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(54) A PRECOOLING DEVICE FOR COOLING THE SUPERCONDUCTIVE COILS OF A SUPERCONDUCTIVE MAGNET AND METHOD THEREOF

(57) The present invention relates to a precooling device (60) for cooling the superconductive coils of a superconductive magnet (10). The precooling device (60) is able to be lodged into a housing (50), thereby forming a cooling chamber (66) where a cryogen fluid can be supplied and removed though ports (61, 62). The cooling system (1) allows reduction of the thermal link between the superconductive coils and the externa environment of the superconductive magnet (10).

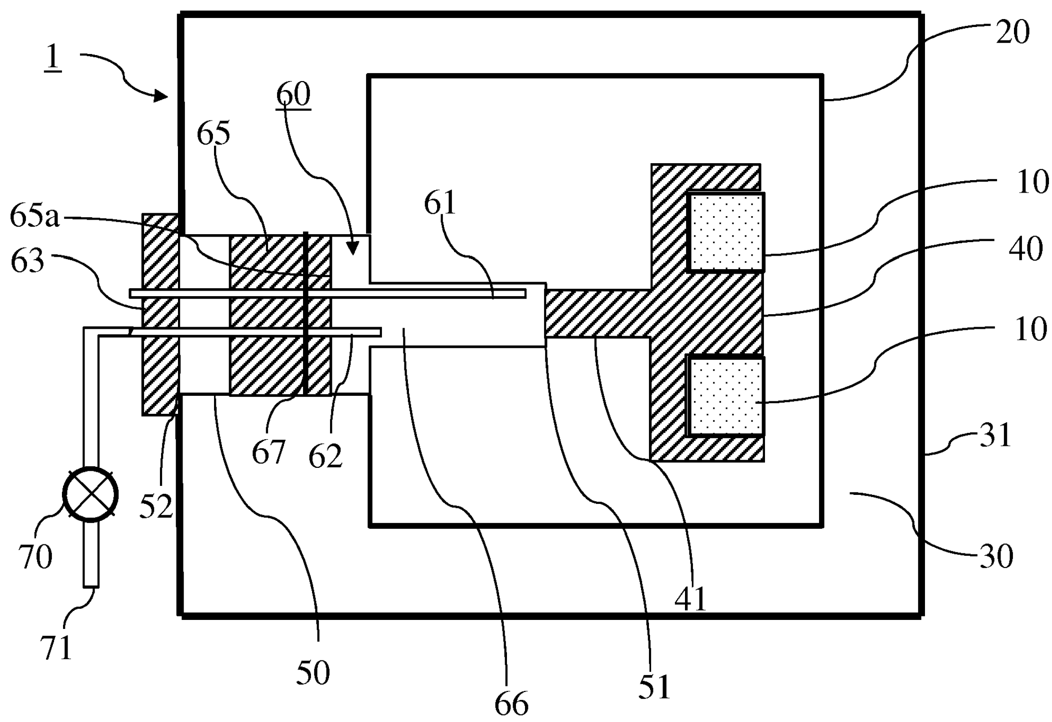

Fig. 3

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Description

Field of the invention

[0001] The invention relates to a device for cooling a superconductive magnet, and more particularly the superconductive coils of a magnet, and used during the cool down operation of a superconductive magnet. The invention also relates to a method for cooling a superconductive magnet during the cool down operation of a superconductive magnet.

Description of prior art

[0002] In the field of ion beam therapy, and more particularly for therapy system using a proton beam, systems are used for generating and transporting proton beams from proton source through an accelerator to patient treatment stations. Such ion beam therapy systems comprise a particle accelerator, a synchrocyclotron for example, a gantry for delivering the proton beam at different angles, and a patient treatment room. In the synchrocyclotron, a superconducting magnet comprises superconducting coils to create intense magnetic field inside the synchrocyclotron.

[0003] A typical magnet system comprises superconducting coils mounted on a mechanical support. The magnet is positioned within a thermal radiation shield. This combination is housed in an outer vacuum container, or an evacuated vacuum chamber, to reduce heat losses. The thermal radiation shield serves to intercept radiated heat from the housing of the evacuated vacuum chamber before it reaches the superconductive magnet. The magnet is thermally linked to a cryogenic refrigerator in a "dry" arrangement, for example with a copper block. In these configurations, heat loads is indirectly removed via the thermal link connected to the refrigerator. Alternatively, the magnet could be positioned within a cryostat, containing a cryogen fluid, like liquid helium, the cryostat being housed within the evacuated vacuum chamber.

[0004] Superconductive magnets in use have to operate at very low temperature, the temperature at which the material changes from the normal resistive state and becomes a superconductor. A superconductive magnet therefore needs to be cooled down before use, which is a slow process and can take many days. Before reaching the low operating temperatures, heat needs to be extracted from the magnet to cool it from ambient temperature to cryogenic temperature. To this end, cooling devices for refrigerating superconductive magnets have been developed. These devices allow heat to be conducted from the magnet to the cooling devices. Various strategies exist to cool down the superconductive magnets. For example, bath cooling, forced cooling or indirect cooling strategies are in use for cooling such magnets.

[0005] Several systems have been developed to ensure correct cooling of the superconducting coils of the magnet and/or the thermal radiation shield. To this end, a device known under the name "cryocooler" has been developed. Such device allows cooling down and maintaining a superconductive magnet under superconductive state temperature. But these devices are quite expensive and are not enough performant during the precooling stage, leading to long precooling periods (over two weeks in some applications) and a premature wear of the cryocooler. Therefore, precooling devices have been developed to speed up the precooling process.

[0006] As an example of precooling device, European patent application n° 90 300 778.6 disclosed a superconductive magnet with a cryogenic precooler. The required cooling effect is achieved using a cryocooler, normally designated as a dual-stage cooler, which often works by the Gifford-McMahon principle. The cryocooler has a head interface connected to the cryostat. A precooler is furthermore present. The precooler is connected in a heat-flow relationship with head stations located on the interface. The interface has inlet and outlet ports for supplying and removing a cryogen fluid. Piping means are furthermore present along the cryocooler in the evacuated chamber disposed between the thermal radiation shield and the outer sleeve of the device.

[0007] Such structure ensures a better precooling process. But several drawbacks are nonetheless present. First, for existing cryocooler, several complex or expensive modifications have to be provided: a new piping network and new connections between the interface and the precooling device have to be implemented. Retrofitting existing cryocooler is therefore not a straightforward task. Furthermore, extra means (the precooler itself, the piping means, etc.) are still present after the precooling stage, during the normal use of the superconductive device. It means that extra cooling power has to be used during the normal use of the magnet to ensure that these extra means are also cooled down. During the precooling stage, the precooler has also to cool the cryocooler, therefore lowering the efficiency of the precooling process. Finally, the cryocooler itself is a significant thermal link between the superconducting coils and the external environment, lowering the efficiency of the cooling process. The cryocooler could be activated, but as already said, discrete use of cryocooler is seek since these devices are expensive and subject to wear. Finally, the precooling device disclosed in this document supplies the cryogen fluid to cool the thermal radiation shield first, and then the interface in contact with the superconductive magnet. Therefore, the cryogen fluid is not at its coldest temperature when it cools down the superconductive magnet. It would be advantageous that cryogen fluids first reach a means in contact with the superconductive magnet, and then the thermal radiation shield, since it takes more time to cool down the magnet than the radiation shield.

Summary of the invention

[0008] To solve, at least partially, the problems of the state of the art, it is an object of the invention to provide a cooling system for a superconductive magnet that enhances the precooling stage of the superconductive magnet. It is an object to provide a precooling system that does not have extra means to be cooled when the superconductive magnet is in use. It is an object of the present invention to provide a precooling means that can be easily adapted to already existing cryocooler. It is an object of the present invention to lower the thermal links between the superconducting coils and the external environment of the superconductive magnet.

[0009] The invention is defined by the independent claims. The dependent claims define advantageous embodiments.

According to the invention, there is provided a cooling system for a superconductive magnet, said system comprising:

- a superconductive coil being part of the superconductive magnet and thermally connected to a cold block, both being surrounded by a thermal radiation shield, said thermal radiation shield being surrounded by an evacuated vacuum chamber,
- a housing projecting into the cooling system configured to arrange a distal portion of the housing to be in thermal contact with the cold block and a proximal portion of the housing extending through a wall of the vacuum chamber.

The cooling system is characterized in that it comprises a removable precooling device cooperating with the housing, the precooling device furthermore comprises a plug hermetically closing the proximal portion of the housing, thereby forming a cooling chamber, and the precooling device further comprises:

- an inlet port able to supply a cooling fluid inside the cooling chamber,
- an outlet port able to remove the cooling fluid from the cooling chamber.

[0010] Since the precooling device is removable, it may be pulled out of the housing when the precooling stage is over. Hence, after the precooling stages, no extra means have to be cooled. The cooling fluid can be supplied next to the distal portion of the housing. Therefore, the cooling fluid cools the cold block at its coldest temperature.

[0011] Preferably, the cooling device according to the invention further comprises an insulator disposed between the plug on one end and the inlet port and the outlet port on the other end, said insulator being able to physically insulate a portion of the cooling chamber wherein the inlet port and the outlet port come out from a portion of the cooling chamber in contact with the plug.

[0012] Indeed, the insulator allows the creation of a reduced cooling chamber located next to the distal portion of the housing. Therefore, the cooling fluid is better isolated from the external environment of the precooling device, and the reduced cooling chamber may allow a more controlled rate of cooling, because it is easier to control the overall temperature of the cooling fluid into the cooling chamber by increasing or decreasing the flow.

[0013] More preferably, in a cooling device according to another embodiment of the invention, the housing is able to house a cryocooler device, and more particularly displacers of a cryocooler, and preferably the two displacers of a two-stage cryocooler device.

[0014] When the housing is adapted to receive a cryocooler, and since the precooling device is removable, it may be replaced by the cryocooler device after the precooling stage. Therefore, retrofitting of existing cooling device comprising a cryocooler is easy and not expensive. And the precooling device and a cryocooler successively share a single housing, therefore limiting thermal bridges between the superconducting magnet and the wall of the vacuum chamber.

[0015] Moreover, the invention concerns a method for precooling a superconductive magnet. The method comprises the following steps:

- furnishing a cooling system according to any embodiment of the invention;
- flowing a cooling fluid through the cooling chamber by opening the inlet port and the outlet port to cool down the superconductive coils of the superconductive magnet reach.

[0016] In a more preferred embodiment of the method, the further steps of:

- removing the precooling device from the housing,
- placing at least one displacer of a cryocooler in the housing and hermetically closing the housing, thereby creating a cryocooler,
- allowing a cooling fluid to enter the cryocooler and return from the cryocooler,
- activating the cryocooler to further cool down the superconductive magnet,

are performed.

Short description of the drawings

[0017] These and further aspects of the invention will be explained in greater detail by way of examples and with reference to the accompanying drawings in which :

Fig.1 shows a transverse sectional view of a cooling device according to one embodiment of the present invention wherein the cryocooler is temporarily replaced with a precooling means, the precooling means being disposed in the housing of the cryocooler;

Fig.2 shows a transverse sectional view of a cooling device according to a second embodiment of the invention;

Fig.3 shows a transverse sectional view of a cooling device according to a third embodiment of the invention;

Fig.4 is a transversal sectional view of a device according the one embodiment of the invention at different stages of a method according to one embodiment of the invention.

[0018] The drawings of the figures are neither drawn to scale nor proportioned. Generally, similar or identical components are denoted by the same reference numerals in the figures.

Detailed description of embodiments of the invention

[0019] Referring to Fig.1, a cooling system (1) for cooling a superconductive magnet (10) is schematically represented. Fig. 1 is a cross section of a system according to one aspect of the present invention. Only a portion of the structure to be cooled is shown. Some components not shown in Fig. 1 and not explained in detail in the following description are generally known in the art. The illustrated device allows a precooling device within a cooling system for a superconductive magnet to be designated. A superconducting magnet is an electromagnet made from coils of superconducting wire, or superconductive coils. Cooled to cryogenic temperatures, the coils are in superconducting state, allowing the conduction of large electric currents, therefore creating intense magnetic fields. One of their uses is in particle accelerators. Preferentially, the coils of the magnet are made up of niobium titanium windings. The superconductive coils may be a Niobium Titanium (NbTi) wire in channel coil. As an example, such a superconductive magnet is sold by ASG (Genoa, Italy) and is identified as a medical coil for the S2C2P Synchrocyclotron for IBA. The superconductive coils may be able to produce a maximum magnetic of at least 1 Tesla. In a preferred embodiment of the invention, the superconducting magnet is cryogen free, also known as a dry superconducting magnet. Preferentially, the superconductive magnet (10) is a cylindrical superconductive magnet. Preferentially, the superconducting magnet is for use in the field of particles acceleration, within a particle accelerator. In a preferred embodiment of the invention, the superconductive magnet (10) is therefore installed within a particle accelerator, like a cyclotron or a synchrocyclotron. The purpose of the superconductive magnet is to create the mean magnetic field used by the particle accelerator during the acceleration stage of particles. In a preferred embodiment of the invention illustrated on Fig. 3, At least two superconductive coils, and alternatively a plurality of superconductive coils, are present in the cooling system.

[0020] The superconductive coils of the magnet (10) are thermally coupled to a cold block (40). The cold block (40) is made up of a thermally conductive material. The cold block could be defined as a mass to be cooled from a temperature to the final precooling temperature or operating temperatures with the help of the cooling device according to the invention. The cold block function is to thermally link the superconductive coils of the magnet (10) to the housing (50). The cold block (40) could be in any materials like a metal or an alloy that have sufficient thermal conductivity capacities to transfer heat from the superconducting magnet to the precooling device. By sufficient thermal conductivity capacities, it should be understood materials with a thermal conductivity over 100 $W.m^{-1}K^{-1}$, more preferentially over 200 $W.m^{-1}K^{-1}$, and still more preferentially over 230 $W.m^{-1}K^{-1}$. For example, the cold block may be in aluminium or copper.

[0021] By thermally coupled, it should be understood that the cold block (40) is in direct contact with the superconductive coils of the magnet, or that the cold block (40) is connected to the superconducting coils of the magnet through heat-conductive connecting pieces or heat-conductive members, like thin copper or aluminium plates. A heat-conductive connecting piece may be a contact plate made of copper, eventually plated with gold or silver or indium. These pieces allow the heat transfer from the superconducting magnet (10) to the cold block (40) and from the cold block (40) to the superconducting magnet (10).

[0022] A thermal radiation shield (20) surrounds the windings of the superconducting magnet (10) but is spaced apart therefrom. The purpose of the radiation shield (20) is to reduce the radiation heat input into the superconducting magnet windings.

[0023] The thermal radiation shield is supported from a vessel which encloses the magnet windings or from the vacuum vessel. The supports are typically made of low thermal conductivity material such as a thin stainless steel wire or a suitable structure from thermoplastic or other materials with low thermal conductivity, well known by a person skilled in the art.

[0024] The radial distance between the superconducting magnet (10) and the surrounding thermal radiation shield (20) are several inches, for example, 1 to 5 cm.

[0025] The thermal radiation shield (20) and the superconducting magnet are designed to operate at different temperatures with the magnet windings at the coldest temperature. The thermal radiation shield may be in a metal material or an alloy with good thermal conductivity capacities, like cooper or aluminium.

[0026] The thermal radiation shield (20) is surrounded by a vacuum chamber (30). The radial distance between thermal radiation shield (20) and the surrounding wall (31) of the vacuum chamber (30) are several inches, for example, 1 to 5 cm. When the superconducting magnet is in use, during the precooling stage, the cooling stage, or during its normal use, the vacuum chamber is evacuated. The interior of the vacuum chamber (30) is therefore under a very low pressure when evacuated, or indeed under a quasi-vacuum, for example under a pressure of less than 10^{-3} mbar, preferably at a pressure of between 10^{-4} mbar and 10^{-5} mbar, and more preferably at a pressure of 10^{-6} mbar or below.

[0027] The system comprises a housing (50). It projects into the cooling system. In other words, the housing (50) projects into the vacuum chamber (30) and inside the thermal radiation shield (20). The housing could be made of stainless steel or any low thermal conductive material to avoid thermal link, and is isolated from the inside of the vacuum chamber, to ensure that the vacuum chamber could still be evacuated. The housing comprises at least a distal portion (51), located towards the superconductive coils of the magnet, and a proximal portion located towards the wall (31) of the vacuum chamber (30), as illustrated on Fig. 1-3.

[0028] The distal portion (51) of the housing (50) is heat-conductively coupled to the cold block (40). As an example, heat-conductive connecting pieces or heat-conductive thin plates may be provided between the distal portion (51) of the housing and the cold block (40). Alternatively, the distal portion (51) of the housing could be in direct contact with a part of the cold block (40). A heat-conductive connecting piece may be a contact plate made of copper or aluminium, eventually plated with gold or silver or indium. These pieces allow the heat transfer from the precooling device to the cold block through the wall of the housing and from the cold block to the superconductive coils of the magnet. These heat-conductive pieces could further be elastic pieces. In a preferred embodiment of the invention, the housing is also heat-conductively coupled to the thermal radiation shield (20). This coupling may be identical to the coupling between the distal portion of the housing and the cold block, i.e. with a heat-conductive connecting piece.

[0029] The proximal portion (52) of the housing extends through the wall (31) of the vacuum chamber (30), thereby creating an opening through the interior of the housing (50).

[0030] The cooling system (1) according to one embodiment of the invention comprises a removable precooling device (60). By removable, it should be understood that the precooling device (60) may be easily inserted inside the housing (50) during the precooling stage of the superconductive coils of the magnet, and easily removed when the precooling stage is over. Due to the particular structure of the precooling device, the evacuated chamber can be kept evacuated while removing the precooling device. When the precooling stage is over, the precooling device is removed and does not have to be further cooled down during the further steps of cooling. Furthermore, since the housing projects into the cooling system, it may be in contact with the thermal radiation shield (20). Hence, the precooling means may be used for cooling the cold block (40) and the heat radiation shield (20) when needed.

[0031] Since it is of the utmost importance to minimize the heat-conductive connection between on one hand the superconductive coils of the magnet and, on the other end the wall of the vacuum chamber, the present cooling system does not have extra means that have to be cooled down after the precooling stage is over because the precooling device may be removed. Hence, when the superconductive magnet is in operation at superconductive temperatures, no precooling means are present and therefore do not have to be cooled down. The precooling step corresponds to a step wherein the temperature of the cold block or the superconductive coils of the magnet is decreased from a starting temperature (for example the environmental temperature, i.e. 25°C or 298.15 K; but not limited to) to a lower temperature. As examples, the lower temperature may correspond to a temperature inferior to 200 K, preferentially inferior to 100 K and more preferentially inferior to 80 K, and most preferentially equal to 77 K. This lower temperature may correspond to a temperature at which the cooling fluid is in liquid state. As an example, when the cooling fluid is liquid nitrogen, this lower temperature may correspond to a temperature of approximatively 77 K, the boiling point temperature of liquid nitrogen. In other words, by precooling, it should be understood that the superconducting coils of the magnet are cooled to about 200 K with the removable precooling device (60) by heat-conduction through the cold block (40), and more preferably to about 100 K, still more preferably to about 80 K. The term about means a temperature from +5 K to -5 K in relation to the cited temperature (i.e. about 80 K means between 85 K and 75 K).

[0032] To this end, the removable precooling device (66) comprises a plug (63). The plug (63) is a means that is able to close hermetically the proximal portion (52) of the housing (50) by cooperating with the wall (31) of the vacuum chamber (30). The plug (63) could be a solid metal plate, like stainless steel. The plug (63) may be attached to the wall (31) with removable screws or removable nuts and bolts. A seal could further be present between the plug (63) and the wall (31) to ensure correct airtightness. Hence, when the plug (63) is in place, the interior of the housing (50) is isolated from any exterior environment, thereby creating a cooling chamber (66).

[0033] During the precooling stage, the cooling chamber (60) is filled with a cooling fluid. To this end, the precooling device (60) comprises an inlet port (61) and an outlet port (62). The inlet port (61) is able to supply a cooling fluid inside the cooling chamber (66); while the outlet port (62) is able to remove the cooling fluid from the cooling chamber (66). These two ports may be the distal extremity of pipes. These two pipes go through the plug (63), and are connected to a fluid pressure system or a pump system that is able to activate the supplying and the removing of the cooling fluid in and out of the cooling chamber (66). The inlet port (61) may be the end of any means able to supply a cooling fluid into the cooling chamber, like a piping means connected to a cooling fluid reservoir. The outlet port may be the end of any means able to remove a cooling fluid from the cooling chamber, like a piping means connected to a vacuum pump.

[0034] By cooling fluid, it should be understood a heat transfer fluid or heat-transfer medium like coolant liquids or refrigerants. In a preferred embodiment of the invention, the cooling fluid is a liquid gases, more preferably liquid nitrogen or liquefied neon, liquid helium or liquid hydrogen. Alternatively, the cooling fluid may be a nanofluid, a coolant consisting in a carrier liquid comprising dispersed nanoparticles. It should be noted that a plurality of different cooling fluids may be used during the precooling stage. As an example, the first cooling fluid in use during the precooling step may be liquid nitrogen, and followed by the use or liquefied neon.

[0035] In a preferred embodiment of the invention, illustrated on Fig.2, the precooling device (60) furthermore comprises an insulator (65). The insulator is disposed between the plug (63) on one hand, and the inlet port (61) and the outlet port on the other hand. The insulator (65) is able to isolate a portion of the cooling chamber wherein the inlet port (61) and the outlet port (62) come out from another portion of the cooling chamber located next to the plug (63). According to this embodiment, the cooling chamber has therefore a reduced volume, and is furthermore better isolated from the surrounding environment of the overall system (1). Hence, the cooling is more efficient. The insulator can be made in a non-metallic material like plastic, resin, or foam In a preferred embodiment, the insulator (65) furthermore comprises at least one sealing member (67), more preferably at least two sealing members, and most preferably at least three sealing members, or more than four sealing members, or even more. These sealing members are disposed on an external surface of the insulator (65), in contact with an internal surface of the housing (50). These sealing members (67) enhance the isolation of the reduced cooling chamber when the precooling device (60) is in place inside the housing. When the housing (50) has a cylinder shape, and the insulator has also a cylinder shape, these sealing members could be "O" rings, made in any elastic materials, like nitril, ethylene propylene diene monomer rubber (EPDM rubber), fluoropolymer elastomer, or polytetrafluoroethylene (PTFE).

[0036] In a preferred embodiment of the invention illustrated on Fig.2 and Fig. 3, the cold block (40) has a finger (41) extending towards the thermal radiation shield (20). In this embodiment, the distal portion (51) of the housing is in contact with the finger (41) of the cold block (40). The finger (41) may be in the same material as the cold block, i.e. a thermally conductive material. With such an embodiment, the overall mass of the cold block (40) may be reduced, thereby reducing the precooling stage length, while the cold block (40) is still in contact with the housing (50) though the finger (41) on one hand, and the superconductive coils on the other hand.

[0037] In a preferred embodiment of the invention illustrated on Fig. 4a, the housing (50) is able to house a cryocooler (100) when the removable precooling device (60) is not present. In a more preferably embodiment, the housing (50) is able to house a two-stage cryocooler, based on the Gifford McMahon cycle. It should be noted that the housing could also be able to house a three-stage cryocooler, or any type of cryocooler. A cryocooler according to this principle is well known in the art. According to this embodiment, a single housing (50) is able to house successively the precooling device and the cryocooler. The already existing cooling systems for superconducting devices are therefore easy to retrofit according to the present invention, without any structural modifications. The device sold under reference SRDK-415D by Sumitomo® is a typical example of a two-stage cryocooler.

[0038] In a preferred embodiment of the invention illustrated on Fig. 3, the inlet port (61) and the outlet port (62) come out inside the cooling chamber (66) at different places. The inlet port (61) may come out in the cooling chamber (66) at a distance of less than 5 cm, preferably less than 1 cm, and more preferably less than 0.2 cm, from the distal portion (51) of the housing (50). With such embodiment, the cooling fluid is supplied into the cooling chamber at its coldest temperature near the distal portion of the housing, enhancing the heat transfer between the cooling fluid and the cold block (40). As a preferred embodiment, or alternative embodiment, the outlet port (62) may come out inside the cooling chamber (66) at a distance of less than XX cm from an inner surface of the plug (63), or when an insulator (65) is present, at a distance of less than 5 cm, preferably less than 1 cm, and more preferably less than 0.2 cm from an inner surface (65a) of the insulator (65). According to this embodiment, the cooling fluid is removed from the cooling chamber far from the distal end (51) of the housing (50), where the cooling fluid has already flew inside the cooling chamber and has therefore already exchanged heat with the cold block (40).

[0039] In a preferred embodiment of the invention, the flow of cooling fluid that comes in and out of the cooling chamber (66) is regulated. This is for example illustrated on Fig. 3. To this end, an extraction controlling means (70) is present on a pipe (71) connected to the outlet port (62). The extraction controlling means (70) is disposed on the pipe (71), downstream of the outlet port (62). The extraction controlling means (70) may be a valve, a pump or a gauge. The extraction controlling means (70) may be controlled par a controller configured for activating the extraction controlling means when needed. Hence, the velocity of the cooling fluid inside the cooling chamber may be controlled. Alternatively, the flow could be regulated by a supply controlling means present on the pipe connected to the inlet port, while the output flow is kept at atmospheric pressure. This alternative embodiment avoids over pressure in the cooling chamber (66).

[0040] In a preferred embodiment, the velocity of the cooling fluid is controlled depending on any one of the following data: the temperature of the housing (50), the temperature of the cold block (40), the volume of the cooling chamber (66), the temperature of the superconductive coils, the temperature of the cooling fluid after being removed from the cooling chamber, etc. To this end, several temperature measurement means may be disposed on an external surface the cold block (40), inside the cooling chamber (66), affixed on an inner or outer surface of the cooling chamber (66), on one superconductive coil. These means allow regulation of flow of cooling fluid removed from the cooling chamber. In a complementary embodiment, similar means may be disposed upstream the inlet port (61) in a same manner, therefore allowing regulation of the cooling fluid supplied in the cooling chamber.

[0041] In a preferred embodiment of the present invention, the precooling means (60) may furthermore comprise means able to disrupt the flow of the cooling fluid inside the cooling chamber (60). These disruptive means may be attached to the inlet port (61) and/or the outlet port (62) and project into the cooling chamber (66). Alternatively, or complementarily, these flow-disrupting means may be attached to the plug (63), or to the insulator (65) when present, and project into the cooling chamber. A flow-disrupting means may be for example a metallic blade or a metallic rod. These flow-disrupting means may be means curved or not, means pierced or not, hollow means of solid means.

These flow-disruptive means allow enhancing the heat transfer between the cooling fluid and the means to be cooled (i.e. the cold block and/or the thermal radiation shield) by increasing the cooling fluid volume potentially in contact with an inner surface of the housing when the cooling fluid flows inside the cooling chamber.

[0042] In a preferred embodiment of the invention, the precooling device (60) also comprises its own housing. The precooling device housing fits the internal surface of the housing (50). By this way, the precooling device may be snug fitted inside the housing (50) before the precooling stage begin. According to this embodiment, the precooling device housing is in a thermal conductive material, like aluminium or copper. When the device comprises its own housing, means for disrupt the flow of cooling fluid may be disposed on an inner surface of the precooling device housing. In other words, these means may be alternatively and/or complementarily attached on an inner surface of the precooling device housing.

[0043] According to a preferred embodiment invention, a heater (5) is disposed on an outer surface of the housing (50), in contact with the distal portion (51) of the housing. Once a low temperature of the superconducting coils is reached, the precooling device is removed from the housing and may be replaced by the displacers of a cryocooler device. The heater (5) heats up locally the housing (50), facilitating the step of placing the displacers.

[0044] According to a preferred embodiment of the invention, the cooling system (1) mays comprise a plurality of housings (50) and a plurality of precooling devices (60).

[0045] The invention is also related to a method for precooling the superconductive coils of a superconductive magnet. The method is illustrated on Fig. 4.

[0046] According to a first embodiment of the method illustrated on Fig. 4b and Fig. 4c, a cooling system according to any one of the embodiments of the invention previously described is provided (Fig. 4b). A precooling device (60), according to any one of the embodiments previously described is provided and installed within the housing (50) (Fig. 4c). The superconductive coils are thereafter cooled down from a starting temperature to a temperature of about 80K by opening the inlet port (61), allowing supplying a cooling fluid inside the cooling chamber (66), and opening the outlet port (62), allowing the cooling fluid to be removed from the cooling chamber (66). Once the superconductive coils of the magnet reach the desired temperature, the precooling stage is over and the precooling device may be removed from the cooling system. The desired temperature may be comprised between 40 K and 120 K, more preferably the desired temperature is comprised between 60 K and 100 K, and still more preferably the desired temperature is comprised between 75 K and 85 K. Alternatively, the desired temperature may be lower than 120 K, more preferable the desired temperature is lower than 100 K, and more preferably, the temperature is lower than 85 K.

[0047] In a preferred embodiment of the method illustrated in Fig. 4b to 4d, once the precooling stage is over, and the precooling device is removed from the housing (50), a cryocooler, and preferably a two-stage cryocooler, is inserted inside the housing (50) in the same place as the removed precooling device (60). By inserting a cryocooler into the housing (50), it should be understood that displacer(s) (100a, 100b) of the cryocooler (100) are inserted inside the housing. During the precooling stage, these displacers could be held at low temperature by storing them in a low temperature room or device. As an example, these displacers could be plunged into liquid nitrogen inside a cryotank during the precooling stage. Before inserting the displacers, a step of removing any trace of the cooling fluid inside the housing (50) may be performed. The cryocooler is then activated, allowing the cooling of the superconductive coils of the magnet from the temperature reached at the end of the precooling stage (around 80 K, or 78 K) to the superconductive temperature (4,2 K). To this end, the cryocooler is supplied with a cooling fluid (for example liquefied neon), and the cryocooler is activated to further cool down the superconductive coils, from the end of precooling stage temperature to the superconductive state temperature.

[0048] A preferred embodiment of the method according to the invention is illustrated on Fig. 4a to Fig. 4d, the system comprises a cryocooler, and the method further comprises the steps of removing the displacers (100a, 100b) of the cryocooler (100) from the housing (50), followed by the step of placing the precooling device (50) inside the housing and hermetically closing the housing with the plug (63). The methods previously presented are thereafter performed.

[0049] A method according to the invention may also comprise steps of regulation of the flowing of the cooling fluid inside the cooling chamber. To this end, an extraction controlling means may be disposed on a pipe downstream connected to the outlet port, and the regulation is controlled by the volume of cooling fluid passing by the outlet port. Alternatively or complementarily, the flowing is regulated by control means disposed on a pipe connected to the outlet port or the inlet port, said control being controlled by a pressure sensor device disposed inside the cooling chamber, and/or a temperature sensor located on the housing (50), on the superconductive coils, on the cold block (40), and/or on the thermal radiation shield (20).

[0050] The present invention has been described in terms of specific embodiments, which are illustrative of the invention and not to be construed as limiting. More generally, it will be appreciated by persons skilled in the art that the present invention is not limited by what has been particularly shown and/or described hereinabove. Reference numerals in the claims do not limit their protective scope.

Use of the verbs "to comprise", "to include", "to be composed of", or any other variant, as well as their respective conjugations, does not exclude the presence of elements other than those stated.

Use of the article "a", "an" or "the" preceding an element does not exclude the presence of a plurality of such elements.

[0051] The invention may also be described as follows:

The present invention relates to a precooling device (60) for cooling the superconductive coils of a superconductive magnet (10). The precooling device (60) is able to be lodged into a housing (50), thereby forming a cooling chamber (66) where a cryogen fluid can be supplied and removed though ports (61, 62). The cooling system (1) allows reduction of the thermal link between the superconductive coils and the externa environment of the superconductive magnet (10).

Claims

1. A cooling system (1) for a superconductive magnet (10), said system (1) comprising:

- a superconductive coil being part of a superconductive magnet (10) thermally connected to a cold block (40), both being surrounded by a thermal radiation shield (20), said thermal radiation shield (20) being surrounded by an evacuated vacuum chamber (30),
- a housing (50) projecting into the cooling system (1) and configured to arrange a distal portion (51) of the housing (50) to be in thermal contact with the cold block (40) and a proximal portion (52) of the housing (50) extending through a wall (31) of the vacuum chamber (30),

characterized in that

the cooling system (1) comprises a removable precooling device (60) cooperating with the housing (50),

the precooling device comprising a plug (63) hermetically closing the proximal portion (52) of the housing (50), thereby forming a cooling chamber (66),

and **in that** the precooling device (60) further comprises:

- an inlet port (61) able to supply a cooling fluid inside the cooling chamber (66),
- an outlet port (62) able to remove the cooling fluid from the cooling chamber (66).

2. The cooling system (1) according to claim 1, **characterized in that** the precooling device (1) further comprises an insulator (65) disposed between the plug (63) on one end and the inlet port (61) and the outlet port (62) on the other end, said insulator (65) being able to physically insulate a portion of the cooling chamber (66) wherein the inlet port (61) and the outlet port (62) come out from a portion of the cooling chamber (66) in contact with the plug (63).

3. The cooling system (1) according to claim 2, **characterized in that** the insulator (65) further comprises at least one sealing member (67) disposed on an external surface of the insulator (65).

4. The cooling system (1) according to any one of the preceding claims, **characterized in that** the cold block (40) further comprises a finger (41) extending towards the thermal radiation shield (20), and **in that** the distal portion (51) of the housing (50) is in contact with the finger (41).

5. The cooling system (1) according to any one of the preceding claims, **characterized in that** the housing is able to house a cryocooler device, and preferably a two stages cryocooler device.

6. The cooling system (1) according to any one of the preceding claims, **characterized in that** the inlet port (61) comes out at a distance less than 5 cm from the distal portion (51) of the housing (50).

7. The cooling system (1) according to claim 4 or to claims 5-6 when dependent from claim 4, **characterized in that** the outlet port (62) comes out at a distance less than 5 cm from an inner surface (65a) of the insulator (65).

8. The cooling system (1) according to any one of the preceding claims, **characterized in that** extraction controlling means (70) able to regulate a flow of the cooling fluid removed from the cooling chamber (66) is disposed on a pipe (62a) downstream connected to the outlet port (62).

9. The cooling system (1) according to any one of the preceding claims, **characterized in that** the housing (50) further comprises means for disrupting a flow of the cooling fluid.

10. A cyclotron comprising a main superconducting magnet, the main superconducting magnet comprising superconductive coils, and a cooling system (1) according to any one of claims 1-9, the cooling system (1) being adapted to cool down the superconductive coils of the main superconducting magnet.

11. A method for precooling a superconductive coil of a superconductive magnet (10), said method comprising the following steps:

a) furnishing a cooling system (1) according to any one of claims 1-10;
b) flowing a cooling fluid through the cooling chamber (66) by opening the inlet port (61) and the outlet port (62) to cool down the superconductive coils of the superconductive magnet.

12. The method of claim 11, further comprising the steps of:

c) removing the precooling device from the housing (50),
d) placing at least one displacer in the housing (50) and hermetically closing the housing (50), thereby creating a cryocooler,
e) allowing a cooling fluid to enter the cryocooler and return from the cryocooler,
f) activating the cryocooler to further cool down the superconductive magnet (10).

13. The method of claim 11 or 12, wherein the further steps of:

g) removing at least one displacer located in the housing (50),
h) placing the precooling device (60) into the housing, and hermetically closing the housing (50),

are performed before the step a).

14. The method according to any one of claims 11 to 13, wherein the flowing is regulated by an extraction controlling means disposed on a pipe downstream connected to the outlet port, said regulation occurring by controlling the volume of cooling fluid passing by the outlet port.

15. The method according to any one of claims 11 to 14, wherein the flowing is regulated by control means disposed on a pipe connected to the outlet port or the inlet port, said control means being controlled by a pressure sensor device disposed inside the cooling chamber or a temperature sensor located on the housing (50), on the superconductive coils, on the cold block (40), and/or on the thermal radiation shield (20).

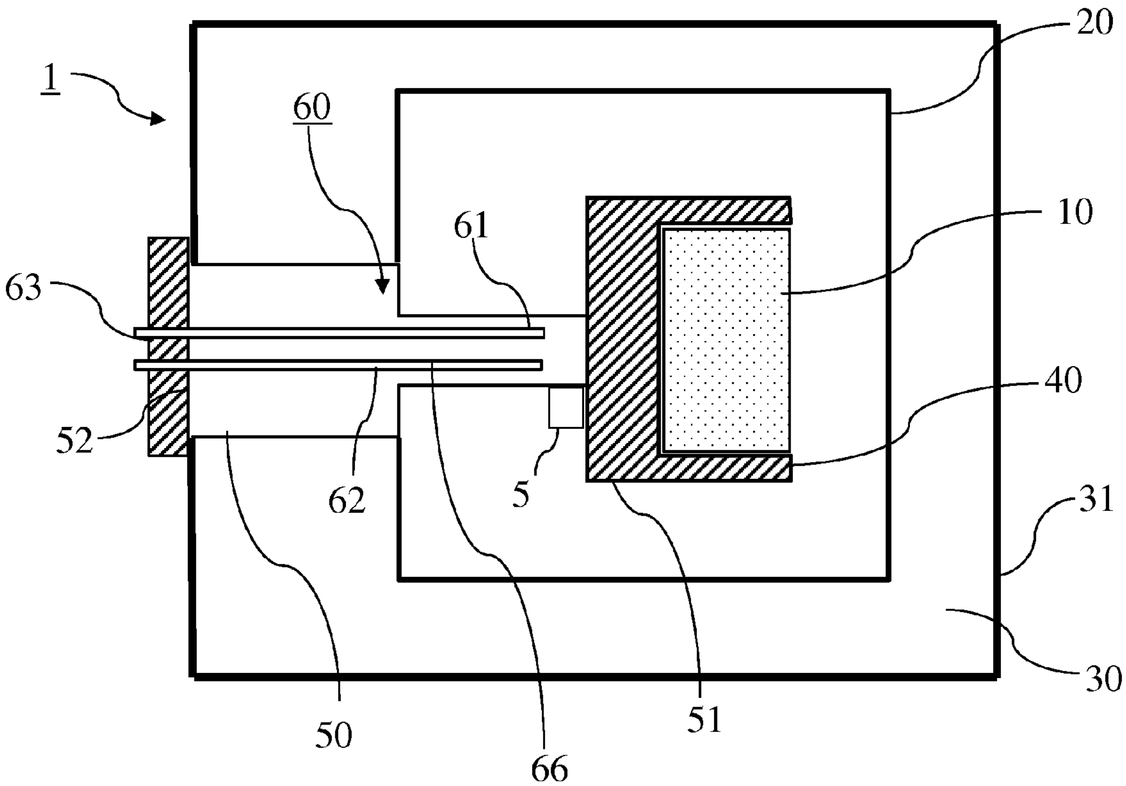
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Fig. 1

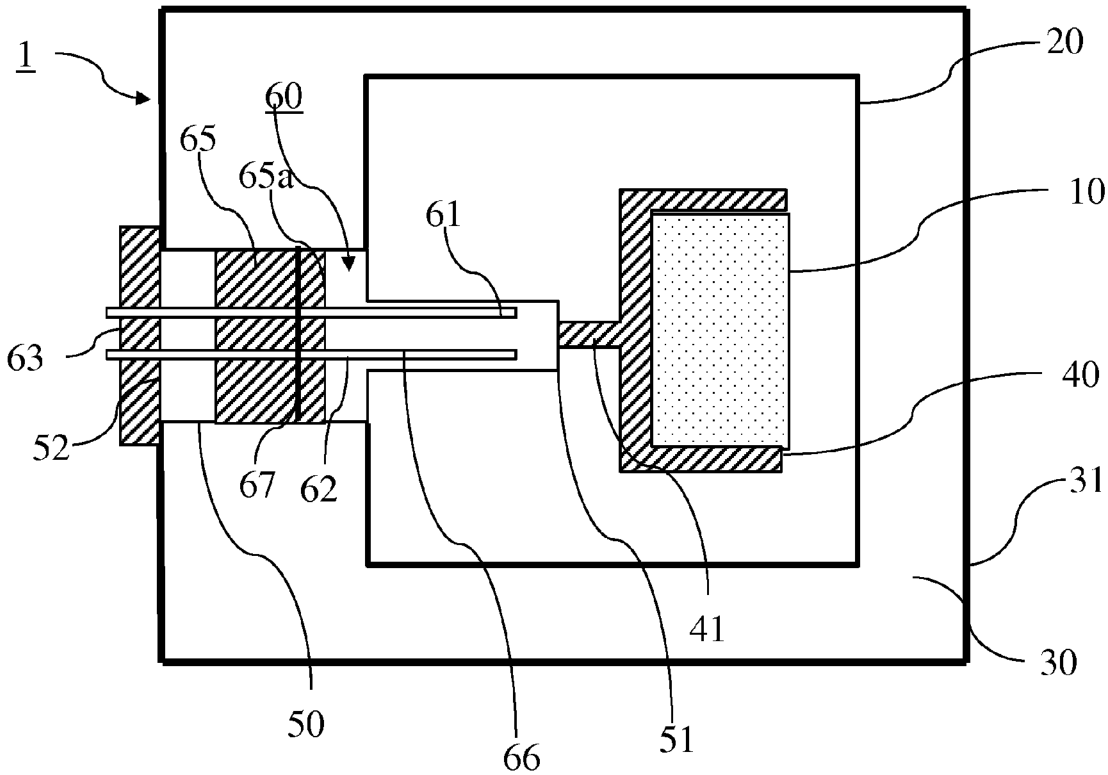
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Fig. 2

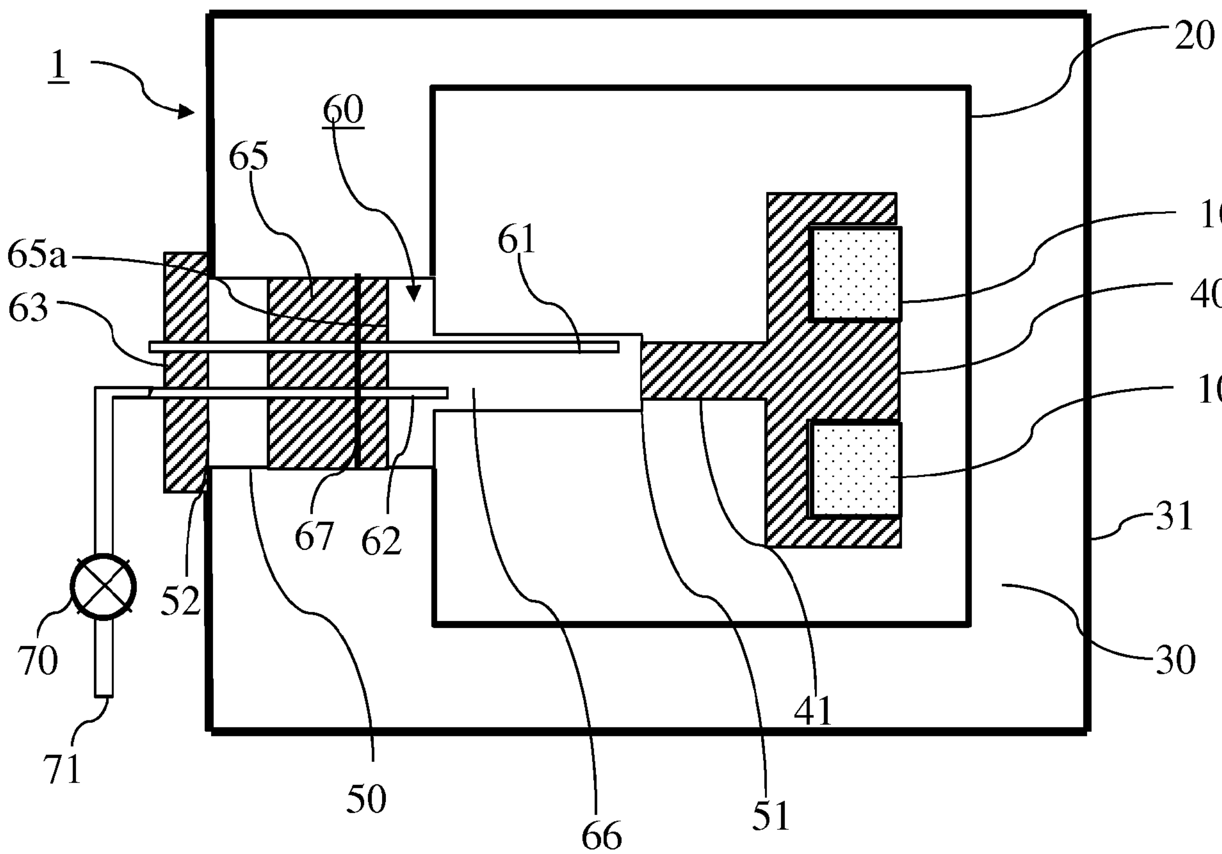

Fig. 3

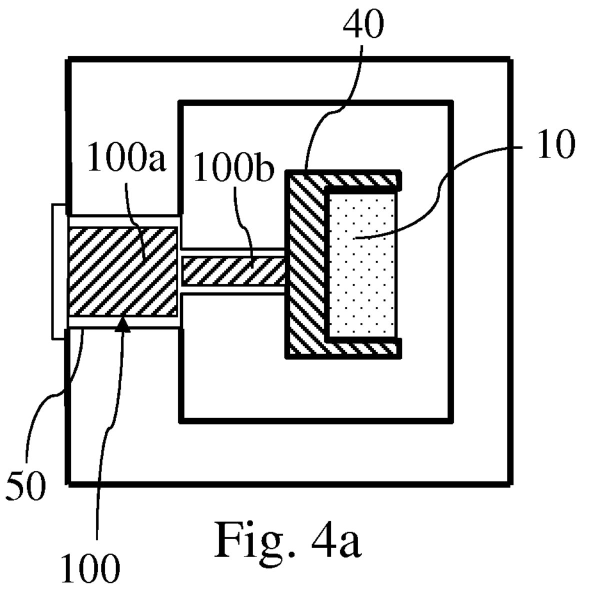

Fig. 4a

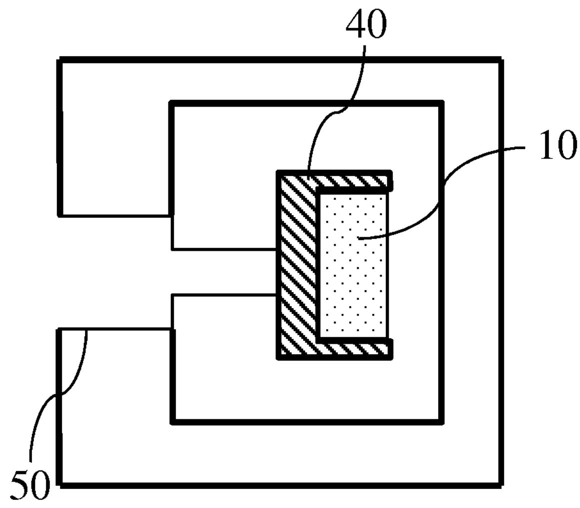

Fig. 4b

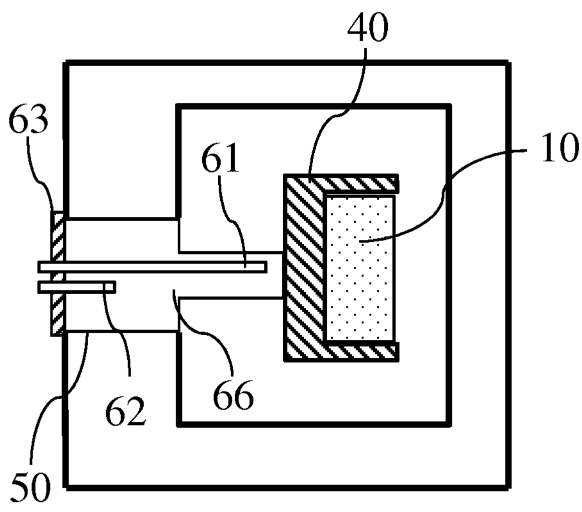

Fig. 4c

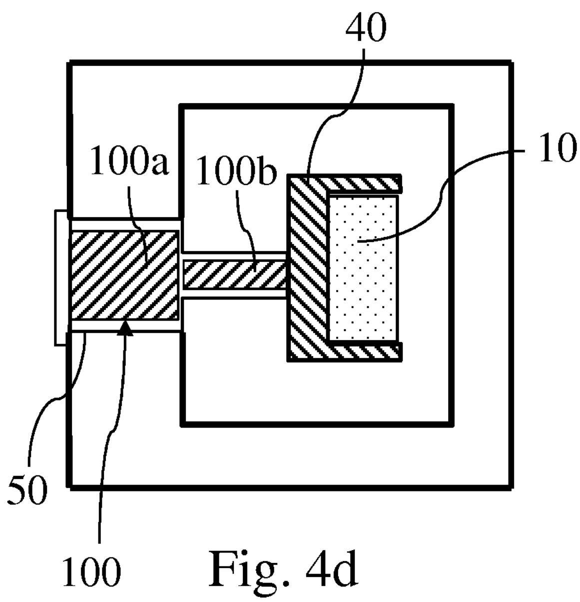

Fig. 4d

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EUROPEAN SEARCH REPORT

Application Number
EP 17 17 8598

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 4 926 646 A (DORRI BIZHAN [US] ET AL) 22 May 1990 (1990-05-22) * abstract; figures 1-6 * * column 3, line 5 - column 4, line 22 * -----	1-15	INV. F25D19/00 G01R33/38 H01F6/04
A	US 2008/036463 A1 (HSIEH HANK [US] ET AL) 14 February 2008 (2008-02-14) * abstract; figure 7 * * paragraph [0053] * -----	1-15	ADD. F25D16/00 F25D3/10
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F25D
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The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	10 November 2017	Yousufi, Stefanie

CATEGORY OF CITED DOCUMENTS

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