

May 13, 1969

W. KAFKA

3,444,307

COOLING SYSTEM FOR SUPERCONDUCTIVE OR CRYOGENIC STRUCTURES

Filed March 21, 1967

Sheet / of 2

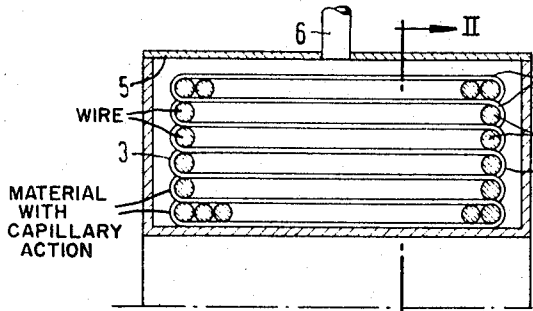


Fig. 1

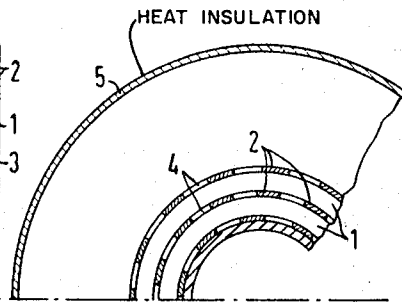


Fig. 2

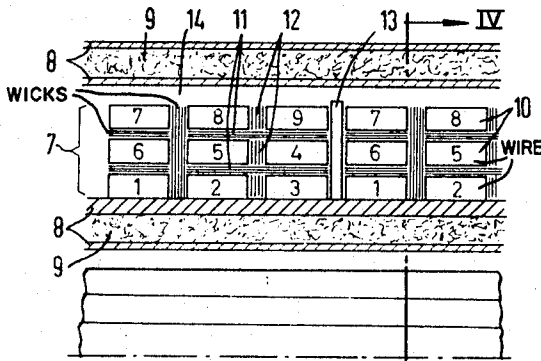


Fig. 3

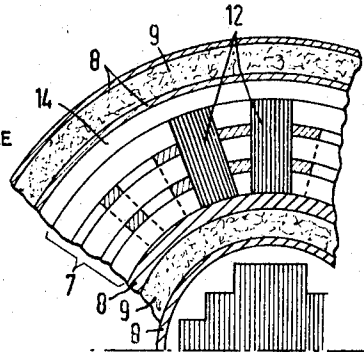


Fig. 4

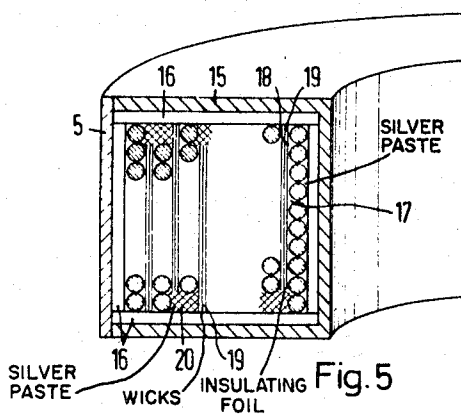


Fig. 5

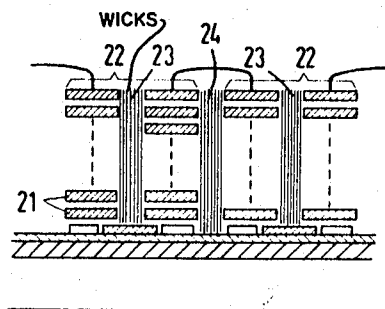


Fig. 6

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Sheet 2 of 2

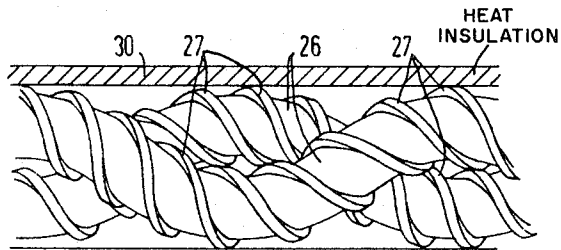


Fig. 7

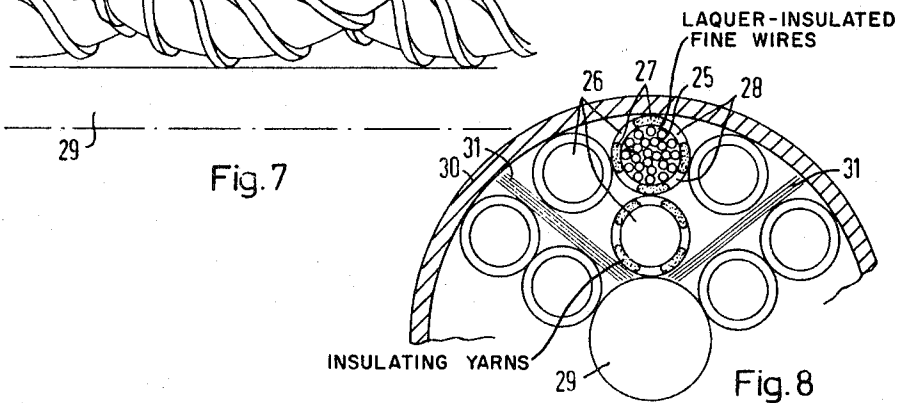


Fig. 8

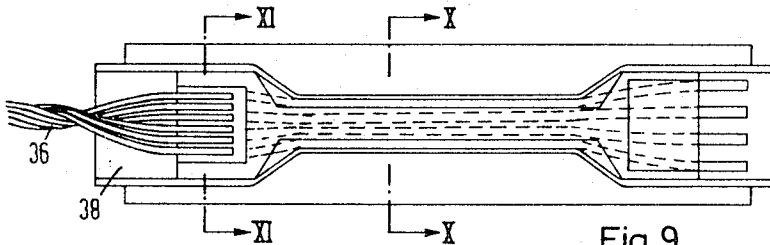


Fig. 9

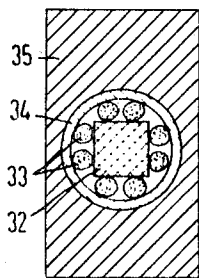


Fig. 10

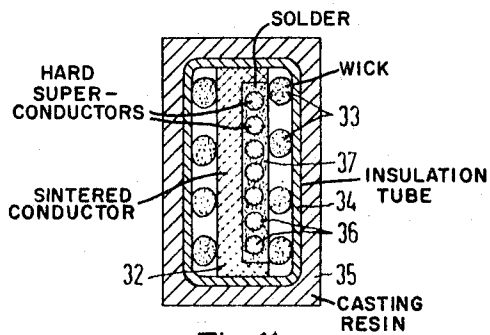


Fig. 11

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2

3,444,307

COOLING SYSTEM FOR SUPERCONDUCTIVE OR CRYOGENIC STRUCTURES

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U.S. Cl. 124—15

12 Claims

ABSTRACT OF THE DISCLOSURE

A system for cooling superconductive or cryogenic structures. The system includes an enclosure means for holding a liquid refrigerant, and a wick means extends into the enclosure means to engage a liquid refrigerant therein. This wick means also extends into engagement with an electrically conductive means for conveying the liquid refrigerant thereto for cooling the same, and a passage means is situated adjacent the wick means to provide an escape path for liquid refrigerant which is at least partly vaporized. The wick means has a mechanical strength great enough to enable it to simultaneously act as a spacer structure, and the wick means may be made of a bundle of cotton or of a bundle of twisted or braided fibers of metal or glass.

My invention relates to superconductive or cryogenic structures.

In particular, my invention relates to the cooling of such structures.

During the operation of superconductive or cryogenic electrically conductive coils, cryotrons, or cables, there is during at least part of the time heat which must be quickly dissipated. With superconductors such heat is present during a change in the current intensity or during a transition into the normal conducting state, while with cryogenic conductors or with normal conductors there is always heat when the latter are loaded. Normally a conductive package of electrical current conductors, such as a coil or a cable composed of a plurality of cable sections, is cooled only at its exterior surface directly by the liquid coolant in the event that a liquid cooling medium is used. The heat which is present in the interior of the conductive package is transported to the exterior surface thereof by heat conduction. Such heat conduction can be facilitated by the insertion of good heat conductors, such as copper foils. In order to retain the desired compactness of the package, however, the inserted heat conductors cannot be made with a sufficient thickness, so that this type of cooling of the current conductors in the interior of a conductive package is highly inadequate.

It is, therefore, a primary object of my invention to provide for liquid cooling of electrical current conductors, particularly superconductive or cryogenic conductors, in such a way that a sufficient cooling will be assured for those locations to which the liquid refrigerant can have access only with difficulty.

In accordance with my invention the electrically conductive means are placed in engagement with a wick means which engages a liquid refrigerant in a suitable enclosure means and which by capillary action conveys the liquid refrigerant by suction to the electrically conductive means for cooling the latter. Also, in accordance with my invention, there is situated adjacent the wick means a passage means which provides an escape path for liquid refrigerant which is at least partly vaporized.

A further object of my invention is to provide a wick structure which has a sufficiently great mechanical strength to enable this wick structure to act at the same time as a

spacer structure. In order to fulfill this latter requirement, the wick means can be composed of a bundle of fine glass fibers, metal fibers, or of a porous tape.

The dissipation of heat from the interior of a structure such as a coil, a cryotron, or a cable having multiple cable sections takes place in accordance with my invention by vaporizing of the liquid refrigerating medium which is continuously replenished by capillary action from outer chambers or passages which are filled with liquid refrigerant into the interior of the structure without relying on gravity or pumps, while the vapor in the interior of the structure can escape through open passages. In the region of the current conductors where the heat is created wicks and passages for the vaporized refrigerating medium alternate with each other. The wicks are composed, for example, of bundles or tapes, braided or twisted fibers, made of glass, silk, cotton, and the like, or they may be composed of fine wires. It is also possible to use tapes composed of a porous mass.

My invention is illustrated by way of example in the accompanying drawings which form part of this application and in which:

FIG. 1 is a fragmentary schematic axial section of a superconductive or cryogenic conducting coil having axially arranged wicks;

FIG. 2 is a fragmentary transverse section of the structure of FIG. 1 taken along the line II—II in FIG. 1;

FIG. 3 is a fragmentary schematic axial section of the secondary coil of a cryogenic transformer having radially arranged wicks;

FIG. 4 is a fragmentary transverse section of the structure of FIG. 3 taken along the line IV—IV in FIG. 3;

FIG. 5 is a fragmentary partly sectional illustration of a superconductive coil having axially arranged wicks;

FIG. 6 is a schematic fragmentary axial section of a coil having disc windings and axially arranged wicks;

FIG. 7 is a fragmentary longitudinal section schematically illustrating a superconductive cable having the structure of the invention;

FIG. 8 is a fragmentary schematic transverse section of the structure of FIG. 7;

FIG. 9 is a schematic longitudinal illustration of a wick-cooled cryotron;

FIG. 10 is a schematic transverse section taken along line X—X of FIG. 9 in the direction of the arrows; and

FIG. 11 is a schematic transverse section taken along line XI—XI of FIG. 9 in the direction of the arrows.

FIGS. 1 and 2 respectively illustrate different views of a wound coil which has no end flanges. The wire 1 of each winding layer is prevented from slipping by means of tapes 2 which are inserted between the winding layers and which surround the latter at their ends. These tapes 2 are made of a material which has capillary action and which conveys liquid refrigerant from the ends 3 of the windings into the interior thereof. The tapes 2 are, as is apparent from FIG. 2, circumferentially distributed about the windings, so that these tapes 2 define between themselves passages 4 forming a passage means through which the vapor present between the winding layers can easily reach the exterior surface of the windings. The windings is situated in a heat-insulating housing 5 which communicates with tubes 6, only one of which is illustrated in FIG. 1, by means of which liquid refrigerant is supplied to the interior of the housing 5 and vapor is conducted away from the interior thereof. As a result of the capillary action of the wick means 2 a pump for the refrigerating medium becomes unnecessary. The interior winding wires are cooled in a faultless manner at every part of the coil.

FIGS. 3 and 4 show in different views sections of a cryogenic transformer having a deeply refrigerated secondary coil 7 for feeding a superconductive or cryogenic

conductive three-phase current cable, the secondary coil being provided with an unillustrated primary winding which is at a normal temperature. The cryogenic conductive secondary coil is situated within a double-walled housing 8 which contains between its walls a heat insulation 9 (superinsulation). The winding is made up of cables 10 of thin wire, these cables being wound in series in the sequence which is numerically indicated in FIG. 3 so that individual winding packages are provided. Between the cables of each package are wicks 11 and 12 which extend both in the axial direction of the coil as well as radially with respect thereto. These wicks hold the windings in spaced relation with respect to each other so as to act as spacers. In addition, the groups of windings are supported in spaced relation with respect to each other by spacer elements 13. Outside of the winding cylinder is a cylindrical chamber 14 for the liquid refrigerating medium, so that in this way the structure is provided with an enclosure means for the refrigerating medium. Of course, the housing 5 of FIG. 1 provides an enclosure means for the refrigerating medium of this embodiment. In both cases the refrigerating medium is a liquid.

In the case of superconductive windings which have continuous shunting by means of a conductive coating of lacquer, the cooling system of the invention which provides conveying of the liquid cooling medium by means of capillary action can be brought about, for example, in the manner shown in FIG. 5. The coil housing 15 is insulated in its interior and is provided with fins 16 which support the windings and at the same time define free chambers for the liquid helium. In order to achieve a continuous shunting for the winding, the individual wire layers carry a silver paste 17 which presses into the tapered spaces defined between adjoining wires. The adjoining wire layers are separated from each other by at least one insulating foil 18 and by wicks 19 which are circumferentially distributed around the winding layers. The transition from one layer to the next is brought about by silver paste 20 or by woven tapes which are impregnated with silver paste. In this way a shunting of the adjoining layers is achieved.

This winding structure of FIG. 5 is achieved in the following manner. After the first wire winding layer has been made, the silver paste is applied and after setting of this paste an insulating tape which is almost as wide as the layer is applied on the latter. This tape consists of an impermeable insulating foil such as, for example, polyethylene terephthalate, provided at its inner surface, in a direction transverse to the axis of the wire, with wicks which extend parallel to the coil axis. Thus, there remains between these wicks small passages through which vapor is withdrawn. At the transition location of the wire from one layer to the next, the free hollow space is filled with silver paste. In order to facilitate the winding it is possible to place at these transition locations woven tapes which are also impregnated with paste.

FIG. 6 illustrates a winding which is wound from tapes 21 in the form of double discs 22. The tapes are insulated from each other or are separated from each other by semi-conductive layers. Between the two components of each double disc there are radially extending wicks 23 inserted in a manner similar to the embodiment of FIG. 3. Also, between adjoining double discs it is possible to arrange wicks 24. The passage means defined between the wicks will in this case also extend radially. At the outside, around the entire disc winding is a free chamber which forms an enclosure means for the liquid refrigerating medium.

FIGS. 7 and 8 show in different cross sections a superconductive or cryogenic conductive cable for very high current intensities. The cable is composed of a multiplicity of very fine wires 25 which, for example, are insulated from each other by lacquer or by glass silk which is spun around the individual wires, and these wires are twisted into the individual cable sections 26. Thicker yarns or fibers 27 are wound around the individual cable sections,

and these fibers 27 are made of an insulating material and define between themselves the passage means 28 through which the outwardly flowing gas can escape. As is apparent particularly from FIG. 7, the elements 27 are helically wound around the cable sections 26 with the elements 27 on one cable section spaced from those on an adjoining cable section. In the interior of the cable is a free enclosure 29 for the refrigerating medium, and within the chamber 29 there is a longitudinal flow of the refrigerating fluid from the supply location of the liquid refrigerant to the discharge location for the vapor, so that this chamber 29 forms not only an enclosure means for the liquid refrigerant but also a passage means for the escape of vapor. With corresponding insulation between the supply and return conductors or between the three phases of an alternating current system, all of the conductors can be situated in a concentric or twisted manner within a single heat-insulating body 30. The penetration of the liquid helium into the interior of the cable sections can be improved by inserting during the manufacture of the cable, wicks 31 which extend perpendicularly with respect to the direction in which the conductors extend.

The wick-cooled cryotron which is illustrated in FIGS. 9-11 includes a sintered gate conductor 32 and wicks 33 which extend parallel to the elongated gate 32. These wicks consist of tightly twisted round glass fiber bundles which provide a capillary action between the individual glass fibers. The tapered spaces defined between adjoining glass fiber bundles act as gas passages. The gate conductor, wicks, and passages are surrounded by an insulating tube or enclosure 34 which prevents impairment of the cooling system by penetration of casting resin into the interior intermediate spaces during casting of the cryotron into a body of casting resin 35. At the location of the connection between the sintered cryotron and the bundle of hard superconductors 36, the cross section of the cryotron is widened into a U-shaped configuration, as is apparent from FIG. 11. In the depression which is created in this way, the cables 36 of hard superconductors are inserted and fixed by solder 37. As a result of this widening, the distance between the glass fiber bundles 33 is also increased. The helium bath contained in the superconductive cable extends into these widened intermediate spaces, so that the wicks terminate in the helium bath.

I claim:

1. In a system for cooling superconductive or cryogenic structures, enclosure means for holding a liquid refrigerant, electrically conductive means for conducting an electric current, wick means extending into said enclosure means to engage a liquid refrigerant therein and also engaging said electrically conductive means for conveying the liquid refrigerant thereto by capillary action, so as to cool said electrically conductive means, and passage means situated adjacent said wick means for providing an escape path for liquid refrigerant which is at least partly vaporized.

2. The combination of claim 1 and wherein said wick means is mechanically strong enough to act as a spacer structure, and said wick means coating with said electrically conductive means to act as a spacer structure therefor.

3. The combination of claim 1 and wherein said wick means includes a bundle of cotton

4. The combination of claim 1 and wherein said wick means is composed of a bundle of fine fibers consisting of glass.

5. The combination of claim 4 and wherein said fibers are twisted.

6. The combination of claim 4 wherein said fibers are braided.

7. The combination of claim 1 and wherein said wick means is composed of porous tapes.

8. The combination of claim 1 and wherein said electrically conductive means is in the form of a coil having a given axial direction and distributed in a radial direction

5

about said axial direction, and said wick means and passage means extending in at least one of said directions.

9. The combination of claim 1 and wherein said electrically conductive means has the form of a plurality of individual cable sections combined into a single cable, and said wick means including a plurality of wicks respectively wound helically around said cable sections with the wicks which engage the individual cable sections being spaced from each other.

10. The combination of claim 1 and wherein said electrically conductive means includes an elongated cryotron gate, and said wick means including a plurality of wicks extending longitudinally along said gate in a direction parallel thereto, and said wicks being spaced from each other.

11. The combination of claim 1 and wherein an

6

insulating tube surrounds and encloses said gate, said wicks, and said passage means.

12. The combination of claim 1 and wherein said wick means is composed of a bundle of fine fibers consisting of metal.

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10 LEWIS H. MYERS, *Primary Examiner*.

A. T. GRIMLEY, *Assistant Examiner*.

U.S. Cl. X.R.

15 62—65.5; 174—27, 29; 335—216