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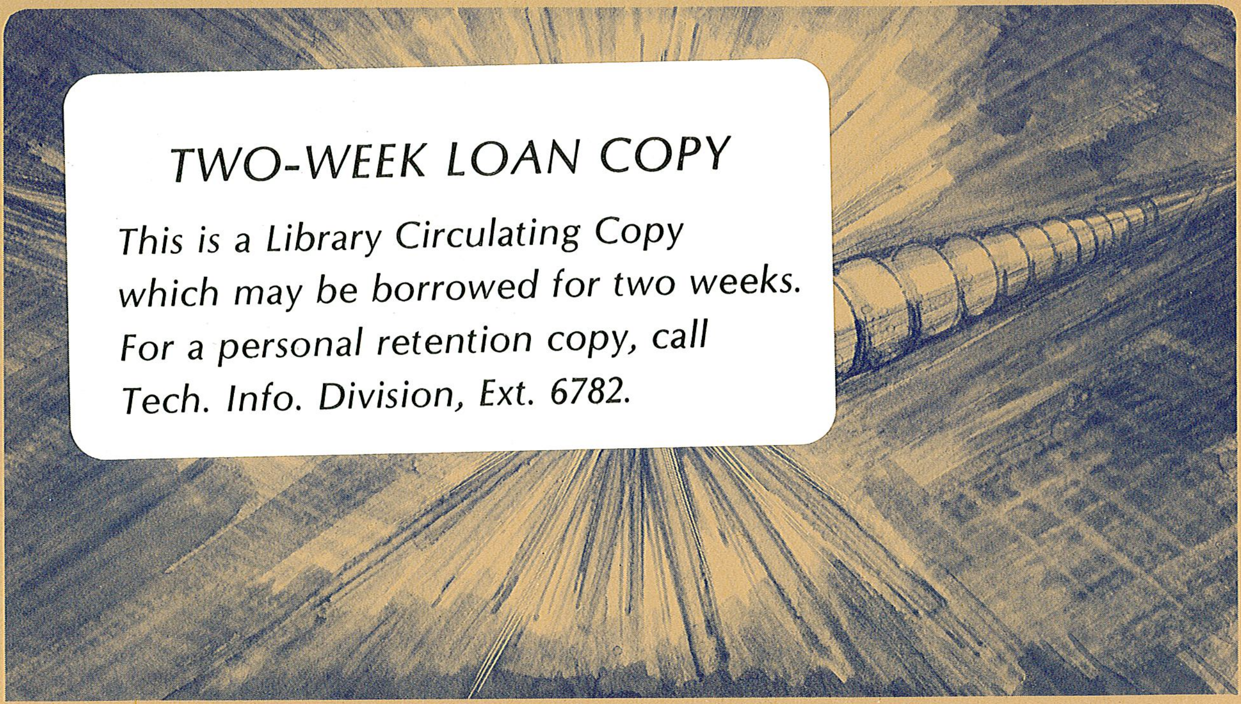

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ABSTRACT

Two superconducting accelerator dipole magnets, with different internal construction features, have been tested in pressurized superfluid helium (1.8K, 1.2 atmosphere) as well as in regular pool boiling helium (4.4K, 1.2 atmosphere) helium. The coils of one magnet were moderately pre-stressed, and 4.2 K design performance was rapidly achieved in the superfluid. The other magnet had very low coil pre-stress, reduced helium ventilation, and displayed degraded performance, even in the superfluid helium.

INTRODUCTION

Degraded performance and subsequent training of pulsed accelerator dipole magnets is usually 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, 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]. It is currently used in support of our magnet development program which has a near term goal (one to two years) of an 8T, NbTi dipole magnet. The cryostat accepts magnets up to 0.32 m diameter and 1.32 m length with current to 3000 A. In initial tests, the volume of helium II surrounding the superconducting magnet was 90 liters. Minimum temperature reached was 1.7 K 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 This coolant for the lower vessel is withdrawn as a liquid at 4.4 K from the upper vessel, cooled in a counterflow heat exchanger, expanded across a JT valve to a low pressure and temperature, vaporized in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 process is shown in Figure 1.

MAGNET DESCRIPTION

A. ESD-10, a moderately pre-stressed coil

ESD-10 is one of the thirteen ESCAR production dipoles, which are described in detail in the final project report[6]. The construction details are shown in Fig. 2. The conductor is a "Rutherford" cable (multifilamentary NbTi in Cu), wrapped with 0.025-mm thick Mylar insulation, with an open helical wrap of 0.175-mm thick B-stage epoxy-impregnated glass tape over the Mylar. The 4-layer thick coil was wound as double-layer halfcylinders on precision winding mandrels. Each assembly was oven baked to cure the B-stage epoxy and the units were then assembled onto a structural bore tube. Circumferential compressive pre-stress was achieved by forcing aluminum compression rings onto the coil. This coil was moderately prestressed; some one third of the summed Lorentz body forces, i.e., 2000 psi compared to a design 6400 psi. The load lines of ESD-10 and short sample curves of the conductors at 4.2K and 1.8K are shown in Fig. 3.

B. D-5, a low pre-stress coil

A modified experimental coil was wound on the ESD-series winding mandrel so the size and conductor block placement is the same in both magnets. The following changes were made in D-5.

The 4 layers were individually wound, rather than using 2 double layers. The first layer central fiberglass-epoxy island was thin and fragile.

The glass wrap on the conductors was replaced with 0.076-mm thick Mylar. The helium ventilation passages were thereby reduced and some 10% more turns could be placed in the winding blocks. The high thermal contraction of the thicker Mylar resulted in the loss of room temperature pre-stress when the magnet was cooled.

Epoxy was added to the interior of the conductor to prevent intra-cable movement and to increase the compresive modulus.

The internal structural tube was machined away in the coil's straight section so that the inner surface of the innermost layer was not internally supported.

The coil ends were lengthened and spacers were inserted between turns so that the maximum field was shifted from the end region to the pole region of the straight section. The inert turns in the straight section were omitted. The load lines for D-5 are similar to those of ESD-10 but yield approximately 15% more field because of the increased number of turns.

TEST RESULTS

A. ESD-10

The training history of ESD-10 is shown in Fig. 4. Originally the magnet was run in its horizontal cryostat and warm iron yoke. The training was slow and regular, typical behavior for this class of magnet with low pre-stress. The same magnet, without the iron, was re-tested in our vertical helium II facility in 1980 and the first and last quenches in helium I and helium II are also shown in Fig. 4. This later run is presented in more detail in Fig. 5. The helium II quench trigger events were not necessarily true quenches and little, if any, energy was deposited in the bath. The training in the helium II was very rapid and, when the bath was returned to 4K, the magnet ramped to its 4.2K short sample limit. We estimate that 50 quenches or more would have been required if the training had been done in helium I at 4.4 K.

B. D-5

The disappointing training history of D-5 is displayed in the rather untidy Fig. 6. The initial performance was degraded, the training in helium I at 4.2K was slow and irregular, and training was largely lost when the magnet was warmed to room temperature. Training did improve in helium II below 2K but not nearly so markedly as in ESD-10, discussed above. In addition to the coil's being loose due to excessive thermal contraction, there is evidence of a compressive failure in the inner fiberglass island

Calorimetry is convenient in a helium II bath because temperature gradients are negligible even with large heat imputs. Thus calorimetric loss measurements are very simple in the helium II vessel where several precision temperature sensors are mounted. Hysteretic loss was measured in the helium II by observing the temperature monitors while the current was being cycled between two current levels. The rate of field change varied from 0.02 to 0.20 tesla per second. The extrapolated cyclic 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. These losses are about what one expects for magnetic hysteresis alone, and if there is a mechanical hysteresis loss in the lower field range, it is not larger than the magnetic loss.

CONCLUSIONS

Helium II operation is a convenient and effective means of accelerating the training of high current density dipole magnets. However even with this technique care must be taken to design magnets so that mechanical constraints are adequate and to use materials with appropriate thermal contraction and mechanical properties. Excessive mechanical losses are readily diagnosed and analysis facilitated.

* * *

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5) Bon Mardion, G., Claudet, G. Seyfert, P., Verdier, J., Adv. Cryo. Engineering, Plenum Press, New York, NY, U.S.A., vol. 23, p. 358, (1978).

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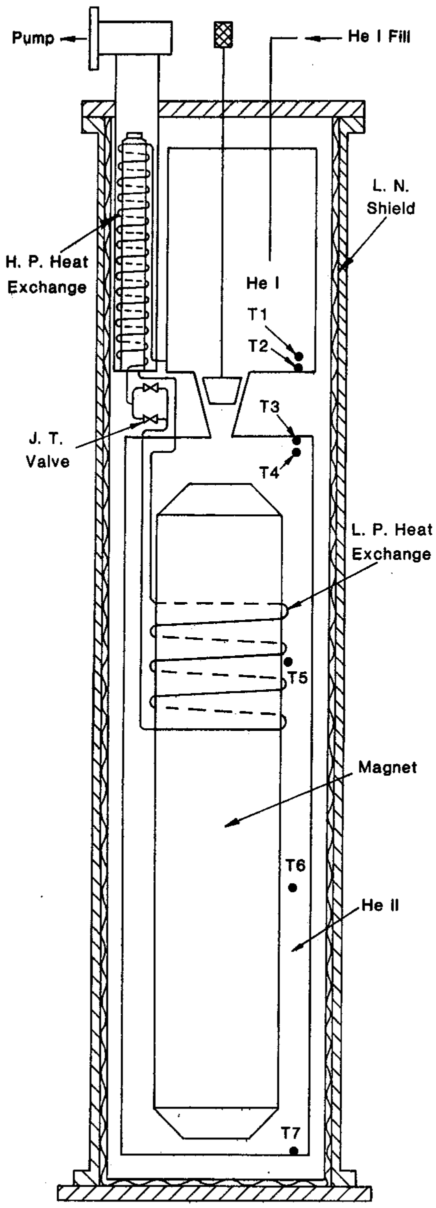

Fig. 1 Helium II facility.

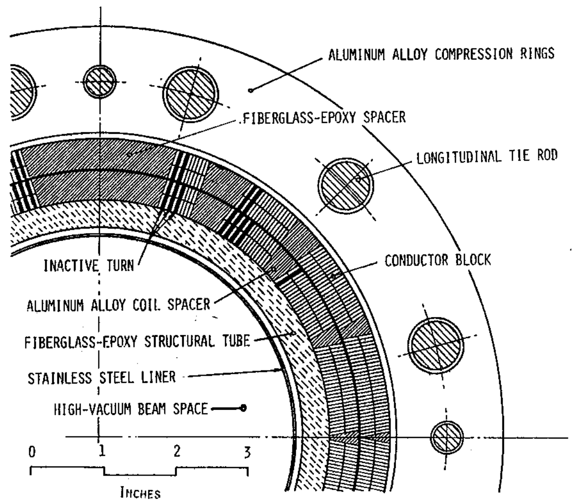

Fig. 2 ESD-10: Dipole, central cross section.

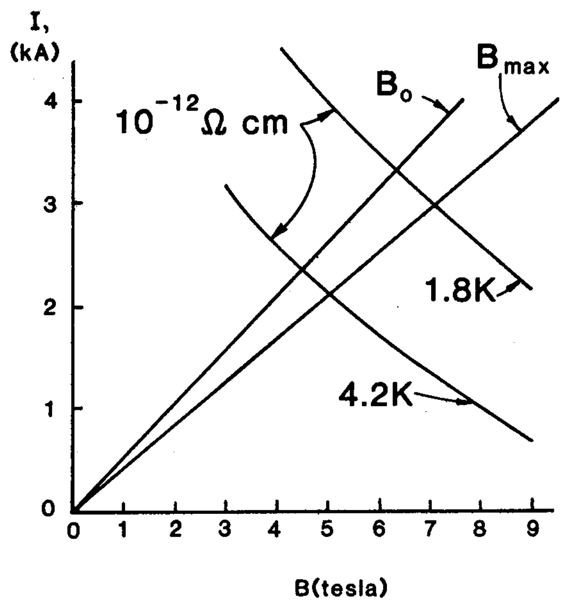

Fig 3. ESD-10: Load lines and short sample curves at 4.2K and 1.8K.

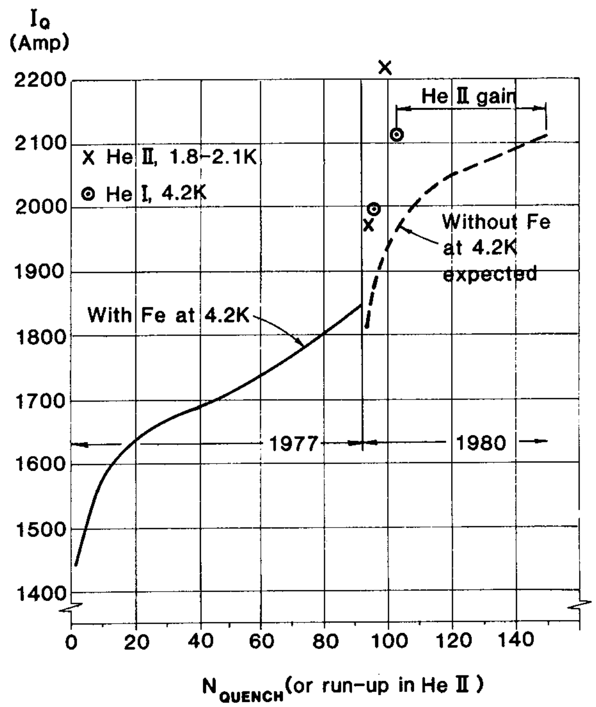

Fig. 4 ESD-10: Entire training history with iron at 4.2K, without iron at 4.2K, and without iron at 1.8K.

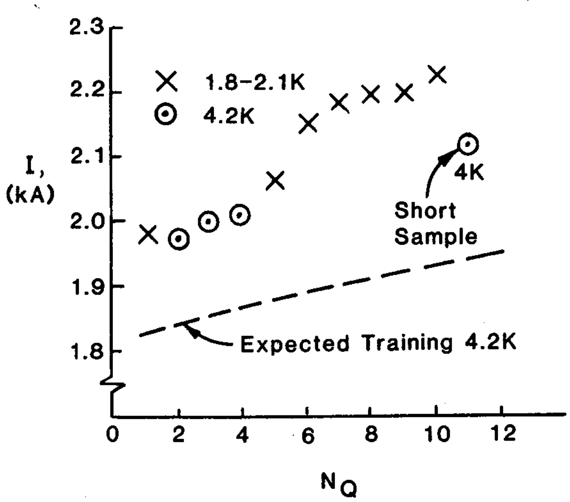

Fig. 5 ESD-10: Training in helium II facility.

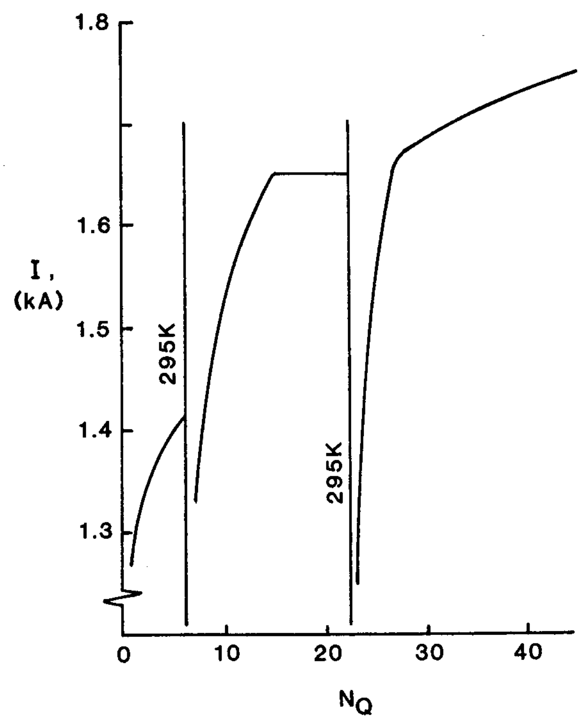

Fig. 6 D-5: Training in helium II facility.