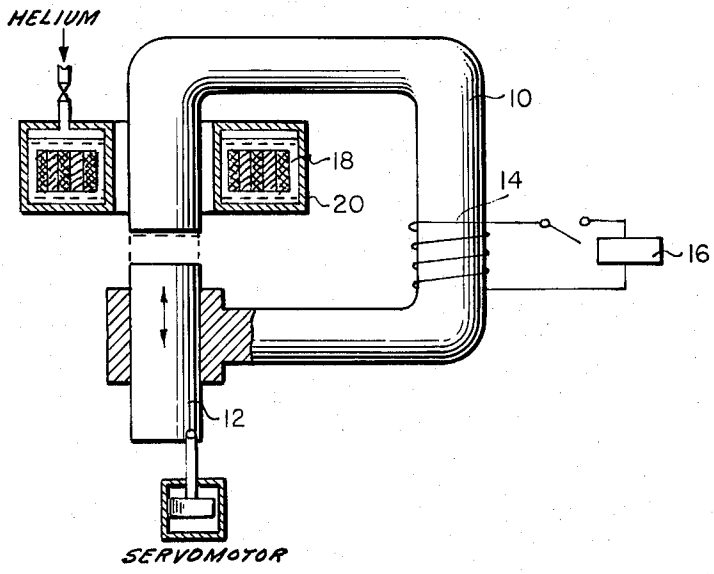
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SUPERCONDUCTING SOLENOID APPARATUS

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# SUPERCONDUCTING SOLENOID APPARATUS

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The present invention relates to superconducting magnets and specifically to a technique of building up a magnetic field and maintaining it with superconductive coils.

In the present state of the art superconductive materials are wound into coils about ferromagnetic or paramagnetic cores. A current is passed through the coil from a power supply and then short circuited. Meanwhile the superconductive material is maintained below its critical temperature by a cryogenic fluid, such as liquid helium.

Such coils are subject to electrical energy losses in lead wires connected to the superconductive material, the soldered connections of such lead wires and the power supply and evaporation losses due to resistance heating in proximity to the cryogenic fluid.

It is an object of the present invention to provide a magnet construction which inherently avoids these losses.

It is another object of the invention to provide a superconductive solenoid which will not burn out due to an accidental instance of reverting to the normal state from the superconductive state.

These and other objects will in part be obvious and will in part appear hereinafter.

The invention is now described with reference to the following description, taken in connection with the accompanying drawing.

The drawing consists of a single figure which is a schematic diagram of a magnet constructed according to a preferred embodiment of the invention.

As shown in the drawing, the magnet comprises a soft iron core **10**, including a movable pole piece **12** which may be moved into the position shown in dotted lines to form a closed magnetic loop. Currents are induced in the core by a copper coil **14** connected to a suitable power supply **16**. The superconducting solenoid **18** comprises closed loops, which may be cylinders as shown in the drawing or closed loop wires. The cylinders can be made of formed and sintered $Nb_3Sn$ powders or extruded Nb-Zr tubing. Non-superconductor cylinders should be provided to radially separate the superconductive cylinders. Copper is a preferred choice for this purpose. Where wire is used, it can be of the type described by Kunzler et al. in 6 Physical Review 89 (1961). However, the wires should be formed into closed loops before sintering.

The superconducting coil is held in a Dewar flask **20** of annular form which is placed around a pole piece of the core **10**.

The operation of this magnet assembly begins with the pole piece **12** closing the air gap of the magnet and the temperature of the superconductive coil above the critical temperature of its constituent material. Power is supplied to the copper coil to induce a field in the iron core up to its saturation limit. Then helium is supplied to the Dewar **20** to lower the temperature of the coil **18** below the critical temperature. So far, no current flows in the superconducting coil.

The copper coil is then cut off from the power supply. This causes a small current to be induced in the superconducting coil, but the iron core remains saturated. Then the air gap is opened by lowering the pole piece **12**. Additional current is induced in the superconducting coil and the constant flow of current without resistance maintains the high field across the air gap. The field in the gap is maintained so long as the coil is kept at liquid



helium temperature and the air gap spacing is not too great. When the air gap spacing is excessive, the coil **18** will go normal. The current in the coils will cause a resistive heating which is dissipated by helium boil-off. The superconductive loops will not burn out.

It will be appreciated by those skilled in the art that the limits of the present invention are defined by the saturation field of the ferromagnetic core—about 25,000 gauss for iron. The diameters of the pole faces are unlimited.

It will also be appreciated by those skilled in the art that variations can be made within the scope of the present invention. For instance, the pole piece **12** can be rigidly attached to the remainder of core **10** and the air gap filled by a removable iron keeper. The superconductive loops can be simple niobium cylinders or hard superconductor alloys made by the diffusion technique described by Saur in Die Naturwissenschaften, 49, p. 129 (1962). The location of the superconducting coil near a pole face, as shown in the drawing, is preferred to reduce stray flux when the air gap is opened. However, this location is not critical to the invention.

What is claimed is:

1. A superconducting magnet characterized by burnout proof protection for superconductive windings and freedom from relatively low critical current capacity section, such as joints, and comprising, in combination: a ferromagnetic core with a magnet gap, means for creating a magnetic field in the core, a superconducting coil electromagnetically linked to the ferromagnetic core, the coil comprising closed rings of superconducting material in an essentially closed space, a cryogenic fluid having a temperature below the critical temperature of the superconducting material, means for admitting said cryogenic fluid to said space for lowering the temperature of the coil below the critical temperature of the superconducting material, a portion of said ferromagnetic core being movable relative to the rest of the core between at least a first position wherein the core has said magnet gap and a second position wherein said gap is closed, with said core portion providing a consistently large cross-section area for bridging the gap in said second position, and means connected to said core portion and constructed and arranged to move said core portion between said first and second positions, and closing the gap of the ferromagnetic core.

2. A superconducting magnet characterized by burnout proof protection for superconductive windings and freedom from relatively low critical current capacity section, such as joints, and comprising in combination: a closed loop ferromagnetic core, a superconducting coil electromagnetically linked to the ferromagnetic core, the coil comprising closed rings of superconducting material in an essentially closed space, a cryogenic fluid having a temperature below the critical temperature of the superconducting material, means for admitting said cryogenic fluid to said space for lowering the temperature of the coil below the critical temperature of the superconducting material, means forming a portion of said closed loop ferromagnetic core of consistently large cross-section area, said means being constructed and arranged so that it is removable from the core to leave a magnet gap in the core when it is removed.

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