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(72) Inventors:
• **Chevtchenko, Oleg Alexander**
2901 HG Capelle aan den IJssel (NL)
• **Bakker, Ralph**
7335 DS Apeldoorn (NL)

(71) Applicant: **HTS-powercables.nl B.V.**
7335 DS Apeldoorn (NL)

(74) Representative: **'t Jong, Bastiaan Jacob**
Inaday Patent B.V.
Hengelosestraat 141
7521 AA Enschede (NL)

(54) **Device for cooling a high temperature superconductor**

(57) The invention relates to a device for cooling a high temperature superconductor, which device comprises a cryocooler using a first heat exchanging medium to cool a second heat exchanging medium to cryogenic temperatures, a heat exchanger having a first channel and a second channel in heat exchanging contact with each other, wherein the first heat exchanging medium flows through the first channel, wherein a third heat ex-

changing medium flows through the second channel and wherein the temperature of the third heat exchanging medium is lower than the temperature of the first heat exchanging medium.

The invention further relates to a cryostat of said superconductor using magnetic suspension for spacing reflective layers of multi-layered thermal insulation.

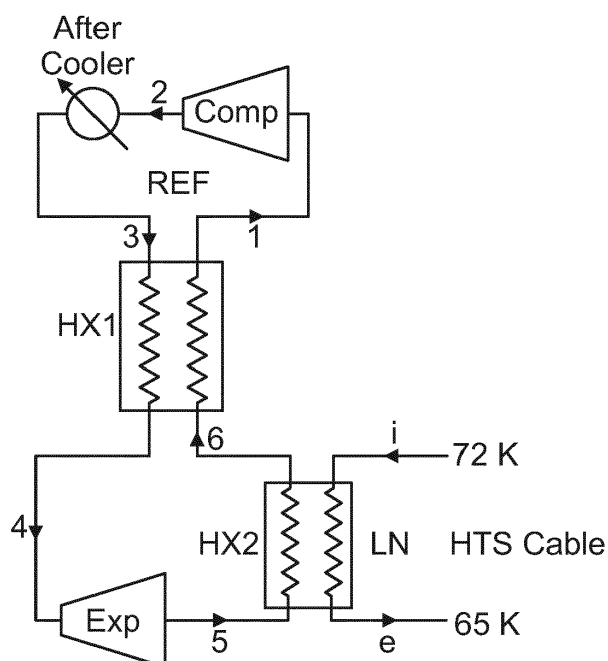


Fig. 1

Description

[0001] The invention relates to a device for cooling a high temperature superconductor, which device comprises a cryocooler using a first heat exchanging medium to cool a second heat exchanging medium to cryogenic temperatures.

[0002] Such a device can be used for cooling of any high temperature superconductor (HTS) power device (such as cable, generator, motor, fault current limiter, or magnet, such as maglev suspension, including that for evacuated tube transport).

[0003] Cryogenic temperatures are typically considered temperatures below -150°C .

[0004] The cooling system of HTS power devices is a known obstacle on the way to their broader use. The current state of the art is such that due to relatively high cooling system cost (e.g., cryostat and refrigerator) a HTS cable (e.g., for 150 kV and below, even when to assume a zero cost for electrically insulated superconductor core) is more expensive than a conventional cross-linked polyethylene (XLPE) cable for the same power capacity. This prevents their use in electric power networks and for this reason only niche application of HTS power cables exist.

[0005] Cryostats and cooling devices for liquid nitrogen are known for many years and it is rather difficult to improve their efficiency and to reduce their cost substantially within a traditional approach.

[0006] One straightforward option to provide cooling of HTS cable cost-effectively is to buy cheaper LN₂ (that is produced by e.g. an air separation plant using waste cold of LNG at the import LNG terminal). However, building such a (relatively large) plant requires a substantial investment that can only be justified when there is for example an adequate demand for cooling (e.g., of many HTS power cables). Such demand is indeed expected in the future. At present, this demand is hindered by relatively high costs of cryostats and cooling.

[0007] It is an object of the invention to reduce the above mentioned disadvantages.

[0008] This object is achieved with a device according to the preamble, which is characterized by a heat exchanger having a first channel and a second channel in heat exchanging contact with the first channel, wherein the first heat exchanging medium flows through the first channel, wherein a third heat exchanging medium flows through the second channel and wherein the temperature of the third heat exchanging medium is lower than the temperature of the first heat exchanging medium.

[0009] Preferable, the third heat exchanging medium is liquid natural gas (LNG).

[0010] The invention allows using the cold of LNG (otherwise often wasted in regasification process) for efficient cooling of a HTS power cable or other HTS device. As a result, so-called cooling penalty factor (the number of Watts needed to remove 1 Watt at lower temperature) can be reduced e.g., from 14 to 8 as will be shown in the

example below. At the same time, LNG is re-gasified and returned to the natural gas distribution network, which creates additional income.

[0011] As a result of the invention, the initial investment costs into the cooling system of a HTS device, such as a cable, reduces, remains the same or slightly increase, but maintenance costs substantially decrease leading to faster return of the investment and to lower lifetime costs. Furthermore, regasification device costs less, is simpler, more compact and efficient; refrigerator costs less, is simpler, more compact and efficient.

[0012] In a preferred embodiment of the device according to the invention the third heat exchanging medium changes phase from liquid to gas when flowing through the second channel and wherein the gaseous third heat exchanging medium is compressed to be fed to a gas distribution system.

[0013] When LNG is used in the device according to the invention, the LNG will change phase in the heat exchanger to gas phase. Although the natural gas can be flared, it could also be compressed and fed to a natural gas distribution system, such that households or factories can use it.

[0014] A further preferred embodiment of the device further comprises a first storage vessel for storing the second heat exchanging medium at cryogenic temperature. Typically, the production of the cryocooler is not in synchronization with the demand for the second medium at cryogenic temperature. Therefore, the first storage vessel provides a buffer to take the differences between supply and demand of the second medium at cryogenic temperature.

[0015] Yet another embodiment of the device according to the invention further comprises a second storage vessel for storing the third heat exchanging medium and wherein the first storage vessel is arranged inside of the second storage vessel.

[0016] By arranging the first storage vessel inside of the second storage vessel, the heat exchange of the first vessel is reduced, such that the second medium is kept better at the low cryogenic temperature.

[0017] In a preferred embodiment the cryocooler is a Brayton cryocooler.

[0018] Further preferred is when the first channel of the heat exchanger is arranged directly downstream of the compressor of the Brayton cryocooler.

[0019] Still a further preferred embodiment of the device according to the invention further comprises a high temperature superconductor device with an inlet and outlet for cooling medium, wherein the second heat exchanging medium is fed to the inlet of the high temperature superconductor device.

[0020] The invention also relates to a cryostat of a high temperature superconductor device for use with the device according to the invention, comprising two concentrically arranged stainless steel tubes, a multi-layered thermal insulation blanket arranged between the two concentrically arranged stainless steel tubes and a plurality

of magnetic suspensions for spacing of the multi-layered thermal insulation blanket and suspending the inner stainless steel tube inside the outer stainless steel tube and for spacing inner reflective layers of μ LTl.

[0021] Preferably, the multi-layered thermal insulation blanket comprises an inner, outer and at least one reflective layer spaced from each by repulsive force of arrays, strips, dots, islands or layers of permanent magnets

[0022] In a further embodiment of the cryostat according to the invention, the permanent magnets in the preferred direction of the heat flow are aligned with low thermal conductivity pins attached to the inner layer of the blanket

[0023] In yet another embodiment of the cryostat according to the invention, permanent magnets in the preferred direction of the heat flow are aligned with each other using tension of the layers.

[0024] By using magnetic suspensions no physical contact is present to keep the inner tube spaced from the outer tube. This contributes to a better insulation.

Example

[0025] For example, a state of the art three phase AC 150 kV, 2.5 kA, 6 km long HTS power cable has the following characteristics: cold dielectric design, three phases in one cryostat, total losses in kW/km: 1 (at no load) and 1.5 (full load). These include: a cryostat 0.5; three electrically insulated HTS cores (0.3 and 0.6 at zero and full currents) a shield (0.2 and 0.3 at zero and full currents); current leads (0.01 and 0.1 at zero and full currents), etc. With some redundancy such cable needs 10 kW cooling capacity available 365 days/year. Such systems are commercially available, cost around 7 M€ (cryostat: 4; refrigerator: 3; note that lifetime of a refrigerator is 20 years, therefore 3x costs of refrigerator are included in order to provide a 40 years long lifetime with required redundancy) and consume electricity for about 90 k€/year.

[0026] To compare, a 150 kV 2.5 kA, 6 km long connection made of conventional XLPE cables (two flat buried cables per phase, each cable has 2500 mm² copper conductor) has an initial investment costs of 7 M€ and losses of 532 kW, which costs 275 k€/year, therefore the 40 year long lifetime costs are: 10 M€ (discounted to today's prices at 6% rate). When conventional XLPE cables are replaced with HTS cables in such connection, the savings on the cable losses amount: 275-90 = 185 k€/year. Therefore, on itself, for the considered HTS power cable system with a traditional cooling system, the expected lifetime costs are: 8 M€ (with 2 M€ saved on the losses). When the present invention is used instead, no economic losses exists, instead a total income is: 1074 k€/year (275 + 799) and a total initial investment is 8 M€: 7 for the cooling system, the costs can be even lower, due to the more compact refrigerator as explained below) and 1 for the regasification and optional storage system). The 10 year lifetime costs in the proposed combined cool-

ing and regasification system are: 0 that is the initial investment costs in the system are fully recovered after 10 years of operation. The 40 year long lifetime costs are: -8 M€ or better, in other words during the lifetime such system pays back at least two times the initial investment in it (all lifetime costs are discounted at 6% to today's price). This feature makes it economically attractive to scale up application of HTS power devices.

[0027] These and other features are further explained in conjunction with the accompanying drawings.

Figure 1 shows a diagram of Turbo-Brayton cryocooler according to the prior art.

Figure 2 shows the T-S diagram of the prior art Brayton cycle for the first heat exchanging medium

Figure 3 shows schematically an embodiment of the device according to the invention.

Figure 4 shows schematically a storage tank for LNG for the device of figure 3

Figure 5 shows schematically the compression of gaseous natural gas to be fed to a gas distribution network.

Figure 6 shows the T-S diagram of the device according to the invention with a Brayton cycle for the first heat exchanging medium

Figures 7 and 8 shows schematically an embodiment of a multilayer thermal vacuum insulation with magnetic suspension inside a cryostat of a high temperature superconductor device according to the invention.

[0028] The prior art Turbo-Brayton cryocooler is explained with regard to figure 1. The cryocooler has for example an electrical input power of 141 kW and cooling capacity of 10 kW at 65-72 K, therefore cooling penalty is 14.1.

[0029] Figure 2 shows the T-S diagram of the prior art Brayton cycle of figure 1 using the properties listed in Table 1.

[0030] In the prior art refrigeration cycle (figs. 1, 2; table 1) electric input power is 141 kW, which at the electricity price of 60 €/MWh is 74 k€/yr, plus there are some costs associated with the water for after-cooler (neglected here).

[0031] Alternatively, to produce the same cooling power, 30 ton/wk of liquid nitrogen (LN2) can be purchased (for 110 k€/yr) using e.g., similar cooling cycle as e.g., in the Ampacity HTS cable project. There the cooling system uses a regular supply of LN2 (and release of N2 gas to the atmosphere, which will become a problem for wider use, especially in densely populated areas) for its operation. In this 1 km long HTS cable project cooling agent is produced elsewhere and supplied as a service. According to Nexans, the cooling system is designed for 4 kW capacity at 67 K, including terminations (6 current leads, overall 0.7 kW at 2.3 kA), they could additionally be cooled with LN2 vapor produced in the precooling unit.

[0032] An embodiment of the device according to the

invention is shown schematically in figures 3.

[0033] For the refrigeration and liquefaction and for cooling of HTS device any known cycles and any appropriate agents can be used (e.g., N₂, He, Ne, Ar, O₂, etc., or any appropriate mixture of these in gas, liquid, supercritical and/or solid state). For the example shown in figure 3 we assume that the HTS device is a cable that is cooled with compressed and sub-cooled N₂, agent used for refrigeration is He (first heat exchanging medium), for liquefaction is nitrogen N₂ (second heat exchanging medium) and for regasification is methane (representing liquefied natural gas, third heat exchanging medium). For regasification liquefied natural gas is commonly used, but any other appropriate mixture of hydro-carbonates is included in the proposed invention. Furthermore, any other appropriate combination of cooling agents, cooling cycles can be used by a person versed in the art.

[0034] Considering an open loop LNG re-gasification process and devices, then every week at least 77 ton of LNG arrives e.g., by ship or track and is stored in a tank, see figure 4.

[0035] From the storage tank LNG is supplied to the heat exchanger HX3 at e.g., atmospheric pressure of 1 bar, where it evaporates (process 9-10) and cools the refrigeration agent. Natural gas vapor after HX3 (point 10) is compressed to e.g., 40 bar (point 11, see fig. 3, right and Table 3) and returned to e.g., natural gas distribution network.

[0036] With the example shown in figures 3, 4 and 5 and using the data of tables 2 and 3, a pressure and temperature of LNG in the after-cooler HX3 of 1 bar and 111.5 K (point 9), however any other combination in the proposed invention is possible, e.g., 0.1 bar and 92 K.

[0037] Figure 4 schematically shows the LNG storage tank, heat exchanger HX3, LN₂ storage tank placed inside the LNG (in order to reduce heating or loss of LN₂ during storage time), additional precooling of cold compressed gas used for cooling of HTS device (e.g., nitrogen, neon, other gas or their mix).

[0038] Figure 5 schematically shows an example of the preferred embodiment to convert natural gas coming out of the heat exchanger HX3 from a cold vapor (e.g., 0.1 MPa, 111.7 K) into a gas suitable for a distribution network (e.g., 4.2 MPa, 300 K, see table 3), which is done here by a cold natural gas compressor, without a need for additional heat exchanger.

[0039] Assuming closed loop refrigeration process and devices, then figure 6 shows the T-S diagram of the device according to the invention with a Brayton cycle for the first heat exchanging medium (helium in this example)

[0040] Cold return He gas after the expander (point 5 at e.g., 5.8 bar and 61.4 K, Table 2, fig. 2) warms up at almost constant pressure in the heat exchanger HX1 (process 5-6, Table 2, figs. 2 and 4), where it cools down the return flow of N₂ from HTS cable and in HX2 (process 6-1), where it cools down the return He flow from the after-cooler HX3; is compressed in the Compressor (to

e.g., 12.2 bar) and cooled in the after-cooler HX3 (to e.g., 115 K in the process: 1-2a-2b-2c-3). The compressed flow is cooled by the return flow in HX2 (process 3-4) and is expanded in the expander (process 4-5).

Liquefaction process and the devices

[0041] The corresponding optional liquefaction process and devices can be arranged in any way known to a person versed in the art. The excessive cooling capacity of the refrigerator is used to make liquid nitrogen LN₂ (e.g., during the hours of low electricity tariff) that is stored in a tank, see fig. 3, left. During the high tariff hours the refrigerator works at reduced capacity thus consuming less electricity and the stored LN₂ is used for cooling HTS cable directly or indirectly.

[0042] In the proposed invention due to the use of cold compressor only 54 kW of input power is needed (to produce 10 kW cooling capacity, as compared to 141 kW input of the prototype cycle), of which 25 kW can be covered by the expander work. In order to after-cool gas after cold compressors, one purchases LNG for 643 k€/yr (77 ton/wk at the price of 160 €/ton). LNG boils in the after-cooler HX3 (e.g., at 1 bar and 111.5 K) its vapor is then compressed with a cold compressor to e.g., 40 bar and room temperature (e.g., 300 K, fig. 5, table 3), the compressor consumes 46 kW. The total consumed power is of the system is therefore: 75 kW = 54-25+46, or 53% of that for the prototype cycle and the cooling penalty is therefore reduced from 14.1 (prototype) to 7.5 (proposed invention). Furthermore, produced natural gas (e.g., at 40 bar and 300 K) is returned e.g., to the gas distribution network for 1508 k€/yr (at 0.3 €/m³, bio-gas can be sold even at 0.4 €/m³). As a result of this regasification process, an income of 799 k€/yr is generated. When needed, electricity cogeneration [5] can be added as well, but not considered here. The whole process can be realized by any means known to a person versed in the art, one example is a floating regasification unit modified according to this invention. When bio-LNG is used as an input, clean (non-fossil) natural gas and clean electricity are produced resulting in even higher income from regasification.

[0043] When relevant, (optional) efficient storage of electricity is organized as follows. Storage tank for LNG (e.g., 80 ton) is needed anyway in order to provide sufficient reserve of the proposed system operation (e.g., one week) and thus reliability of the cooling system for HTS device, e.g., cable.

[0044] For the most efficient storage and saving of electricity, a liquid N₂ tank (e.g., 5-10 ton) can be added and placed e.g., inside of LNG tank in order to reduce the heat leaks, see explained in fig. 4 (other option could be e.g., cooling of thermal shield around the LN₂ tank with LNG). In this case a cold of LNG is used to intercept most of the heat leak to the stored liquid nitrogen. During e.g., low electricity tariff hours the system stores LN₂ and consumes more electricity than required for 10 kW cooling capacity needed for HTS device, and during high elec-

tricity tariff hours the system uses less electricity (for the refrigeration) and instead uses stored LN2 to provide the cooling capacity of 10 kW (in this period nitrogen flow from HTS device is at least partly sub-cooled in the LN2 bath of fig. 4 and not by the refrigerator) and therefore stores and saves electricity very efficiently (almost 100% efficient in e.g., storing and saving of ~250 kWh in a 24 hour cycle). Furthermore, in addition to the described internal processing and in order to increase flexibility of the proposed system, LN2 and LNG can be traded both ways: supplied from external sources and provided to external consumers.

[0045] Figures 7 and 8 shows schematically an embodiment of a multilayer thermal vacuum insulation with magnetic suspension inside a cryostat of a high temperature superconductor device according to the invention.

[0046] A prior art cryostat of a HTS cable is made of two concentric stainless steel tubes or shells (that are usually corrugated for flexibility), a space in between contains multilayer thermal insulation (MLI) in vacuum (typically at the level 10-5 Torr or better). Such cryostat is commercially available, provides a heat leak of about 1W/m and costs around 0.5-0.7 M€/km, which on itself is comparable to the costs of typical XLPE cable, see above. Most of the thermal barrier for the heat leak is provided by MLI and recent attempts to improve its properties include e.g., introduction of lumped (instead of uniformly distributed) interlayer spacers [10-12].

[0047] Attempts to reduce cryostat cost are targeting 0.1-0.2 M€/km, foreseen options include e.g., replacement of outer cryostat shell made of stainless steel with polymer, such as polyethylene [10], etc.

[0048] Known arrangement uses LNG to thermally shield a superconducting cable placed inside. For example known from US20140051582. However, this arrangement is more complex and has safety issues due to possible interactions between LNG and superconducting cable (e.g., a spark in the cable ignites a fire in LNG vapor, e.g., a lighting attracted by a cable ignites LNG vapor, etc.).

[0049] Outer wall of a cryostat is made of any appropriate material: metal (e.g., stainless steel, e. g. magnetic or non-magnetic), concrete (e.g., ductal or quantz), plastic or their combination. Protective layer (e.g., line X can be used as well).

[0050] To ensure low friction of coolant inside the cryostat, along the length cryostat is made semi-flexible, a combination of longer rigid and shorter corrugated tubes (or bellows).

[0051] Furthermore, cryostat can have a tubular or other cross-section, or their mix (e.g., inner wall tubular, outer wall trapezium).

[0052] In such cryostat most of the thermal barrier is due to the multilayer thermal insulation that prevents the heat leak by radiation, thermal conductivity of solids and (convection) of gases. Furthermore, it is known that at around 300 K radiation dominates, while at around 70 K thermal conductivity prevails [10]. In the proposed inven-

tion in order to arrive at the record low heat leaks through cryostat walls (e.g., 0.2 W/m), the radiation is suppressed to the desired level by known means (e.g., number of reflective layers, better reflectivity, variable distance between reflective layers), the thermal conductivity of gases is suppressed by removing (most of) fiber spacers and selecting low outgassing materials, while the thermal conductivity of solids is suppressed by removing most of mechanical spacers that are replaced with magnetic suspension.

[0053] Most efficient Multilayer thermal insulation (μ LTI) is used to reduce heat influx from the room temperature (300 K) to 70 K zone. This includes classical, or self-pumped, or integral, or NICS MLI. A disadvantage of integral and NICS MLI is that density of layers is lower and the insulation blankets are much thicker as compared to conventional μ LTI.

[0054] Integrated MLI is known where separate radiation shields are spaced with an array of posts in particular interconnected to radiation shields or sheets comprising the MLI layers (see e.g.: US8234835) and in addition the posts in each layer can be connected to each other with support arms or beams. A particular disadvantage of this solution is that the said posts are interconnected to each other in the preferential direction of the heat flux and because they have to transfer mechanical load in the same direction, the contact resistance cannot be made sufficiently low.

[0055] The remaining solid state posts are made of material with high compressive strength, low thermal conductivity and low outgassing and have a function to provide mechanical strength to the MLI blanket. For instance, in order to withstand a uniform pressure of 2 bar=2kgf/cm², such an array of posts can be introduced with a certain density. For instance, stainless steel has a compressive strength of 200 MPA, in other words one stainless steel post (per 1cm² of blanket) with a cross-section of 0.2 mm² can in principle hold a uniform pressure of 2 bar applied to the blanket. However, a solid state heat flux of such post (in the temperature range 300 K to 70 K) is about 0.3 W (assuming the post is 1 mm long) and for 1m² array of such posts a heat flux is 3000 W/m², (which is 30,000 times higher as compared to the target of 0.1 W/m²). Thus it is rather impossible to provide the required mechanical strength of MLI using solid state posts. On the other hand, two permanent magnets PM (each 3 mm thick, 5 mm in diameter: 0.18 cm²area) create a pressure of 5 kgf/cm², in other words PM density of 0.2 PM/cm² is in principle sufficient to counteract atmospheric pressure of 1 kgf/cm² without a post. Furthermore, a stable suspension and thus counteraction to atmospheric pressure is created with a PM-ReBCO pair, e.g. with ReBCO superconductor attached to the inner cryostat wall.

[0056] Furthermore, to ensure that all NdFeB dots (islands, nodes) are firmly position against each other in an ordered array, in every layer a net can be added made of any appropriate material, e.g. glass fibers or activated

carbon fibers with NdFeB dots positioned in the nodes of the net. Edges of the net are fixed to the edges of MLI using one of the known ways (e.g. as in coolcat insulation). Another way to ensure magnetic dots remain firmly positioned against each other is by adding pins in the preferential direction of the heat flux, said pins do not carry mechanical load and only align said magnetic dots against each other in a column.

[0057] A typical HTS power cable phase (a former, Cu conductor, HTS core, electrical insulation, electric and magnetic shields, liquid nitrogen, etc.) without a cryostat weights 10-20 kg/m. Three phases (without a cryostat) weight less than 50 kg/m. A typical diameter of three phases is 0.2 m. Therefore a pressure on the cryostat wall due to the cable weight (acting on 1/3 of the cryostat inner wall surface) is about 3 kN/m² (kPa). This pressure can be created by 50/m² pairs of PM-REBCO (e.g., Nd-FeB PM diameter 20 mm, 5 mm height, REBCO similar dimensions, each creating a suspension force of 6 kg). The expected cost is 0.1M€/km (estimated from the ET3 data, where 10 x heavier loads are suspended and the cost is 1M€/km), which is acceptable, considering the total cost of a cryostat with the heat influx of 1W/m is 0.5-0.7 M€/km.

[0058] Mechanical spacers have a function of transferring mechanical load between inner and outer cryostat walls.

[0059] The proposed Multi-Layer Thermal Insulation (μ LTI) aims to achieve record low heat leaks approaching the radiation limit (such as 0.2 W/m², in the temperature range between 65 and 300 K, with 10 reflective layers and emissivity of 0.02). It consists of sufficient number (e.g., 10) of reflective layers 2 with low emissivity (e.g., 0.02), such as Al foil or any other with comparable or superior properties: emissivity, outgassing, strength, thermal properties, costs, etc., allowing heating up to e.g., 500 K under vacuum in order to remove residual gasses, such as e.g., a thin copper foil or a polymer film on both sides covered with a few μ m thick high reflective Al, Ag, or Au, etc. layers. In the state of the art MLI a fine fiber glass paper is used as a distributed spacer of reflective layers. It is known however, that such spacer often prevents removal of residual gases and degrades thermal conductivity of MLI. In order to remove the gases, such paper can be loaded with activated carbon particles or fibers. Furthermore, since thermal conductivity of glass fiber paper depends on thermal contact resistance between the fibers, thermal conductivity of such MLI increases with mechanical load. To solve this problem, arrays of special lumped interlayer spacers able to carry mechanical load of MLI are used. However, they generally decrease layer density and increase the thickness of MLI blanket, which limits their applications. In the proposed invention, we replace most of such spacers with the proposed interlayer spacer using magnetic levitation (suspension) of permanent magnets.

[0060] The proposed interlayer spacer transmits mechanical load using repulsion forces between stationary

permanent magnets. A column of e.g., ring-shaped permanent magnet clips 4 of one spacer, see fig. 7. is arranged in such a way that two clips with a reflective layer in between have the same direction of magnetization and therefore attract each other, while clips from two adjacent reflective layers repel each other. To circumvent the Earnshaw's theorem, a pin attached e.g., to the innermost μ LTI layer is used. Such pin does not transmit mechanical load through μ LTI, therefore it has smaller thermal conductance as compared to any other lumped spacer that does.

[0061] The e.g., 10 mm long and 1 mm outer diameter pins (e.g., a thin-wall tube made of material with good mechanical strength, non-magnetic, low thermal, low electrical conductivities and good vacuum outgassing properties, such as Kevlar, polyimide, nylon, or even stainless steel) are used to mutually align the permanent magnet clips 4 against each other and to limit their possible movements preferentially to one degree of freedom (along the pin, which is vertical direction in the figure 7). In the circumferential direction the ends of outer (inner) layer are locked. The pins also provide structural integrity so that layers of μ LTI can move in respect to each other only in one direction. The pins themselves do not transmit mechanical load through μ LTI, this is done by the magnetic forces. This is why each such pin has a smaller cross-section as compared to any mechanical support pin. Innermost and outermost layers of μ LTI can be made for instance of thin foil (e.g., 50 μ m stainless steel or copper with Al layer deposited on both sides). The pins are attached to the inner surface of the innermost layer in any way appropriate. The about 10 μ m thick inner reflective μ LTI layers are made of e.g., Al foil, or polymer film (or Cu-foil) covered on both sides with Al, or Ag, or Au layers.

[0062] Figure 7 shows: interior arrangement of the proposed μ LTI: 11 - innermost layer; 12- inner reflective layers, only one is shown for simplicity; 13- outermost layer; 14-permanent magnet clips, only one set is shown; 15 - alignment pin, only one is shown for simplicity.

[0063] Figure 8 shows: magnetic levitation of MLI blanket inside a cryostat, 21- inner cryostat wall; 22- superconductor (e.g., YBCO) attached to it; 23- permanent magnet attached to the μ LTI blanket 24; 25- pin with a limiting cup; 26 - outer cryostat wall.

Claims

1. Device for cooling a high temperature superconductor, which device comprises a cryocooler using a first heat exchanging medium to cool a second heat exchanging medium to cryogenic temperatures, **characterized by** a heat exchanger having a first channel and a second channel in heat exchanging contact with the first channel, wherein the first heat exchanging medium flows through the first channel, wherein a third heat exchanging medium flows through the

second channel and wherein the temperature of the third heat exchanging medium is lower than the temperature of the first heat exchanging medium.

2. Device according to claim 1, wherein the third heat exchanging medium is liquid natural gas. 5
3. Device according to claim 2, wherein the third heat exchanging medium changes phase from liquid to gas when flowing through the second channel and wherein the gaseous third heat exchanging medium is compressed to be fed to a gas distribution system. 10
4. Device according to any of the preceding claims, further comprising a first storage vessel for storing the second heat exchanging medium at cryogenic temperature. 15
5. Device according to claim 4, further comprising a second storage vessel for storing the third heat exchanging medium and wherein the first storage vessel is arranged inside of the second storage vessel. 20
6. Device according to any of the preceding claims, wherein the cryocooler is a Brayton, Stirling or pulse tube cryocooler. 25
7. Device according to claim 6, wherein the first channel of the heat exchanger is arranged directly downstream of the compressor of the Brayton, Stirling or pulse tube cryocooler. 30
8. Device according to any of the preceding claims, further comprising a high temperature superconductor device with an inlet and outlet for cooling medium, wherein the second heat exchanging medium is fed to the inlet of the high temperature superconductor device. 35
9. Cryostat of a high temperature superconductor device for use with the device of claim 8, comprising two concentrically arranged stainless steel tubes, a multi-layered thermal insulation blanket arranged between the two concentrically arranged stainless steel tubes and a plurality of magnetic suspensions for spacing of the multi-layered thermal insulation blanket and suspending the inner stainless steel tube inside the outer stainless steel tube. 40 45
10. Cryostat according to claim 9, wherein the multi-layered thermal insulation blanket comprises an inner, outer and at least one reflective layer spaced from each by repulsive force of arrays, strips, dots, islands or layers of permanent magnets 50 55
11. Cryostat according to claim 10 wherein the permanent magnets in the preferred direction of the heat flow are aligned with low thermal conductivity pins

attached to the inner layer of the blanket

12. Cryostat according to claim 11 wherein permanent magnets in the preferred direction of the heat flow are aligned with each other using tension of the layers.

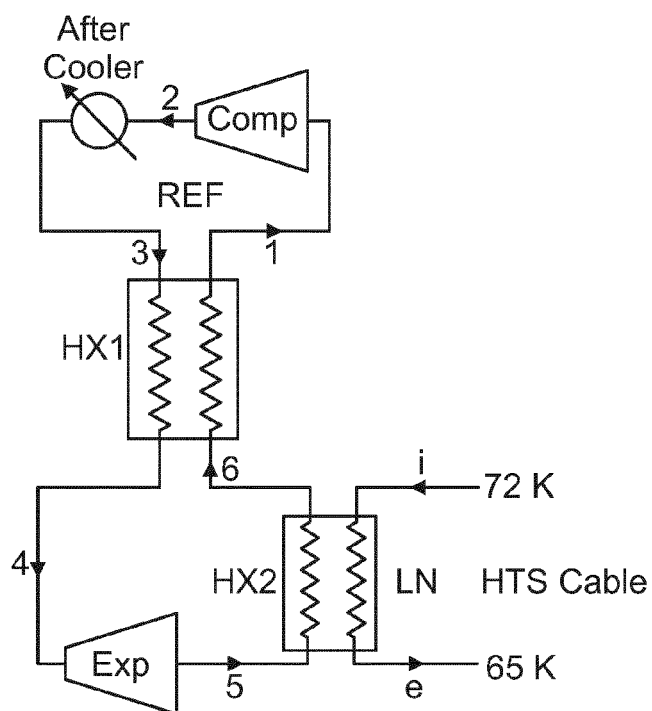


Fig. 1

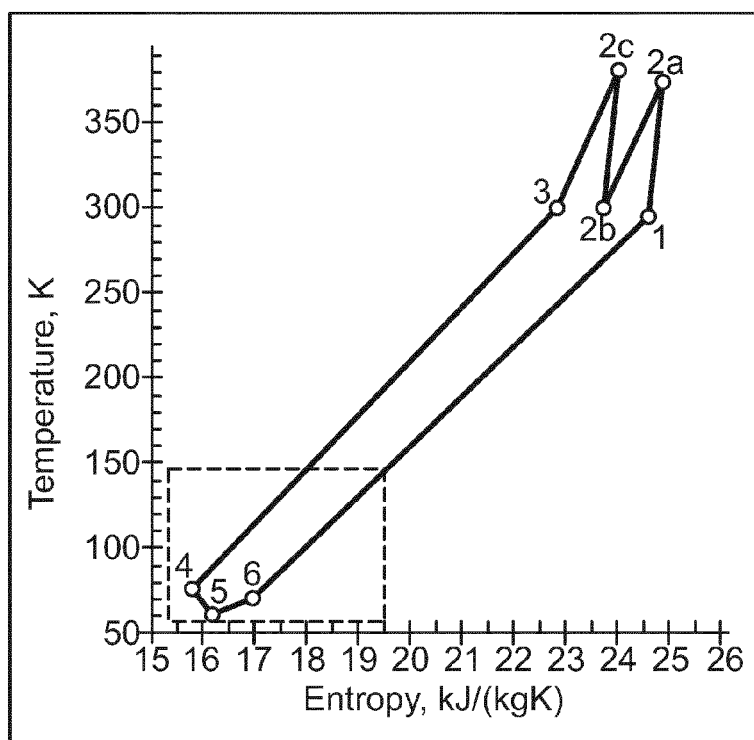


Fig. 2

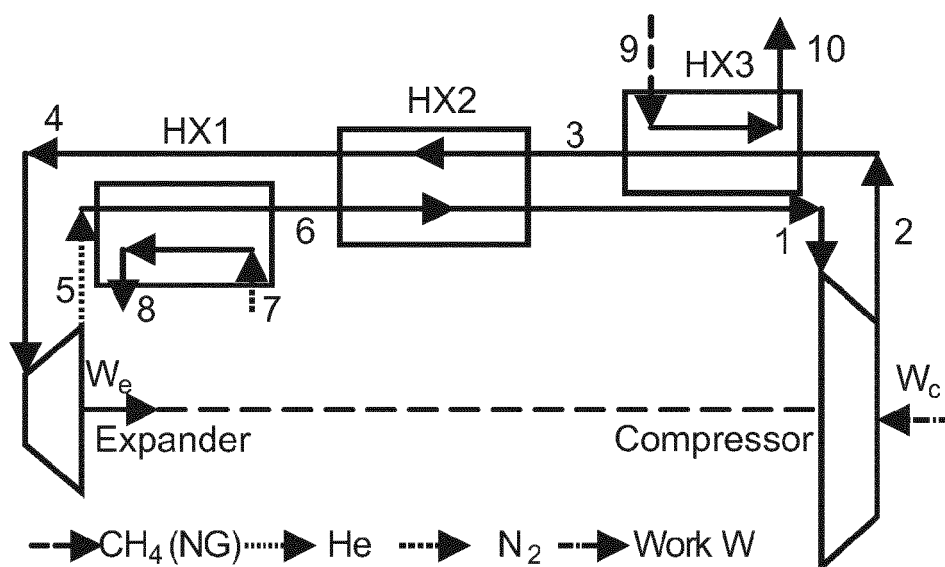


Fig. 3

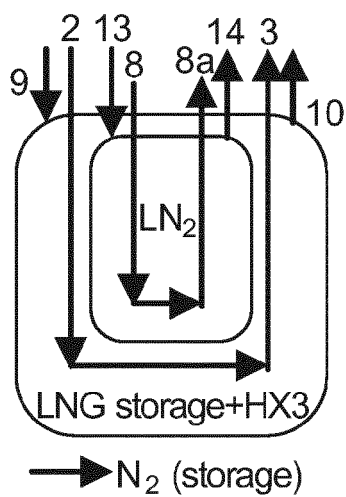


Fig. 4

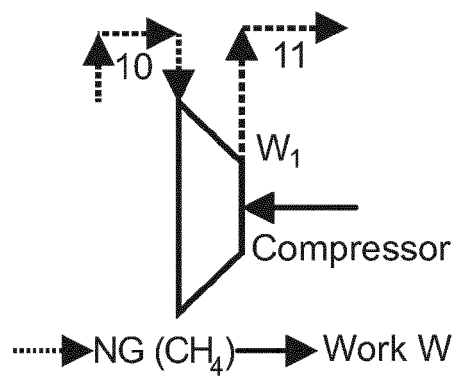


Fig. 5

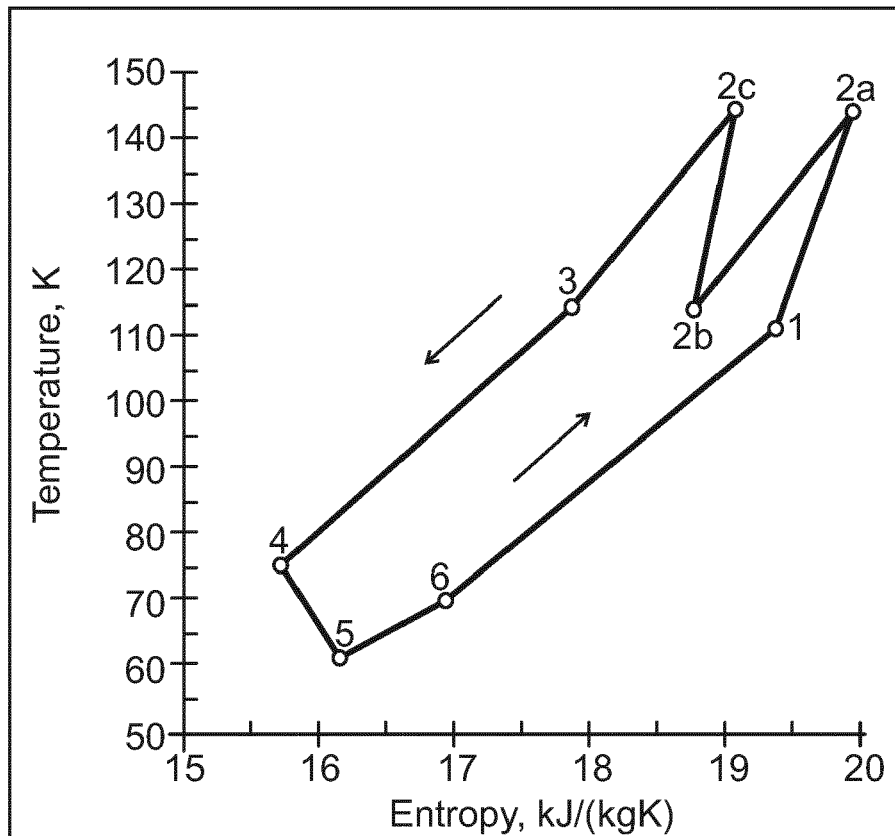


Fig. 6

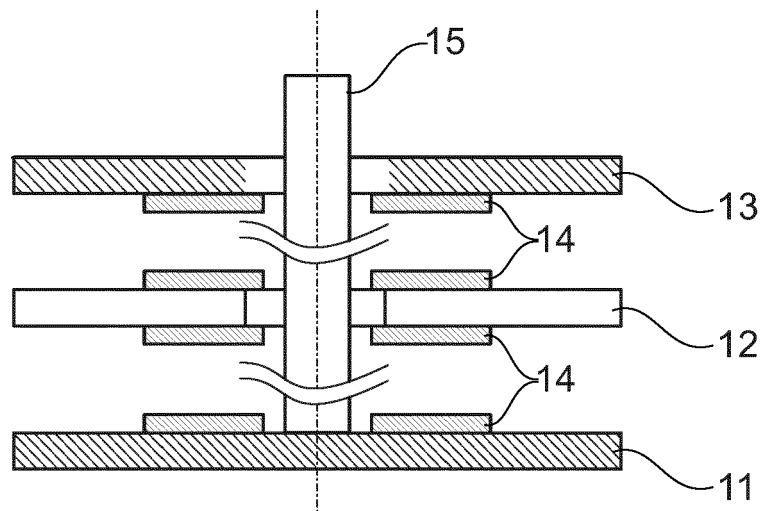


Fig. 7

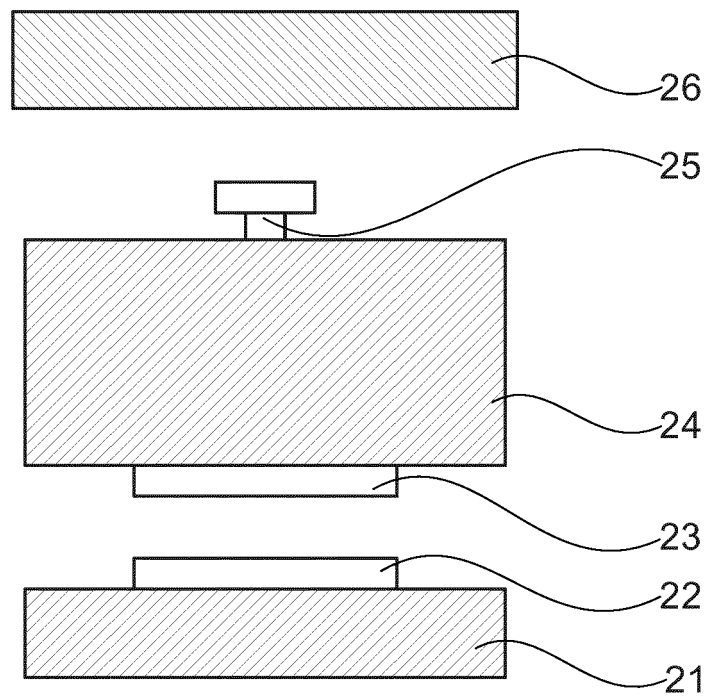


Fig. 8

Table 1.

Helium gas, 0.2091 kg/s				
point	P, MPa	T, K	H, J/g	S, J/gK
1	0.5	295.0	1540	24.6
2a	0.8	374.0	1951	24.9
2b	0.8	300.0	1567	23.7
2c	1.3	380.4	1986	24.0
3	1.2	300.0	1568	22.8
4	1.2	75.8	402	15.7
5	0.6	61.4	325	16.2
6	0.6	70.5	373	16.9

Table 2.

Helium gas, 0.2091 kg/s				
point	P, MPa	T, K	H, J/g	S, J/gK
1	0.55	112.0	588.5	19.4
2a	0.80	145.0	761.2	19.9
2b	0.79	115.0	605.2	18.8
2c	1.22	145.0	762.6	19.1
3	1.21	115.0	606.4	17.9
4	1.19	75.8	402.0	15.7
5	0.58	61.4	325.3	16.2
6	0.56	70.5	372.8	16.9

Table 3.

Methane, G kg/s = 0.127492				
	P, MPa	T, K	H, J/g	S, J/gK
9	0.10	111.5	-0.6	0.0
10	0.10	111.7	510.8	4.6
11	4.20	300.0	873.5	4.7

Fig. 9

**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 14 20 0513

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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			F25B F25J

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

2

Place of search	Date of completion of the search	Examiner
Munich	15 September 2015	Lucic, Anita
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document		

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**INCOMPLETE SEARCH
SHEET C**

Application Number

EP 14 20 0513

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Claim(s) completely searchable:
1-8

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Claim(s) not searched:
9-12

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 07.09.2015 filed in reply to the invitation pursuant to Rule 62a(1) EPC. Thus, the search report has been drawn up on the basis of independent claim 1 and its associated dependent claims 2-8.

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**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

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