Research Matters SPRING 2005 Sc

Building a hybrid magnet

Part of the team participating on the hybrid project

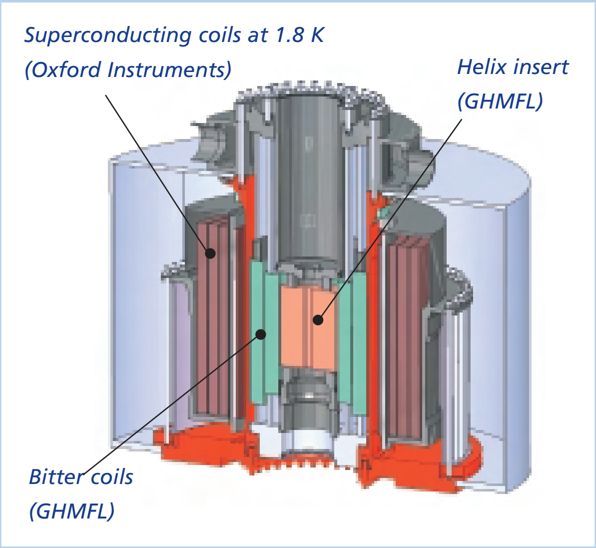

Figure 1 Schematic section of the superconducting outsert cryostat

Hybrid magnet systems are used to create stable magnetic fields, generally above 30 T, in a relatively large bore (30 mm or greater). They are composed of two concentric magnets, an outer superconducting magnet (outsert) and an inner resistive magnet (insert). Due to coupling effects, however, faults in the resistive magnet can translate directly into a combination of fast magnetic field transient and large mechanical forces applied to the superconducting winding.

Therefore, the most critical aspect of hybrid magnet design is that the outsert and cryostat structures be capable of enduring loads generated by resistive insert faults (asymmetric trip) and withstanding a resistive insert trip without quenching. During a fault, forces of up to 100 tons are generated on the superconducting magnet. Second to this, it must be possible to sweep the magnet to field in a relatively short time and to run the system for extended periods without a liquefier. To meet these stringent requirements the GHMFL turned to Oxford Instruments Superconductivity for the production of a durable 8 T class superconducting solenoid, as well as the magnet's cryostat and cryogenic system.

The 8 T outsert

A superconducting magnet system can be segmented into four primary components: a quench detection system, quench shield, a magnet active protection system, and the superconducting magnet itself (Figure 1). The first line of defence against insert faults is the quench detection system, which measures the change in voltage at each end of the magnetic coil. Importantly, the design of the detection system has been kept sensitive enough to resist the voltage changes associated with a transition (few hundreds of millivolts) but at the same time, insensitive to the high inductive voltage associated with an insert trip (few kilivolts). A false positive quench detection during an insert trip would otherwise cause the firing of the heaters and, consequently, a magnetic quench.

Assembled inside the cryostat between the helium magnet vessel and the inner bore, The quench shield consists of a cold worked, oxygen-free copper tube encased inside a 35 mm thick, AISI 316 LN cast stainless steel tube. In the event of an insert trip (or asymmetric trip) the shield will act to slow down the magnetic flux transient experienced by the outsert, strongly reducing AC loss in this superconducting magnet. The mitigation of fault effects is further improved by the magnet active protection system, which, in cases of a resistive insert trip (or quench), sends a signal to the electronic control system to temporarily disconnect the power supply and dump part of the magnet's energy into an external resistor.

The principal component of the outsert, the superconducting magnet, is comprised of three layer-wound concentric solenoids of equal length, the main characteristics of which are displayed in Table 1. Each of these coils is composed of a Rutherford Type cable with a stainless steel insert, which functions as a resistive barrier to inter-strand coupling currents, while also increasing the global specific heat of the conductor. The dimensions of the conductors were defined based on requirements for temperature margins, mechanical stresses, and maximum quench temperature.

Testing the Superconducting Magnet System

Preliminary tests of the superconducting magnet were carried out on its own in a bucket dewar up to 7 T (guaranteed field), together with the quench shield. All primary aspects of the magnet's performance were examined.

- To investigate the system's performance ability to resist quenching, heaters were glued to the inner coil and fired to purposely induce quench state. At each of the four current intervals tested, (600A, 900A, 1000A, and 1160A) the magnet successfully reached a minimum of 7 T at 2.5 K (higher than the system's 1.8 K operating temperature).
- Quench behaviour was then investigated by measuring and recording voltages in different sections of the magnet while the heaters were again fired. During a quench, most of the resistive voltage was found to concentrate inside the middle coil, while inductive voltage was more uniformly distributed across all three

Figure 2 The fully assembled cryostat

About the GHMFL

The Grenoble High Magnetic Field Laboratory is a French laboratory, funded by the Centre National de la Recherche Scientifique, and run as a user facility. Located on the Polygone Scientifique Louis Néel in Grenoble, the lab is closely situated to a number of CNRS laboratories including: the Centre d'Etudes Nucléaires de Grenoble (CEA Grenoble), the Institut Laue-Langevin (ILL), the European Synchrotron Radiation Facilities (ESRF) and the Institut de Biologie Structurale (IBS).

Operating over 5,000 hours a year, the facility is capable of producing steady magnetic fields of up to 30 T for use by external researchers as well as resident scientists who pursue their own research activities. The latter are also responsible for welcoming and providing technical and scientific assistance to external users. The broad range of experiments conducted at the GHMFL includes research in the fields of:

- Semiconductors
- Low dimensional electron systems
- Superconductors
- Biochemistry
- Magnetohydrodynamics
- Magnets and magnetic instrumentation

coils. This caused a high positive uncompensated voltage in the middle coil and a corresponding negative voltage in the outer coil. Due to the conservative approach used in the design's insulation, however, the higher than expected voltage did not lead to any problems at the coils' insulation layers.

The performance of the quench shield was measured indirectly during low-current magnet dumps and forced quenches by measuring the total field at the magnetic centre with a Hall probe. Experimental quench-shield current measurements were found to closely follow the calculated estimates during full current quenches, currents of up to 5 MA have been measured in the field quench.

Importantly, the magnetic system held up very well during mechanical strain tests. The three coils were equipped with strain gauges measuring both hoop and axial strain throughout their inner and outer surfaces'. During a ramp up to 1160A, measured strains fit soundly with theoretical values and the linear behaviour of the strain indicated no sign of plastic deformation in the winding.

	Inner coil	Middle coil	Outer coil
Internal diameter (mm)	1100	1226	1322
External diameter (mm)	1210	1306	1516
Axial length (mm)	1400	1400	1400
Cable size (mm^2)	5.84 x 3.66	5 x 1.8	5 x 1.7
Steel Insert size (mm^2)	4.6 x 2.5	3.8 x 0.6	3.8 x 0.6
Number of strands	24	16	14
Reinforcing Strip size (mm^2)	5.9 x 2.5	5 x 2.5	5 x 2.5
Number of layers	8	14	14
Number of turns / layer	230	267	267
Number of joints	3	4	4

Table 1 Geometric Coil Data;

Bringing it all together

The final assembly of the cryostat and its components was completed in Grenoble and the completed system is currently undergoing it's second round of testing. In these recent tests, the superconducting magnet has been operated in combination with the bitter part of the resistive magnet to produce a total field of 15.5 T (outsert at 7 T and insert at 8.5 T). The GHMFL team is now waiting for the installation of the polyhelix resistive magnet and the ultimate completion of the hybrid system. Once connected, the two systems will produce a 40 T field in a 34 mm bore resulting in one of the world's most advanced environments for high field magnetic research.

Reference

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