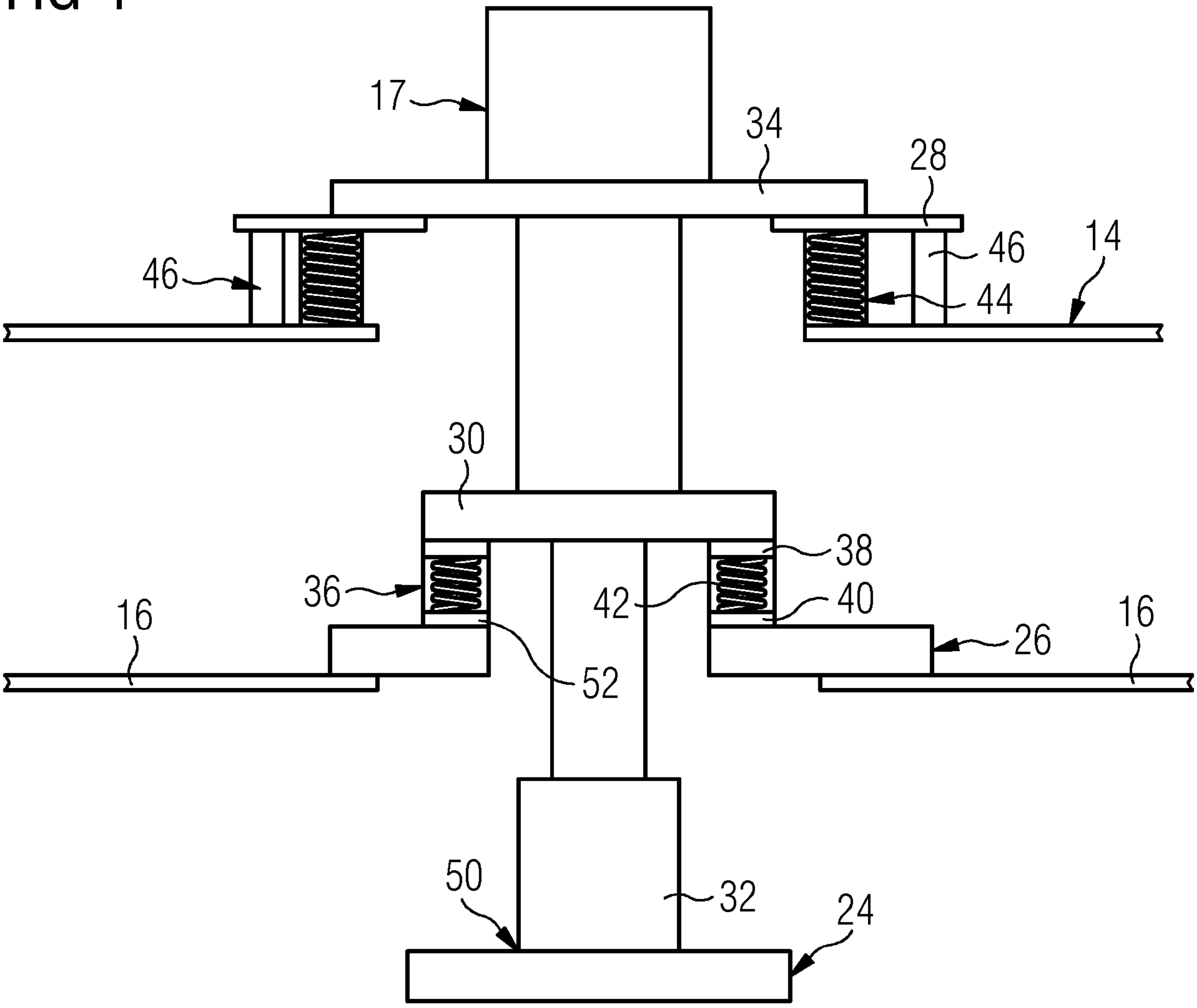

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FIG 5

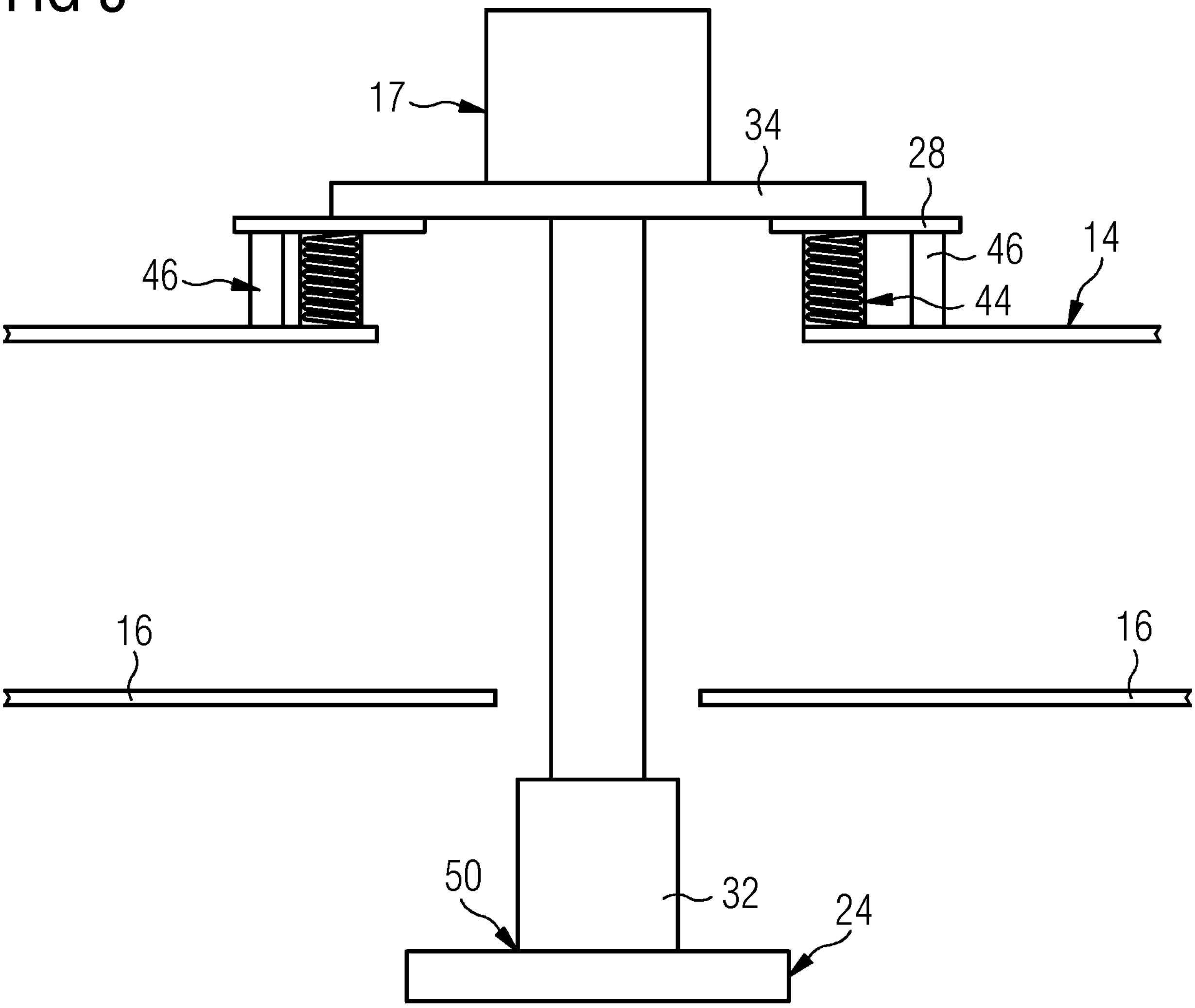
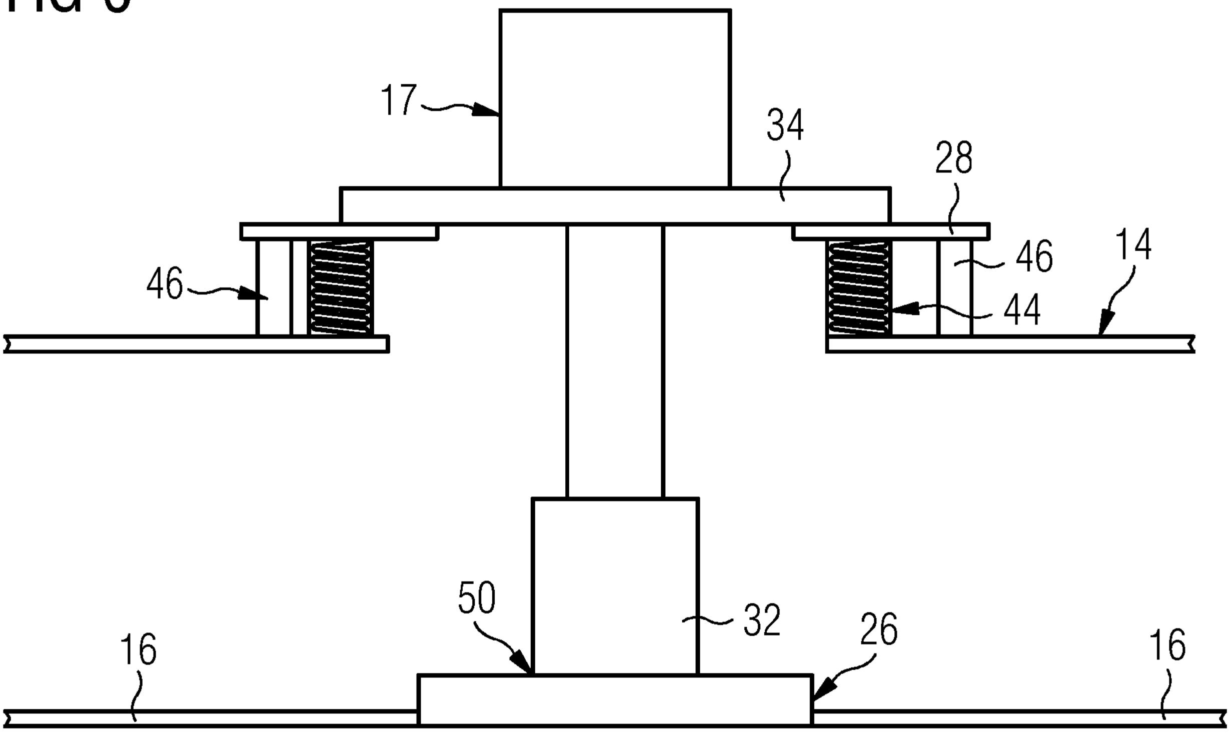


FIG 6



16 07 15

REFRIGERATOR DE-COUPLING DEVICE

The present invention relates to cryogenic cooling arrangements as applied to cryogen-cooled equipment. It may particularly be applied to cooling of superconducting magnets for MRI systems, but may also be applied to cryogenic cooling arrangements for other applications.

Conventionally, cryogenically cooled equipment is housed within a cryostat comprising an outer vacuum container (OVC) which provides thermal insulation.

Fig. 1 illustrates a cross-section through a conventional cylindrical superconducting magnet for an MRI system. Superconducting coils 11 are housed within a cryogen vessel 12, itself housed within OVC 14. A thermal radiation shield 16 is provided between the cryogen vessel 12 and the OVC 14 to shield the cryogen vessel 12 from radiant heat from the OVC 14. Turret 19 houses access neck 20 which allows liquid cryogen to be poured into the cryogen vessel 12, and also provides access to the interior of the cryogen vessel. A cryogenic refrigerator 17 is provided, mounted in a refrigerator sock 15 in a second turret 18. The interior of the refrigerator sock 15 is in communication with the interior of the cryogen vessel 12. In operation, a certain quantity of liquid cryogen is introduced into the cryogen vessel 12 and cools 11 the coils. In operation, heat is generated within the coils 11. That heat causes evaporation of some of the liquid cryogen, and the resulting cryogen gas makes its way into the refrigerator sock 15. Cryogenic refrigerator 17 cools a heat exchanger to below the boiling point of the cryogen, so the cryogen gas recondenses on the heat exchanger into liquid cryogen which runs back into cryogen vessel 12.

In other conventional arrangements, the superconducting coils 12 may not be inside the cryogen vessel, but a much smaller cryogen vessel may be provided instead and thermally linked to the superconducting coils by an appropriate means, such as a cryogen-filled tube, or a solid thermal bus.

During transport, or during power failure, or service operations, and at some other times, the cryogenic refrigerator 17 may be inoperative although the cooled equipment – the superconducting coils in this example – remains cold. In such situations, heat will leak into the cryostat and cause boiling of the liquid cryogen, which will be lost. In the case of a cooled superconducting magnet, the magnet may quench, leading to rapid loss of cryogen. In a worst-case scenario, the cooled equipment will heat up to ambient temperature, and will need to be cooled back to its cryogenic operating temperature before it can be brought into service. This will require significant time and energy to operate the refrigerator, and will also require a fresh supply of liquid cryogen, which may not be readily available.

The refrigerator 17 itself provides a significant path for heat influx when inoperative. It has been estimated that a current cryogenic refrigerator, when inoperative, provides a heat flux of 3W to 5W over a temperature difference of 300K to 4K. The present invention aims to reduce the thermal influx to cryogenically cooled equipment by an inoperative refrigerator.

The present invention accordingly provides equipment as set out in the appended claims.

The above, and further, objects, characteristics and advantages of the present invention will be more apparent from consideration of the following description of certain embodiments thereof, in conjunction with the accompanying drawings, wherein:
Fig. 1 illustrates a cross section of a superconducting magnet for an MRI system cooled by partial immersion in liquid cryogen;

Fig. 2 illustrates an embodiment of the present invention in a first state;

Fig. 3 illustrates the embodiment of Fig. 2 in a second state; and

Figs. 4-6 illustrate further embodiments of the present invention in the first state.

Fig. 2 illustrates an arrangement according to a feature of the present invention, and comprises a refrigerator 17 mounted in a closed sock 22. The closed sock extends from an OVC port provided in the OVC 14 to a second-stage intercept 24. The second stage intercept may be exposed to the interior of cryogen vessel 12, may be attached to a further heat exchanger which is exposed to the interior of cryogen vessel 12, or may be in thermal contact with equipment to be cooled by other arrangements, such as a solid thermal bus or a cryogen-filled tube. The closed sock 22 also comprises a first-stage intercept 26 which is in thermal contact with the thermal radiation shield 16. A moveable mounting flange 28 is a notable feature of the invention, and will be described in more detail below. Closed sock 22 is preferably evacuated.

Cryogenic refrigerator 17 is a two-stage refrigerator. It has a first cooling stage 30 which is cooled to a first cryogenic temperature, for example in the range of 50 K - 100 K, and a second cooling stage 32 which is cooled to a second cryogenic temperature, for example in the order of 4K. In use, and in the first state, illustrated in Fig. 1, the first cooling stage 30 is in thermal contact with the first-stage intercept 26, the second cooling stage 32 is in thermal contact with the second-stage intercept 24 and a mounting flange 34 of the refrigerator 17 is mounted onto the moveable mounting flange 28.

Mechanical and thermal contact between second cooling stage 32 and the second-stage intercept 24 may either be a direct “hard” contact between those two features, each typically of copper, aluminium or other suitable thermally conducting material, or an interface layer may be provided between them, for example a layer of indium, or a thermally conductive grease such as that known as N-grease.

Thermal contact between first cooling stage 30 and first-stage intercept 26 is provided by a resilient thermal link 36. This may comprise a sprung thermal bus, in which upper 38 and lower 40 thermally conductive plates, for example of copper, aluminium or other suitable thermally conductive material, are linked by a resilient member 42, which may be a plurality of coil springs, as illustrated, a number of leaf springs or an equivalent which will be apparent to those skilled in the art. Good thermal conductivity should be provided between upper 38 and lower 40 thermally conductive plates. This may be through the material of the springs or other resilient member 42, or a separate thermal path, for example a copper or aluminium braid or laminate bolted, soldered, brazed or welded to the upper 38 and lower 40 thermally conductive plates.

Moveable mounting flange 28 is mechanically sealed to the surface of the OVC 14 by a seal 44. Seal 44 may be a bellows, for example of stainless steel, soldered brazed or welded to the OVC 14 and to the moveable mounting flange 28. Alternatively, the seal 44 may comprise a piston arrangement with an o-ring or similar polymer seal between relatively moving parts. Of particular relevance to the present invention are actuators 46. These bridge the seal 44 and are mechanically linked to the OVC 14 and the moveable mounting flange 34. Actuators 46 may be piston arrangements, hydraulically or pneumatically driven. They may be electrically driven. In each case, the actuators are preferably energised in response to the same power supply used to operate the refrigerator 17. The actuators 44 are preferably located outside of the evacuated volume defined by the closed sock 22, seal 44 and refrigerator 17.

In the first state, illustrated in Fig. 1, actuators are in their active, contracted, state. The actuators urge the moveable mounting flange 28 towards the surface of the OVC 14 at the OVC port. Seal 44 is compressed. Second cooling stage 32 of refrigerator 17 is pressed into thermal contact with second-stage intercept 24. Resilient thermal link 36 is compressed between first cooling stage 30 and first-stage intercept 26. Effective thermal conduction paths are provided between second cooling stage 32 and second-stage intercept 24, and between first cooling stage 30 and first-stage intercept 26. It this state, refrigerator 17 may operate to effectively cool the thermal radiation shield 16 and the contents of the cryogen vessel 12, or other cryogenically-cooled equipment.

When the actuators 46 are de-activated, for example by removing their power supply, the moveable mounting flange rises. This may be due to a spring bias inherent in bellows used as seal 44, or may be due to other springs provided for the purpose. Without breaking the vacuum in the closed sock 22, the refrigerator 17 is lifted by the moveable mounting flange, breaking the thermal contact between second cooling stage 32 and second-stage intercept 24, and between first cooling stage 30 and first-stage intercept 26. As the refrigerator 17 is inoperative, its temperature will rise towards ambient temperature. However, since the refrigerator 17 is no longer in thermal contact with the first-stage intercept 26 or the second-stage intercept 24, thermal influx due to the refrigerator will be much reduced as compared to conventional arrangements. Some radiant heat will be supplied by the refrigerator to the first-stage intercept 26 and the second-stage intercept 24, but this will be much less than the heat transfer that would occur if the refrigerator were still in thermal contact with the first-stage intercept 26 and the second-stage intercept 24.

When the actuators 46 are energised again, which may be on restoration of power to the refrigerator, the actuators 46 contract, lowering the moveable mounting flange 28 towards the OVC 14 at the OVC port. Seal 44 is compressed, which may involve compression of a bellows, or compression of springs which bias a piston arrangement to an extended position. Second cooling stage 32 of refrigerator 17 is pressed into thermal contact with second-stage intercept 24. Resilient thermal link 36 is compressed between first cooling stage 30 and first-stage intercept 26. The refrigerator and its mounting arrangement return to their first state, illustrated in Fig. 1.

Preferably, the actuators are powered by a same power as is used to power the cryogenic refrigerator 17. In such an arrangement, when power to the refrigerator is interrupted for any reason, power will also be removed from the actuators. In alternative embodiments, though, the actuators 46 may be independently controlled, so that the thermal linking of the refrigerator 17 to the first- and second-stage intercepts 24, 26 is independent of the operating state of the refrigerator.

In other embodiments, actuators may be placed so as to bear down upon the moveable mounting flange 28 when energised, and to allow the moveable mounting flange 28 to rise under spring bias from bellows seal 44 or other springs when the actuators are not energised. Resilient thermal link 36 may be attached to first cooling stage 30 or first-stage intercept 26, and be pressed into contact with the other when the actuators are energised.

In operation, contact will be broken and re-made between second cooling stage 32 of refrigerator 17 and second-stage intercept 24, and resilient thermal link 36 and first cooling stage 30 or first-stage intercept 26. The contacts may be broken and remade. The contacts may include an indium interface or thermal grease interface or a dry interface between polished surfaces or any other suitable thermal connection.

In use, in the first state of Fig. 1, thermal and mechanical contact is maintained between the refrigerator and the cooled equipment, with a consistent force. The force is generated by applying force to an ambient-temperature end of the refrigerator, for example using at least one pneumatic or hydraulic cylinder as actuator 44. The force is transferred through the refrigerator to the cold interfaces 50, 52. Typically, the refrigerator 17 has two stages and is in thermal and mechanical contact with cooled equipment at a corresponding two interfaces 50, 52. One interface 52 may have a spring plate arrangement 42 to accommodate build tolerances and changes in dimensions due to thermal expansion and contraction.

Spring arrangements, either a bellows seal 4 or a spring acting between the moveable mounting flange 28 and OVC 14 work against the actuators 46 and are sufficient to overcome atmospheric pressure acting on the refrigerator and moveable mounting flange 28. When actuators 46 are energised, the refrigerator is in thermal contact with the cooled equipment. When the actuators are not energised, the spring arrangements elevate the refrigerator out of contact with the cooled equipment.

In other embodiments, the orientation may be reversed, such that the refrigerator is elevated into contact with the cooled equipment when the actuators are energised, and the refrigerator descends out of contact with the cooled equipment when the actuators are de-energised.

In other embodiments, the actuators 46 may be arranged to maintain the refrigerator 17 in contact with the cooled equipment for a certain time after removal of a power source. For example, in case of power failure to the refrigerator, the actuators 46 may maintain the refrigerator in position for a few minutes or up to a few hours depending on system requirements. The certain time may lie between 3 minutes and

10 hours. That way, short power failures may be tolerated without removing the refrigerator from thermal contact with the cooled equipment, yet such thermal contact will be effectively broken in case of longer power failures. Repeated connections and disconnections of the thermal contact between the refrigerator and the cooled equipment may degrade the interface, so it may be preferred to avoid thermal disconnection of the refrigerator 17 unless a long-term power failure occurs.

The invention described enables a consistent known force be applied to the thermal connections of the refrigerator and the system being cooled whilst they are in contact. This known force will depend on the spring force at the seal 44, atmospheric pressure acting on refrigerator 17 and moveable mounting flange 28, and force provided by actuators 46. The invention allows for a repeatable joint to be achieved to ensure adequate thermal contact to all thermal stages when the refrigerator is in operation, yet thermally disconnects the refrigerator from the cooled equipment when power is removed from the actuators 46.

The mechanical tolerance provided by the seal 44 and resilient member 42 allows assembly of the structure of the invention even in the presence of dimensional variation of parts. The structure of the present invention thereby aids assembly of components to ensure parts are coupled consistently and squarely, reducing the risk of damage to components during initial build or during service. The assembly of the refrigerator 17 with the actuators 46 can be arranged so that the refrigerator is aligned squarely with the intercepts 24, 26 and can be engaged and disengaged with repeated accuracy.

The invention enables automatic breaking of the thermal connections between the thermal stages of the refrigerator and the intercepts of the closed sock 22. This is a significant advantage as the lack of manual intervention will avoid a considerable and possibly critical delay, as compared to a solution in which manual intervention is required to thermally disconnect the refrigerator.

Preferably, volume defined by the closed sock 22, the refrigerator 17, seal 44 and moveable mounting flange 34 remains under vacuum even when the refrigerator 17 is thermally disconnected from the cooled equipment. This is advantageous as the heat load to the cooled equipment is less than if that volume contained a gas. The system may rapidly return to an operating condition when refrigeration is restored, as there is no need to evacuate gas from the closed sock 22, and no risk that such gas might solidify into a frost which would reduce the effectiveness of thermal contact between refrigerator and cooled equipment.

In embodiments where the actuators 46 are pneumatically operated, a pressure supplied to operate the actuators may come from an independent supply or may possibly be taken from a compressor which supplies compressed gas to the refrigerator 17.

In other embodiments, a separate pressure supply may be provided for hydraulically or pneumatically operating the actuators 46. Preferably, any moving or magnetic components of the pressure supply may be remote from the magnet system and connected by relatively small bore hoses, since a relatively small volume of pressurised gas or liquid is required to operate the actuators.

If a hydraulic cylinder is preferred then it may be possible to use water as the operating medium depending on cylinder selection. This may suit the installation as water may already be required for cooling other components.

Fig. 4 schematically represents another embodiment of the invention in its first state, corresponding to the first state illustrated in Fig. 2.

In this embodiment, no cryogen vessel is provided. Intercept 24 is provided and represents the refrigerator contact surface for a conduction-cooled arrangement. In this arrangement, the cooled equipment is not cooled by partial immersion in a bath of liquid cryogen, but is cooled by conduction through a solid conduction path thermally linked to the intercept 24. In embodiments such as shown in Fig. 4, the refrigerator 17 shares the same vacuum space as the cooled equipment. Sock 22 (Fig. 2) is not provided in the embodiment of Fig. 4. It may be preferred to extend the thermal radiation shield 16 to more closely match the size of the refrigerator, as no space is taken by the sock. This may reduce thermal radiation to the cooled equipment which is an important consideration particularly when the refrigerator is not operating.

Fig. 5 shows another embodiment of the invention, where the refrigerator 17 is a single-stage refrigerator. In this embodiment, no sock is provided, as in Fig. 4, and thermal radiation shield 16 is brought closer to the refrigerator. Similar amendments could be made to the embodiment of Fig. 2, where a sock 22 may be provided, but would not be directly cooled by a single-stage refrigerator.

Fig. 6 shows a yet further embodiment, a similar arrangement to that of Fig. 5, provided specifically to cool the thermal radiation shield by a single-stage refrigerator. In alternative embodiments, a sock may or may not be provided.

CLAIMS:

1. A refrigerator de-coupling device for thermally coupling and decoupling a cryogenic refrigerator (17) to and from cooled equipment (12),
comprising:
- a closed sock (22);
- a thermal intercept (24, 26) exposed to the interior of the closed sock (22) and in thermal contact with equipment to be cooled; and
- a moveable mounting flange (28) mounted and sealed (44) at an otherwise-open end of the closed sock (22),

characterised in that the moveable mounting flange (28) is provided with a spring bias means urging it away from the OVC port, and is further provided with at least one actuator (46) which, when active, urges the moveable mounting flange (28) towards the closed sock (22) with a force greater than a force provided by the spring bias means.

2. A refrigerator de-coupling device according to claim 1, comprising first (26) and second (24) thermal intercepts exposed to the interior of the closed sock.

3. A cryostat in combination with a refrigerator de-coupling device according to claim 2, the cryostat comprising cooled equipment (12) within an outer vacuum container (OVC) (14) and a thermal radiation shield (16) located between the OVC and the cooled equipment (12), the first intercept (26) being in thermal contact with the thermal radiation shield and the second intercept (24) being in thermal contact with the cooled equipment, the closed sock (22) and the moveable mounting flange (28) being mounted on the OVC.

4. A cryostat in combination with a refrigerator de-coupling device for thermally coupling and decoupling a cryogenic refrigerator (17) to and from cooled equipment (12),

- the cryostat comprising cooled equipment (12) within an outer vacuum container (OVC) (14) and a thermal radiation shield (16) located between the OVC and the cooled equipment (12), the OVC comprising an OVC port, the refrigerator de-coupling device being mounted at the OVC port;
- the refrigerator de-coupling device comprising:
- a thermal intercept (24) in thermal contact with equipment to be cooled; and
- a moveable mounting flange (28) mounted and sealed (44) at an otherwise-open OVC port,

characterised in that the moveable mounting flange (28) is provided with a spring bias means urging it away from the OVC port, and is further provided with at least one actuator (46) which, when active, urges the moveable mounting flange (28) towards the OVC port with a force greater than a force provided by the spring bias means.

5. A cryostat in combination with a refrigerator de-coupling device, according to claim 3, wherein a first intercept (26) is provided in thermal contact with the thermal radiation shield and a second intercept (24) is provided in thermal contact with the equipment to be cooled.

6. A cryogenic refrigerator (17), in combination with a refrigerator de-coupling device according to claim 1, the cryogenic refrigerator comprising a mounting flange (34) which is mounted to the moveable mounting flange (28), the cryogenic refrigerator also being provided with a cooling stage (32) which is driven in to, and out of, thermal contact with the thermal intercept (24) by operation of the actuator(s).

7. A two-stage cryogenic refrigerator (17), in combination with a refrigerator de-coupling device according to claim 2, the cryogenic refrigerator comprising a mounting flange (34) which is mounted to the moveable mounting flange (28), the cryogenic refrigerator also being provided with a first cooling stage (30) which is driven in to, and out of, thermal contact with a first-stage thermal intercept (26) and a second cooling stage (32) which is driven in to, and out of, contact with a second-stage thermal intercept (24) by operation of the actuator(s).

8. A two-stage cryogenic refrigerator (17) in combination with a refrigerator de-coupling device, according to claim 7, wherein thermal contact between first cooling stage (30) and first-stage thermal intercept (26) is provided by a resilient thermal link (36).

9. A two-stage cryogenic refrigerator (17) in combination with a refrigerator de-coupling device, according to claim 8, wherein the resilient thermal link (36) comprises upper (38) and lower (40) thermally conductive plates linked by a resilient member (42).

10. A cryogenic refrigerator (17) in combination with a refrigerator de-coupling device, according to any of claims 6-9, wherein the actuator(s) are activated by a power source which also provides power to the cryogenic refrigerator.

11. A cryogenic refrigerator (17) in combination with a refrigerator de-coupling device, according to any of claims 6-10, wherein a thermally-conductive grease is provided as an interface layer between a first cooling stage (30) and a first-stage thermal intercept (26); and/or between a second cooling stage (32) and second-stage thermal intercept (24).

12. A refrigerator de-coupling device according to claim 1, wherein the moveable mounting flange (28) is mechanically sealed to the surface of the OVC (14) by a bellows.

13. A refrigerator de-coupling device according to claim 1, wherein the moveable mounting flange (28) is mechanically sealed to the surface of the OVC (14) by a piston arrangement with a polymer seal between relatively moving parts.

14. A refrigerator de-coupling device according to claim 1, wherein the actuators (46) are piston arrangements, hydraulically or pneumatically driven.

15. A cryogenic refrigerator (17) in combination with a refrigerator de-coupling device, according to any of claims 6-11, wherein the actuator(s) (46) is/are arranged to remain in an active state after removal of a power source from the refrigerator (17) for a certain time after removal of a power source.

16. A cryogenic refrigerator (17) in combination with a refrigerator de-coupling device, according to claim 15, wherein the certain time lies between 3 minutes and 10 hours.

Intellectual
Property
Office

Application No:	GB1508548.3	**Examiner:**	Stephen Hart
Claims searched:	1 - 3 & 5 - 16	**Date of search:**	26 October 2015

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1 - 3 & 5 - 16	US 2008/104968 A1 (MASSACHUSETTS INST TECHNOLOGY) see whole document, especially figs 1A & 1B, paras. [0021], [0024] - [0031], [0039] & [0040].
A		US 5235818 A1 (MITSUBISHI ELECTRIC CORP) see whole document, especially figs 2 & 2A, col. 1 lines 52 - 57, col. 5 lines 17 - 37, col. 5 line 54 - col. 7 line 18.
A		US 2005/229620 A1 (OXFORD INSTR SUPERCONDUCTIVITY) see fig 2 and paras. [0033] & [0034].
A		US 4763483 A (HELIX TECH CORP) see lone figure and col. 4 lines 9 - 14.

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{X} :

Worldwide search of patent documents classified in the following areas of the IPC

F17C; F25B; F25D; G01R; H01F

The following online and other databases have been used in the preparation of this search report

Online: WPI, EPODOC, TXTA

International Classification:

Subclass	Subgroup	Valid From
F25B	0009/00	01/01/2006
F17C	0003/08	01/01/2006
F25D	0019/00	01/01/2006
H01F	0006/04	01/01/2006