May 12, 1964 W. B. COTTINGHAM ETAL 3,133,144

CRYOSTAT

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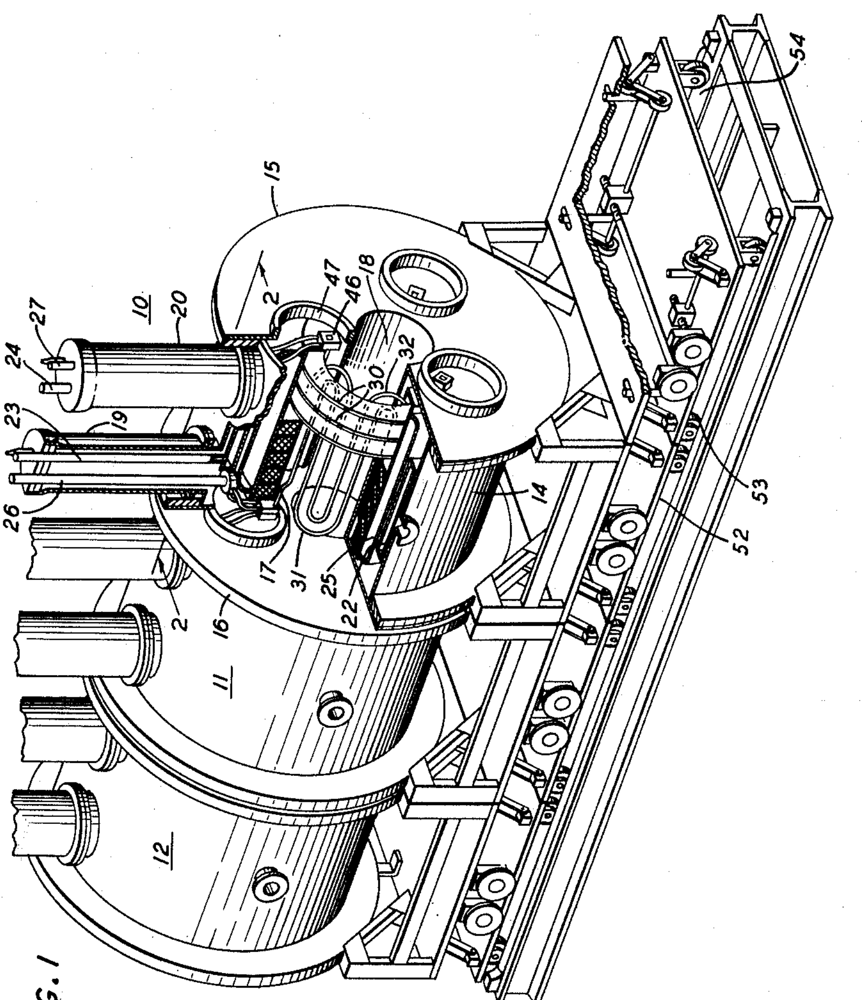

FIG. 1

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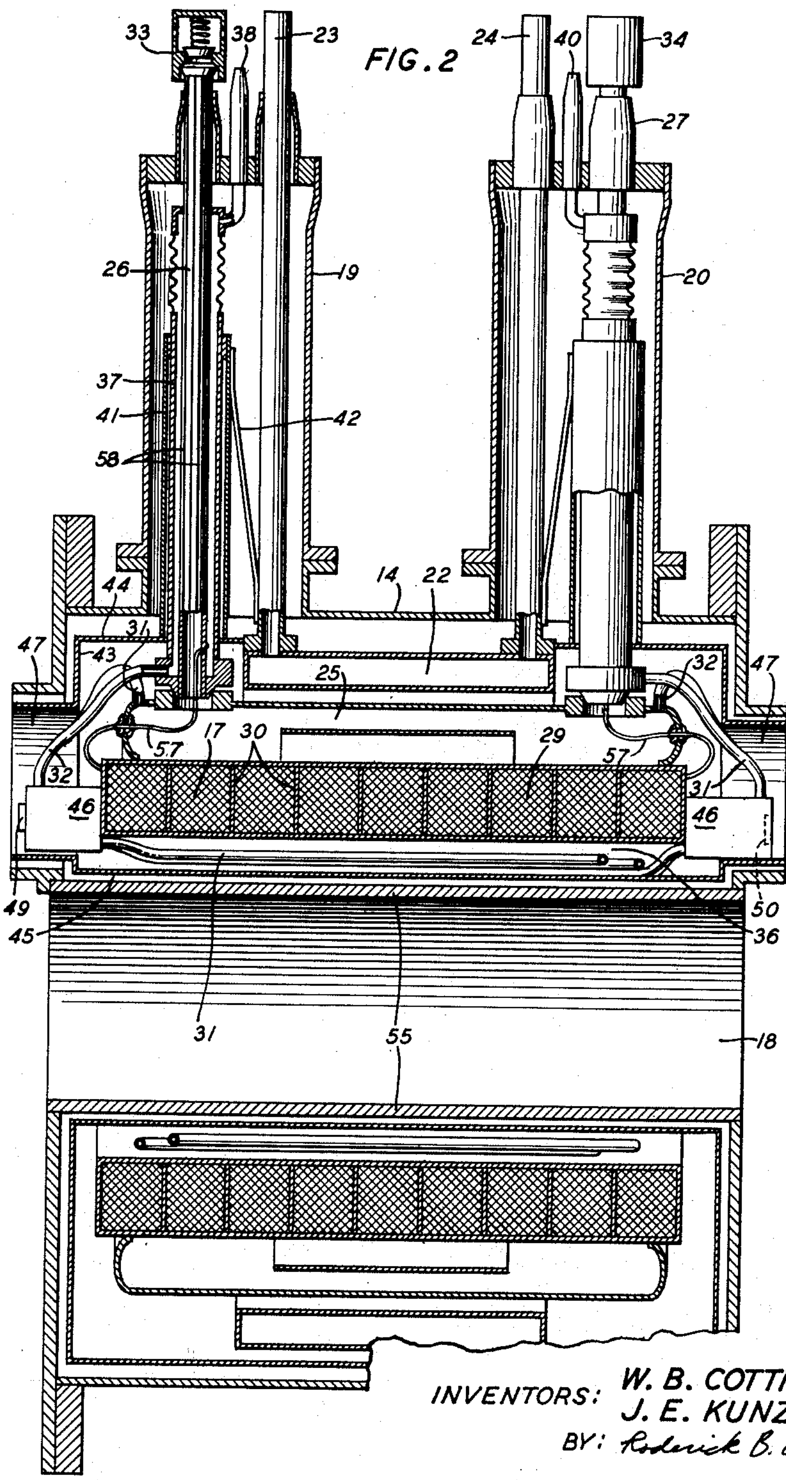

FIG. 2

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CRYOSTAT

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This invention relates to cryostats and, more particularly, to cryostats for refrigerating superconducting electromagnets.

Considerable use has been made recently of the discovery that certain superconductors can be shaped into solenoids. Superconductive solenoids are capable of producing extremely high magnetic fields and for this reason are valuable laboratory tools for such purposes as plasma and atomic research. These solenoids tend, however, to be difficult to work with because they must normally be contained in a bath of liquefied gas such as helium to maintain the extremely low temperatures that are necessary for superconductivity. Liquid helium, with a boiling point of about 4° K., requires such elaborate insulation that the test volume within the solenoid, as well as the solenoid itself, is almost inaccessible.

It is therefore an object of this invention to make more accessible the test volume within a supercooled solenoid.

It is another object of this invention to simplify the cryostat structure that is necessary for supercooling a superconductive solenoid.

Another object of this invention is a cryostat-solenoid package that can be easily attached to other cryostat-solenoid packages for the purpose of forming a uniform, intense magnetic field of any desired length.

It is a further object of this invention to supercool a superconductive solenoid efficiently.

These and other objects of our invention are attained in an illustrative embodiment thereof which comprises an evacuated cylindrical annular encasement containing a superconductive solenoid to be refrigerated to approximately 4° K. According to one feature of the invention, the encasement is divided into successive concentric annular chambers. An outer annular chamber contains liquid nitrogen which surrounds and insulates an annular chamber of liquid helium. The helium chamber surrounds a chamber containing the superconductive solenoid. Within the solenoid is a chamber containing folded piping for transmitting evaporated helium gases from the helium chamber. A cylindrical shield thermally connected to the liquid nitrogen chamber insulates the helium piping from the inner wall of the encasement. After the helium gases cool the inner surface of the solenoid they are transmitted out of the cryostat by an annular exhaust pipe that coaxially surrounds the helium input pipe so that the input liquid helium is efficiently insulated.

According to another feature of the invention the encasement includes a pair of annular end plates having a plurality of portholes for exposing heavy steel spacers on the solenoid. The spacers can be keyed to similar spacers of other cryostat-solenoid packages so that an extended magnetic field of any desired length can be attained. The spacers separate the solenoids, which are attracted by powerful magnetic forces, they align the solenoids, and they act as thermal conductors.

These and other objects and features of the invention will be more fully appreciated from a consideration of the following detailed description, taken in conjunction with the accompanying drawing, in which,

FIG. 1 is a perspective view, partly in section, of our invention; and

FIG. 2 is a section taken along lines 2—2 of FIG. 1.

Referring now to FIG. 1 there are shown three cryostat packages **10**, **11**, and **12** which are joined together in accordance with the invention. Cryostat **10** is shown partly in section and comprises an evacuated encasement **14** having annular end plates **15** and **16**. Contained within the encasement is a solenoid **17** which is made of a material such as an alloy of 75% niobium and 25% zirconium by weight, which displays superconductive characteristics at temperatures approaching absolute zero. The purpose of the cryostat is to maintain such low temperatures while electrical current flows through the solenoid. As is known, under these conditions, a large magnetic field can be produced in the test volume **18** surrounded by the solenoid **17**.

With reference to both of the figures, cryostat package **10** has two input terminals **19** and **20** for receiving liquid nitrogen and liquid helium. Liquid nitrogen, with a boiling point of about 77° K., is introduced into an annular chamber **22** through an input line **23** in terminal **19** and on input line **24** in terminal **20**. The nitrogen in chamber **22** and input line **23** is insulated by vacuum spaces within encasement **14** and terminal **19**; experience has shown that it is not necessary to seal the end of input pipes **23** and **24** which are accordingly left open.

Liquid helium, with a boiling point of about 4° K., is introduced into another annular chamber **25** through an input line **26** in terminal **19** and an input line **27** in terminal **20**. Helium chamber **25** coaxially surrounds the superconductive solenoid **17** and maintains it at an appropriately low temperature. The solenoid **17** is contained within an annular chamber **29** which is segmented by a plurality of ribs **30**. When solenoid **17** is energized the resulting magnetic field exerts a powerful attractive force among the coils thereof which tends to force them together. The ribs **30** counter this force and maintain the desired shape of the solenoid.

The inner surface of solenoid **17** is cooled by a pair of folded pipes **31** and **32** that transmit evaporated helium gas from helium chamber **25**. The helium input pipes **26** and **27** are sealed by safety valves **33** and **34**, respectively, which prevent the cold evaporated helium gas from escaping to the atmosphere. At this juncture it should be pointed out that the cryostat packages **10**, **11**, and **12** are structurally symmetrical so that the right portion of FIG. 2, which is only partially shown in cross-section, is essentially the same as the left portion. The safety valves **33** and **34** allow passage of helium gas only if it builds up to a dangerously high pressure; otherwise the gas is allowed to pass into pipes **31** and **32**.

Pipes **31** and **32** are contained within an annular chamber **36** which is enclosed by the solenoid **17**. As can be seen from FIG. 1, pipes **31** and **32** are folded in a serpentine shape and are interleaved to form an annular cylinder within chamber **36**. We have found that this construction gives uniform refrigeration of the solenoid and makes maximum use of the evaporated helium. Because the pipes are well insulated, as will be explained later, the helium remains at essentially 4° K. as it circulates through chamber **36**.

Helium gas is transmitted by pipe **31** from a point near terminal **19**, through chamber **36**, to terminal **20**, while pipe **32** transmits it from terminal **20** to terminal **19**. As best seen in FIG. 2, the helium gas from pipe **31** is exhausted through an annular exhaust pipe **37** to a vent **38**. Exhaust pipe **37** surrounds, and is coaxial with, helium input line **26**, thereby insulating the helium input line. Likewise, gas from folded pipe **31** is exhausted through a vent **40** via an annular exhaust pipe that surrounds and insulates helium input line **27**. Further insulation is provided by a nitrogen shield jacket **41** which surrounds annular exhaust pipe **37**. The shield jacket is made of a thermally conductive material such as copper and is connected to nitrogen input line **23** by a thermal conductor **42**. Shield jacket **41** is therefore maintained at approximately liquid nitrogen temperature, 77° K. A similar shield jacket is included in terminal **20**. For the sake of clarity, exhaust pipe **37** and its associated elements are not shown in FIG. 1.

The solenoid **17** is advantageously energized by a plurality of lead wires **57** which are connected to a plurality of leads **58** that are printed upon helium input line **26**. The evaporated helium gases flowing through exhaust pipe **37** cool the printed circuit leads **58** and prevent normal resistance heat in the leads from deleteriously boiling away liquid helium in helium chamber **25**.

A nitrogen shield **45** is used to insulate folded pipes **31** and **32** in essentially the same manner as described above. Shield **45** is of copper and is connected by thermal conductors **43** and **44** to shield jacket **41** and to a similar shield jacket in terminal **20** to maintain it at liquid nitrogen temperatures. It should also be noted that annular thermal conductor **43** and cylindrical thermal conductor **44** are also at the liquid nitrogen temperature and therefore insulate the solenoid. The test volume **18** is defined by an inner cylindrical wall **55**. It can be appreciated, particularly from FIG. 1, that test volume **18** is readily accessible and that objects are easily admitted and removed therefrom. It is, of course, not usually necessary to refrigerate the test volume.

Attached at each end of the solenoid are three stainless steel spacers **46** arranged 120 degrees apart. Each of the spacers can be exposed by a porthole **47** which is either vacuum sealed by a cover (not shown) or clamped in a vacuum-tight relationship to other cryostat packages as shown in FIG. 1. By attaching two or more cryostat packages in this manner a magnetic field of any desired length can be attained. However, the extraordinarily large attractive forces produced by the adjacent solenoids would normally collapse them; the steel spacers **46** give sufficient re-enforcement to prevent such collapse. Further, the spacers act as thermal conductors and thereby equalize the temperatures of adjacent solenoids.

The spacers **46** on one end of each solenoid contain a key projection **49** while the spacers on the other end contain a keyhole **50** adapted to receive such a projection. When the three key projections of one solenoid are fitted into the three keyholes of an adjacent solenoid, the two solenoids are accurately aligned. This is an important consideration because if two adjacent solenoids are slightly misaligned their large magnetic fields will produce a torque that may actually rotate one solenoid around the other. To insure further their accurate alignment, each cryostat package is mounted on a platform **52**, which in turn is mounted by wheels **53** on a common track **54**. The desired number of cryostat packages can then be placed on the track and rolled into an accurate position with a minimum of alignment problems.

In summary, it can be appreciated that an important advantage of our device is that it combines accessibility of the solenoid and the solenoid's test volume with efficient cooling. Further, it is quite flexible in that any desired number of packages can be combined. The device shown was built to produce flux densities of up to 100 kilogauss. Each package is approximately 20 inches long and has an inside diameter of 7 inches with the other components being substantially drawn to scale. It is to be understood, however, that the disclosed embodiment is only illustrative of our invention. Various other forms can be made by one skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. In combination:

an evacuated cylindrical casing having a pair of annular end plates;

said casing coaxially surrounding a first annular chamber adapted for containing liquid nitrogen;

said first annular chamber coaxially surrounding a sec-

ond annular chamber adapted for containing liquid helium;

said second annular chamber adapted for coaxially surrounding a solenoid of superconducting material;

said casing having a cylindrical inner wall defining a central aperture;

a folded pipe which is constructed to define a hollow cylinder being located between said solenoid and said inner wall;

said pipe being connected to said second chamber and being adapted to transmit evaporated helium therefrom;

said solenoid coaxially surrounding and being closely adjacent to said folded pipe;

a plurality of thermal conductors connected to each end of said solenoid;

and means in said end plates for exposing said thermal conductors.

2. A cryostat for supercooling a superconductive solenoid comprising:

a cylindrical encasement containing a plurality of concentric cylindrical chambers;

an input terminal at each end of said encasement;

a liquid nitrogen input pipe and a liquid helium input pipe in each of said input terminals;

said nitrogen input pipe comprising means for transmitting liquid nitrogen to a first cylindrical chamber;

said helium input pipe comprising means for transmitting liquid helium to a second cylindrical chamber within the first chamber;

a superconductive solenoid being contained in a third cylindrical chamber within the second chamber;

a pair of hollow pipes being contained in a fourth cylindrical chamber within the third chamber;

a cylinder of thermally conductive material which is connected to said first chamber forming the inner wall of said fourth chamber thereby thermally insulating said pair of pipes;

one end of each of said pipes being connected to an opposite end of said second chamber and adapted for receiving evaporated helium gases and the other end of each of said pipes being connected respectively to a separate annular exhaust pipe; each of the annular exhaust pipes coaxially surrounding one of the liquid helium input pipes, thereby thermally insulating the input pipes;

a plurality of steel spacers on each end of said third chamber;

the spacers on one end containing key projections and the spacers on the other end containing keyholes;

and a plurality of portholes in said encasement for exposing said spacers.

3. The cryostat of claim 2 further comprising:

means for energizing said superconductive solenoid comprising printed circuit leads printed on the exterior of said helium input pipes, said leads being surrounded by said annular exhaust pipe, whereby substantially all resistance heat generated in the leads is dissipated by helium gases flowing through the exhaust pipe.

4. A cryostat comprising:

an evacuated encasement having a cylindrical outer wall, a cylindrical inner wall and a pair of end plates;

said encasement containing first, second, third and fourth concentric annular chambers, the first chamber surrounding the second chamber, the second chamber surrounding the third chamber, and the third chamber surrounding the fourth chamber;

the first annular chamber being adapted to contain a first liquefied gas;

the second annular chamber being adapted to contain a second liquefied gas having a lower boiling point than the first gas;

the third chamber containing a solenoid;

the fourth chamber containing piping which has an open end communicating with the second chamber and being adapted to transmit evaporated gas from the second chamber, thereby refrigerating the fourth chamber.

5. A device for producing an extended magnetic field of high intensity comprising:

a plurality of encasements each having a cylindrical outer wall and a cylindrical inner wall connected by a pair of end plates;

two input terminals extending into opposite ends of the outer wall of each encasement;

each input terminal comprising a helium input pipe and nitrogen input pipe;

each of the encasements containing a separate first annular chamber which is connected at opposite ends to a nitrogen input pipe;

each of said first annular chambers coaxially surrounding a separate second annular chamber which is connected at opposite ends to a separate helium input pipe;

said nitrogen input pipes and said helium input pipes each respectively comprising means for transmitting liquid nitrogen to one of said first chambers and liquid helium into one of said second chambers;

each of said second chambers coaxially surrounding a separate third annular chamber which is segmented into a plurality of annular sub-chambers;

each of said sub-chambers containing a plurality of circular windings of a wire made of superconductive material;

each of said third chambers coaxially surrounding a separate fourth chamber which contains two serpentine folded pipes;

said pipes each being connected to said second chamber and being adapted to transmit evaporated helium therefrom;

each of said fourth chambers coaxially surrounding a separate fifth annular chamber which is defined by said fourth chamber and the cylindrical inner wall of the respective encasement;

each of said fifth chambers containing a cylindrical wall of thermally conductive material which is thermally connected to said first chamber;

a plurality of spacers on each end of each of said third chambers;

the spacers on one end of each of the third chambers having key projections and the remaining spacers having key holes for receiving said projections;

and a plurality of portholes in each of said end plates for exposing said spacers;

the spacers of each of said third chambers being keyed to spacers of other third chambers;

and the volume within the inner walls of all of said encasements forming a test volume for containing magnetic fields generated by said superconductive windings.

6. A device for producing a high intensity magnetic field comprising:

an encasement having a cylindrical outer wall and a cylindrical inner wall being connected by annular end plates;

two input terminals extending into opposite ends of said outer wall;

each input terminal comprising a helium input pipe and a nitrogen input pipe;

a first annular chamber within said encasement being connected at opposite ends to a nitrogen input pipe;

said first annular chamber coaxially surrounding a second annular chamber which is connected at opposite ends to said helium input pipe;

said nitrogen input pipe and said helium input pipe respectively comprising means for transmitting liquid nitrogen to said first chamber and said helium to said second chamber;

said second chamber coaxially surrounding a third annular chamber which is segmented into a plurality of annular sub-chambers;

each of said sub-chambers containing a plurality of circular windings of a wire made of superconductive material;

said third chamber coaxially surrounding a fourth chamber which contains two serpentine folded pipes which are interleaved with respect to each other;

an annular exhaust pipe coaxially surrounding each of said helium input pipes;

said folded pipes each being connected at one end to said second chamber and at the other end to opposite annular exhaust pipes and further being adapted to transmit evaporated helium from said second chamber to one of said exhaust pipes;

said fourth chamber coaxially surrounding a fifth annular chamber which is defined by said fourth chamber and a cylindrical inner wall of the encasement;

said fifth chamber containing a cylindrical wall of thermally conductive material which is thermally connected to said first chamber, all of said five chambers being separated from each other and from said outer wall by an annular vacuum space;

a plurality of spacers on each end of said third chamber;

the spacers on one end of the third chamber having key projections, the remaining spacers having key holes for receiving key projections;

and a plurality of portholes in each of said end plates for exposing said spacers.

References Cited in the file of this patent

UNITED STATES PATENTS

2,816,232	Burstein	Dec. 10, 1957
3,015,960	Steele	Jan. 9, 1962