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Abstract

Data from tests in He II of four 1-meter-long magnets are presented. The maximum quench current is increased up to 30 percent, compared with tests in He I. Data from calorimetric measurements of heat generated during cyclic operation are presented. Quenches were induced by heaters placed near the conductor, and the energy required to induce quenches in He II and in He I are compared.

Introduction

Degraded performance and subsequent training of pulsed accelerator dipole magnets is often attributed to coil mechanical motion and associated local heat generation. We and others, have conjectured that the enhanced heat transfer to superfluid helium would remove this heat without quenches. In addition, the increased current capacity of superconductors at 1.8K should allow magnet operation at increased fields, subjecting the windings to stresses of ~1.5 to 1.7 times greater than the normal operating stress at 4.2K thereby accelerating or circumventing the training process.

The Superfluid Test Facility

A facility for testing superconducting accelerator magnets in a pressurized bath of helium II has been constructed and operated [1,2]. The cryostat accepts magnets up to 0.32 m diameter and 1.32 m length with current to 7000 A. In initial tests, the volume of helium II surrounding the superconducting magnet was 90 liters. Minimum temperature reached was 1.7K at which point the pumping system was throttled to maintain steady temperature.

A two reservoir system, similar in principle to that of Claudet[3] and Bon Mardion[4,5], is used. The lower vessel, which contains the magnet and is completely filled with liquid, is pressurized to slightly over one atmosphere by contact with an upper saturated helium bath. This 28-liter bath also intercepts the major conduction heat loads from the vessel supports, current leads, and instrumentation leads, and supplies coolant to reduce the lower vessel temperature below T_λ. This coolant for the lower vessel is withdrawn as a liquid at 4.4K from the upper vessel, cooled in a counterflow heat exchanger, expanded across a JT valve to a low pressure and temperature, vaporized in a coil immersed in the lower reservoir, and warmed in the counterflow heat exchanger before exhausting to the vacuum system. This apparatus is shown in Figure 1.

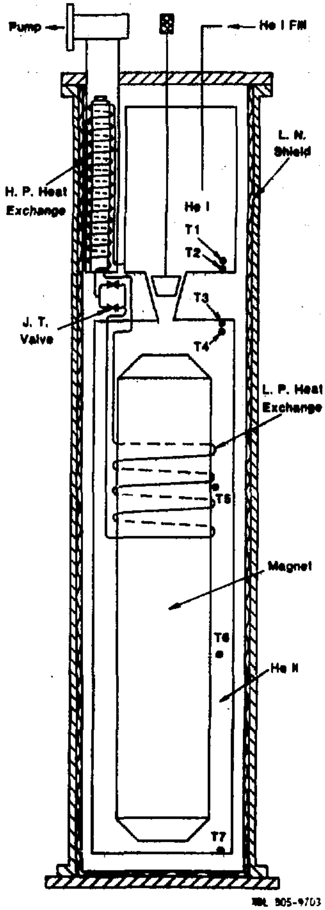

Figure 1: Schematic of pressurized helium II apparatus, showing locations of temperature sensors.

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Magnet Descriptions

**A. D-4 (number ESD-10)

I.D. = 16.5 cm
Small (4.90 mm X 0.85 mm) RHEL Cable-Staybrite insulation
4 current blocks
Mylar + B-stage glass insulation
4 layers
Aluminum ring and collet compression
Pre-stress 100 to 200 atmospheres, less than half the Lorentz forces

**B. D-5

I.D. = 16.5 cm
Small RHEL Cable - staybrite insulation --
4 current blocks
Epoxy in cable - Kapton + Mylar + Epoxy
4 layers
Aluminum ring and collet compression
Cold pre-stress below 100 atmospheres

***C. D-7A

I.D. = 7.6 cm
Large (7.55 mm x 1.25 mm) RHEL Cable - Staybrite insulation
2 layer design
Fermi Doubler Conductor Pattern
Kapton 25 μm thick
Mylar 25 μm thick NO epoxy
Aluminum ring and collet compression
Cold pre-stress about 5,000 psi, greater than Lorentz force

***D. D-7B

Similar to D-7A above but "zebra" cable is used with half the strands insulated with Stabrite and the other half with copper oxide. The thickness of Mylar is 50 microns. The cold pre-stress is somewhat lower than that of D-7A.

** These magnets are described in more detail in ref 6 LBL-10756.
*** These magnets are described in more detail in ref 7 LBL-11752 (this conference).

Test Results

A. ESD-10

Originally this magnet was operated in regular helium in its horizontal cryostat with a warm iron yoke. The training was slow and regular, some 90 quenches to 95 percent of short sample, and is typical behavior for this class of magnet with low pre-stress. The magnet, without the iron, was re-tested in the vertical helium II facility. First the magnet was powered in helium II at 1.8K to 92 percent of the 4.2K short sample limit. Next the temperature was raised to 4.2K and the magnet quenched at the current previously reached in the superfluid runup. Two more quenches at 4.2K confirmed the training curve to be expected in regular helium. We estimate that 50 more quenches would have been required to reach short sample current at 4.2K. Then six more runups or quenches took place in helium II. The current was run to 105 percent of the 4.2K short sample. The system was again warmed to 4.2K, the magnet quenched at 100 percent of short sample.

B. D-5

This magnet exhibited considerable training together with loss of memory on warming to room temperature. It trained faster in helium II than in helium I but did not reach short sample performance in either cooling mode.

Hysteretic loss was measured in the helium II by observing the temperature monitors while the current was being cycled between two current levels. Calorimetry is convenient in a helium II bath because temperature gradients are negligible even with large heat inputs. The rate of field change varied from 0.02 to 0.20 tesla per second. The extrapolated cycle loss, at zero field change rate, is 120 joules per cycle between 0 and 3.3 tesla, and 22 joules per cycle between 2.9 and 3.9 tesla - about what one expects for magnetic hysteresis alone.

C. D-7A

The initial testing of this magnet was complicated by a short that caused an extreme charge-rate dependence. A charging time longer than 2000 seconds was required to reach critical current. The first such slow ramp was run in helium II and the short sample limit, at 1.9K, of 6400 amperes was achieved. The associated high voltage from our extraction circuit may have cleared the apparent short. Short sample performance was then achieved in both helium II (6500 A at 1.8K) and helium I (5000 A) at ramp rates up to 1 tesla per second. After a room temperature warm up and cooldown, the magnet still performed at short sample.

Hysteretic loss in helium II was determined as discussed above (in D-5 section). In addition to the expected superconductor hysteretic loss, we had anomalous losses, possibly associated with the magnet short.

Table 1

Current Range, A	Current Rate A/s	Temp Range, K	Heat Rate, W	Heat Rate, J/cyc
0-1000	240	1.85-1.90	6.98	58.6
0-1000	120	" "	1.94	32.3
4000-5000	180	" "	2.35	26.0
4000-5000	120	" "	0.99	16.5
500-600	290	1.95-2.00	7.69	6.4
2500-2600	290	" "	7.25	6.0
4950-5050	290	" "	6.77	5.64
2000-3000	240	" "	3.20	26.7

Electrical heaters were built into the magnet between the center island and the first conductor turn of the inner layer. The heaters could be powered either in a continuous or pulsed mode. For heat pulses longer than about 250 milliseconds quench current depended on the power delivered to the heater, whereas for shorter times, it depended on total energy. Table II contains the heater quench data, at various magnet currents, in helium I and helium II. It is clear that several times as much energy is required to initiate a quench in helium II as in helium I. The quantitative interpretation of this data is uncertain because not all the heater energy is delivered to the superconductor.

D. D-7B

D-7B has 50 percent thicker insulation than D-7A. Charge rates up to 0.3T/s produced little effect on quench current. Some training in helium I was observed, to the short sample current of 4700A amperes. In helium II, the 2K short sample limit of 5465 amperes was achieved on the first quench.

Table II

I	Helium I <250 ms	Helium I 1sec	Helium I Cont.	Helium II <250 ms	Helium II 1sec	Helium II Cont.
2000A	220 mj	1200 mj				
3000A	180 mj	750 mj				
4000A	120 mj	390 mj	0.45W	220 mj	1000 mj	1.3W
4500A	90 mj	270 mj				

References

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