

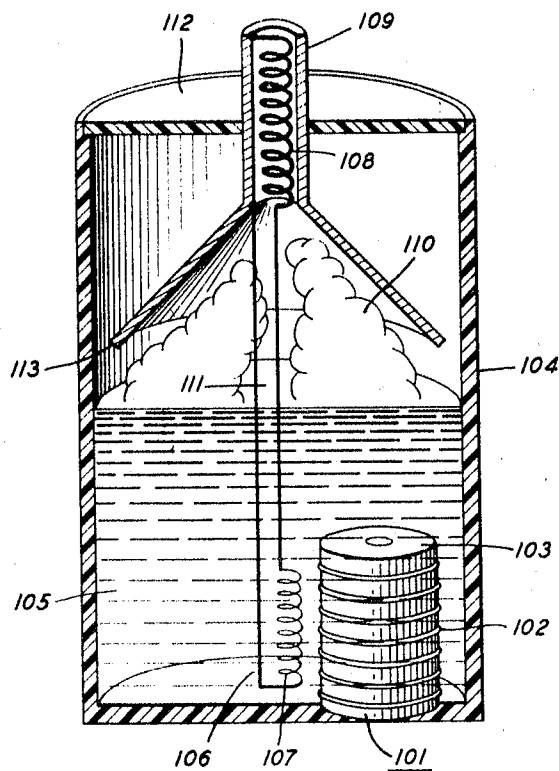
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PROTECTIVE CIRCUIT FOR SUPERCONDUCTING MAGNET

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PROTECTIVE CIRCUIT FOR SUPERCONDUCTING
MAGNET

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9 Claims

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In the case of particularly large magnets, a protective arrangement of the type indicated requires the use of relatively heavy conductors between the secondary coil and the dumping circuit in order to avoid excessive inductive voltages. Conductors of such magnitude, however, also conduct heat into the cryostat during normal operation and as a result, an unacceptable amount of helium can be lost through a more or less constant boiling-off process.

SUMMARY OF THE INVENTION

The object of the invention is to avoid the potentially damaging effects of suddenly collapsing magnetic fields in superconducting magnets while still maintaining the attendant loss of the cooling medium at an acceptable level. This object and related objects are achieved in accordance with the principles of the invention by providing a superconducting magnet arrangement with a closely coupled secondary winding which has a time constant (L/R) of sufficient length to allow a relatively gentle decay of the field. Energy coupled into the secondary winding is in turn conducted to a resistive member within the cryostat. The resistive member is characterized by a large thermal mass that is positioned above the level of the liquid cooling medium to ensure minimum thermal contact therewith.

In accordance with an important aspect of the invention the thermal mass operates effectively as a heat exchanger in absorbing the heat energy that results from a suddenly collapsing field. In the event of a field collapse, a portion of the attendant heat energy that appears in the secondary winding and in the magnet structure vaporizes a small amount of the cooling medium. The resulting low temperature gas is directed against the thermal mass resistive element as a coolant before it is permitted to escape through the cryostat vent. In this way, the potentially destructive release of heat energy is effectively and gradually dissipated and the magnet structure is fully protected from damage.

BRIEF DESCRIPTION OF THE DRAWING

The single figure of the drawing is a sketch, partially in cross section, of a superconducting magnet assembly in accordance with the invention.

DETAILED DESCRIPTION

In the figure a superconducting magnet structure **101** is formed from a superconducting coil **102** around a core member **103**. The coil **102** may be formed from any suitable superconducting material such as one of the many niobiumzirconium alloys. A number of specific types of superconductive magnet coil structures are known in the art, one illustrative structure being shown in Patent 3,129,359, issued to J. E. Kunzler, on Apr. 14, 1964.

The magnet structure **101** is immersed in a cooling medium **105**, such as liquid helium, for example, to ensure the maintenance of a temperature less than the superconducting temperature level that is peculiar to the particular material of the coil **102**. The magnet structure **101** and the liquid helium bath **105** are contained within a cryostat **104** to ensure maximum isolation from ambient temperatures.

In accordance with the invention a secondary winding assembly **106** is employed to dissipate energy that is inductively transferred thereto upon any sudden collapse of the field of the magnet structure **101**. The secondary assembly **106** includes a first coil **107** that is closely coupled to the coil **102** to ensure efficient energy transfer from a collapsing field.

The time constant characterized by the L/R ratio of the coil **107** should be kept as long as practicable to extend the time duration of energy transfer. A further requirement for the coil **107** is that its resistance should

ABSTRACT OF THE DISCLOSURE

A secondary winding is closely coupled to the windings of a superconducting magnet in a cryostat containing liquid helium. An appreciable thermal mass is positioned above the level of the liquid helium and is connected electrically to the secondary. The thermal mass serves as a heat exchanger that is cooled by gaseous helium whenever excess and potentially destructive energy produced by a sudden collapse of the magnetic field is transferred from the magnet to the secondary and thence to the thermal mass.

BACKGROUND OF THE INVENTION

Field of the invention

This invention relates to superconducting electromagnets and more particularly to protective arrangements for dissipating the excess and potentially destructive energy that is released by the relatively sudden collapse of the superconducting magnet's magnetic field.

Description of the prior art

It is known that high strength magnetic fields may be produced by means of superconducting electromagnets that are constructed by coiling one or more turns of a superconducting wire or other superconducting element about a common core. The magnet structure is typically immersed in a low temperature environment such as liquid helium, for example, in a suitable insulating container such as a Dewar flask or cryostat. The low temperature environment is essential to maintain the magnet coil in its superconducting state. These magnets have the advantage of compactness and practically negligible power requirements. Persistent currents can be established in the coils owing to their superconducting properties and hence the power supply need be connected to the coil only for initial energization or, at most, only intermittently. A complete stable magnetic field can thus be maintained so long as the coils are kept at or below their critical temperature and critical field.

When superconducting magnets are operated at high magnetic fields, they are particularly susceptible to an accidental collapsing of the field. A field collapse of this nature may occur within a fraction of a second and can result in a destructive shock wave. Additionally, if the magnet is sufficiently large and the field sufficiently high, the energy induced in the coils by the collapsing field may be converted into heat energy great enough in magnitude to melt, vaporize or even explode the magnet structure.

In order to provide a measure of protection against the inherent dangers of a suddenly collapsed magnetic field, a number of prior art superconducting magnet systems employ some means of dissipating the excess energy created thereby. In the case of relatively small magnets, for example, it has been possible to connect an energy dissipating or dumping circuit external to the cryostat. Energy from the magnet coil may be transferred to a closely coupled secondary coil within the cryostat and from the secondary coil to the external dumping circuit by way of connecting leads.

be as low as practicable to minimize the translation of current into heat energy at that point. Accordingly, the coil 107 should be formed from a high conductivity material such as aluminum or copper, aluminum having the advantage of low magnetoresistance.

Leads 111 are employed to connect the secondary coil 107 to a heat exchanger coil 108 and to a large thermal mass resistive heat sink 109 which is in form similar to an inverted funnel. Alternatively the coil 108 and the heat sink 109 may be replaced by a common heat sink mass. The combined material of the coil 108 and the heat sink 109 should be sufficient to limit heating to less than several hundred degrees C. when all of the energy from a collapsing field is dumped into it. In order to be reasonably effective, however, the temperature rise of the heat sink 109 should be at least a substantial fraction of 100° K.

The combination of the thermal sink 109 and the coil 108 operates, in effect, as a heat exchanger which is cooled by escaping helium gas 110 which is forced to pass through the heat exchanger. The spacing between the rim 113 of the mouth portion of the funnel-like heat exchanger 109 and the wall of the cryostat 104 is sufficiently limited to ensure that most of the gas reaches the neck portion or vent. The resistance of the heat exchanger combination (coil 108 and heat sink 109) is made very large compared to the secondary winding 107 in order to ensure that most of the translation from electrical energy to heat energy takes place outside of the liquid helium bath 105. In this connection, design consideration must be given to the increased resistance of the coil 107 that results from the heat generated therein during the collapse of the magnetic field. In accordance with the invention, suitable alloys may be selected to form coil 108 and the heat sink 109 in order to achieve the appropriate combination of resistance and thermal mass.

SUMMARY OF OPERATION OF THE EMBODIMENT

Whenever the coil 102 is "driven normal" (i.e., becomes suddenly nonmagnetic), much of the energy in the resulting collapsing field is transferred to the secondary winding 107, the L/R time constant of which should be large compared to that of the windings 102 in their normal or nonsuperconducting state in order to ensure efficient coupling. The rate of collapse of the field is controlled by the time constant of the secondary windings 107. Since most of the resistance of the secondary winding assembly 106 is in the winding 108 and in the heat sink 109, most of the heat will be generated there. Owing to the fact that the coupling between the windings 102 and 107 is not ideal, however, some heat is developed within the magnet structure 101. This heat evaporates a certain amount of liquid helium. The gaseous helium passes through the heat exchanger consisting of the coil 108 and the heat sink 109, thus cooling these elements. Even assuming that the coupling between the coils 102 and 107 were to approach the ideal, and the resistance of the coil 107 were negligible as compared to the heat exchanger elements 108 and 109, heat would still flow from the thermal sink 109 down the leads 111 into the helium bath 105, thus providing the gas 110 for removing heat from the heat exchanger 109.

It is to be understood that the embodiment described herein is merely illustrative of the principles of the invention. Various modifications thereto may be effected by persons skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. Superconducting magnet apparatus comprising, in combination, a first coil of superconductive material, a secondary coil closely coupled to said first coil but insulatedly separated therefrom, a liquid cooling medium for maintaining said first coil below its superconducting temperature, said first coil and said secondary coil being immersed in said liquid, an insulated container for maintaining said liquid at a substantially fixed temperature, a highly resistive heat sink positioned in said container above the level of said liquid, and conductive means connecting said secondary coil to said heat sink, whereby energy coupled into said secondary coil by any sudden collapse of the field of said superconducting magnet is translated into heat energy in said heat sink, said heat sink being cooled by gas resulting from the partial vaporization of said liquid.

2. Apparatus in accordance with claim 1 wherein the electrical resistance of said heat sink is substantially higher than the electrical resistance of said secondary coil.

3. Apparatus in accordance with claim 1 wherein said heat sink comprises an inverted funnel-shaped member with the neck portion thereof forming a vent for said container.

4. Apparatus in accordance with claim 3 wherein said heat sink further includes a relatively high resistance coil positioned in said neck portion of said funnel and electrically connected thereto.

5. Superconducting magnet apparatus comprising, in combination, a first coil of superconducting material, a secondary coil closely coupled to said first coil but insulatedly separated therefrom, a cryostat and a liquid coolant contained therein, said first coil and said secondary coil being immersed in said coolant, means within said cryostat above the level of said liquid for translating electrical energy into heat energy, and electrically conductive means connecting said secondary coil to said translating means, said translating means being positioned to permit the cooling thereof by vaporized portions of said liquid.

6. Apparatus in accordance with claim 5 wherein said liquid is helium.

7. Apparatus in accordance with claim 5 wherein said translating means comprises electrically conductive material having a relatively high thermal mass.

8. Apparatus in accordance with claim 7 wherein said translating means comprises an inverted funnel member with the neck portion thereof forming a vent for escaping helium gas.

9. Apparatus in accordance with claim 8 including a relatively high resistance coil positioned in the neck portion of said funnel member, said last-named coil being electrically connected to said funnel member.

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LEE T. HIX, Primary Examiner

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