HORIZONTAL DIPOLE SUPERCONDUCTING MAGNET USING MULTILAYER INSULATION

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Abstract

A new type of horizontal dipole superconducting magnet using multilayer insulation was built and tested successfully. In the magnet new multilayer insulators were mounted in the vacuum space of a cryostat. The anisotropic expansive magnetic forces acting on the coil windings are transmitted through the multilayer insulators to the mechanical girders in a space at room temperature and supported.

The magnet has a horizontal bore to which a room temperature access is provided for MHD generator research channel: A central field of 20 kG is generated in the working bore of 21.4 cm diam. The coil is wound with a solder-type composite superconductor (Ti-Nb-Ta and copper substrate). The cryostat is 160 cm long, 85 cm o.d. including the girders.

I. Introduction

One of the major problems in constructing large dipole superconducting magnet is how to support the expansive anisotropic magnetic force acting on the coil windings. In some superconducting magnets ever built, the structural members, the so-called girders, for supporting the magnetic forces were placed in liquid helium, surrounding the coil windings.[1]

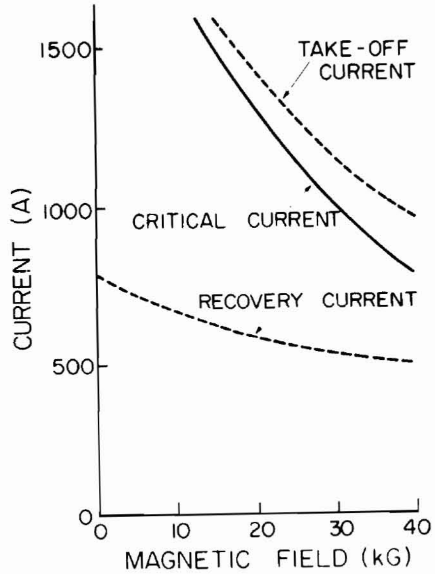

Fig. 1. Characteristics of superconductor.

The purpose of this paper is to describe a new type of dipole superconducting magnet[2] in which the girders are brought out in a space at room temperature. New multilayer insulators[3] are mounted in the vacuum space of the cryostat to transmit the radial magnetic forces to the girders at room temperature. The magnet is a horizontal one and has a horizontal access bore provided for MHD research.

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II. Coil Windings

The coil is wound with a composite superconductor consisting of ten copper-clad Ti-25% Nb-5% Ta 0.25 mm diam wires embedded with Pb-Sn solder in a groove of a copper strip 0.12 cm thick by 1.0 cm wide.[4] Figure 1 shows the characteristics of the superconductors; the operating current of the coil was designed to be 1000 A at 26.2 kG, which corresponds to a maximum field of 18.6 kG on the axis of the bore.

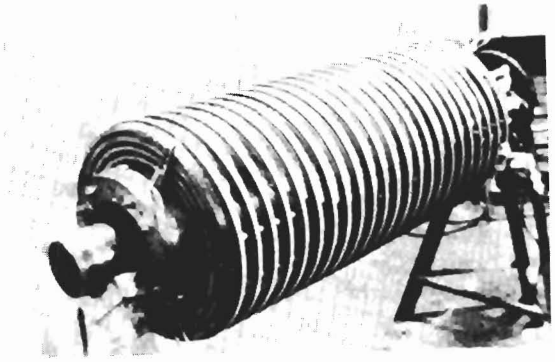

Fig. 2. Completed coil winding.

The coil is composed of four concentric layers, each layer consisting of two saddle-shaped windings. The ring-type spacers which are made of epoxy insulated copper strip are inserted between the neighbouring winding layers. The purpose of the ring-type spacer is to provide the space for circulation of the helium coolant. The magnetic force produced in each winding layer is transmitted through these ring-type spacers to the outermost layer; the resultant total outgoing force is calculated to be 0.76 tons per cm of axial length for operating current of 1000 A. Figure 2 shows the completed coil windings prior to the assembly in the cryostat.

III. Cryostat

Figure 3 schematically shows the cross section of the cryostat: The coil is fixed in the cylindrical helium vessel. The vessel is surrounded by the vacuum space of the cryostat, in which the multilayer insulators are mounted. A series of ring-shaped girders, welded on the outer surface of the vacuum shell, supports the magnetic forces which are transmitted through the multilayer insulators.

The multilayer insulators are required to act as cryogenic thermal insulators and also as mechanical compression members. Thermal and mechanical properties of several kinds of multilayer insulators were investigated. A lamination of aluminized mylar film and nylon fibrous paper was selected for this cryostat. The average thermal conductivity of this material under a compression load of 3 kg/cm^2 is shown in Table I.

Table I. Average thermal conductivity of the multilayer insulator.

(Aluminized mylar film and nylon fibrous paper, compression load of 3 kg/cm^2)

Temperature	Thermal conductivity
T_2 .....T_1 (°K)	(Cal/cm s °K)
300.....80	5×10^{-5}
80.....20	3×10^{-5}
20.....4.2	1×10^{-5}

In the cryostat, as shown in Fig. 3, the multilayer insulators are divided into three sections by two thermal shields which are cooled by evaporated helium gas and liquid nitrogen, respectively. The total thickness of the multilayer insulators is 3.8 cm. The initial compression of 5 kg/cm^2 was applied on the multilayer by the insertion of wedges betwen the insulator and the vacuum vessel of the cryostat; the purpose of this initial compression is to eliminate the compressive deformation of the mounted multilayer insulators during the energization of the magnet.

IV. Test Results

The completed magnet is shown in Fig. 4. The coil was cooled down to 15°K by cold gas from the helium refrigerator. Then, the liquid helium of 32 liters was consumed for cooling from 15 to 4.2°K. The quantity of liquid helium stored in the cryostat was 130 liters.

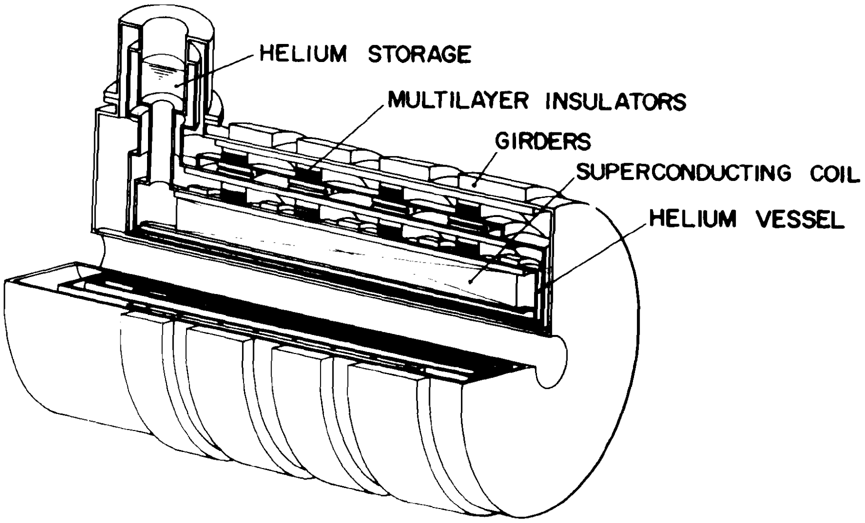

Fig. 3. Schematic view of the cryostat.

A series of energizing tests were performed to observe the characteristics of the magnet. A central field measured at 1000 A was 18.5 kG. The critical current observed was 1080 A. The liquid helium boil-off rate was 11 liters/h during magnet energization. The deformations of the girders and the cryostat due to the magnetic force were measured using strain gauge. The maximum expansive deformation of the girders was measured of 0.12 mm in diameter. These measured values are close to the calculation or the predicted values.

V. Conclusion

A new type of horizontal dipole superconducting magnet was constructed and tested successfully. The test results prove the practicability of the new structure transmitting the magnetic force through multilayer insulators to the mechanical supports at room temperature. This structure will be widely used in various types of superconducting magnets in which large forces are exerted on coil windings.

References

1. Z. J. J. Stekly et al., "A large experimental superconducting magnet for MHD power generation," 1966 Meeting of International Institute of Refrigeration, Boulder (June, 1966).
2. M. Iwamoto et al., "Compact superconducting magnet utilizing multilayer insulation," Fifth International Conference on Magnetohydrodynamic Electric Power Generation, Munich (April, 1971).
3. T. Moriguchi, K. Akashi, and O. Ogino, "Thermal conductivity of multilayer insulation from 4.2 - 300 K under compression loads," XIII International Congress of Refrigeration, Washington (August, 1971).
4. M. Iwamoto and T. Satow, "The performance of composite copper-superconductor soldered conductors," Cryogenic Engineering Conference, Cleveland (August, 1968), published in Advances in Cryogenic Engineering, Vol. 17.

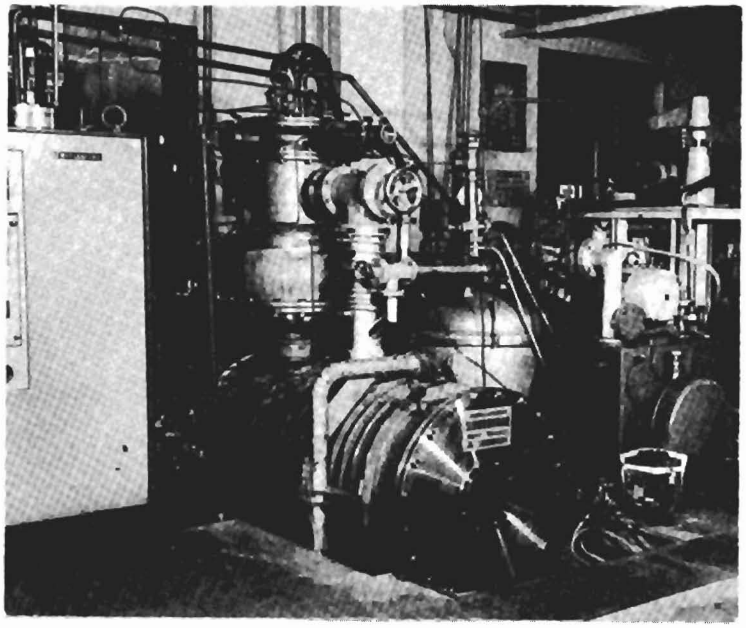

Fig. 4. Completed magnet and refrigeration system.