EFFECTS OF SOLDERING VOID ON RECOVERY CHARACTERISTICS
OF A
CRYOSTABLE SUPERCONDUCTOR

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by

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Summary

A conductor for a cryostable magnet is usually made by soldering a superconducting matrix to an OFHC copper strip. The presence of voids between the matrix and the stabilizer due to the imperfection in the soldering bond is of great concern to magnet designers. An experiment was set up to investigate the effect of the void on the characteristics of hot end recovery and cold end recovery for CFFF superconductors. Tests were made on samples having different lengths of soldering void under various magnetic field strengths and injecting energies. The recovery current and the temperature distributions along the matrix and the copper stabilizer were mentioned. The test results are presented.

Introduction

Large superconducting magnets, whether they are used in MHD generators, fusion or energy storage, are normally designed as cryostable magnets. That is, under a normal operating condition the magnet will always recover from a normal transition.¹

A cryostable conductor is usually made by soldering a superconducting matrix with a copper stabilizer. So, when an energy package deposits on a conductor, the conductor temperature will rise and go beyond the saturation temperature. Under this condition, the transporting current can partially or completely switch to the stabilizer, and then switch back after the matrix temperature drops.

It is very hard to have lengthy superconducting matrix and copper stabilizer soldered together without any void. Therefore, it is important to know what effect, if any, a void has on the recovery characteristics of a conductor. We have prepared a series of tests to examine the recovery characteristics of the CFFF SCMS² conductor with various void lengths at different magnetic fields under steady-state and transient conditions.

Experimental Set-Up

Figure 1 is a sketch of Grade A CFFF SCMS conductor. Its important parameters are listed in Table I. A void was made by first unsoldering a section of the conductor and separating the superconducting matrix from the copper stabilizer, then covering a section of the longitudinal groove on the stabilizer by a layer of mylar tape and carefully soldering the matrix back to the stabilizer. The tape-covered area served as a void. The length of void was examined and measured by x ray. The void was always created right in the middle section of the sample conductor. A wire heater was put against the matrix in the middle of the void section. A segment of pultruded fiberglass insulator used in the CFFF SCMS magnet winding was used to cover both faces of the sample conductor to simulate the face cooling condition on the magnet winding.

Round Micarta plate with saw-cut channel was made to accommodate the sample conductor as shown in Fig. 2.

The conductor was bent along the channel in a manner which minimized the inductive voltage on the sample. To minimize the noise, the conductor is tightly clamped by Micarta cover plates. The whole sample was secured within the warm bore of an external magnet. The effective length of the sample was 112.9 cm. Figure 3 is the sample holder with the external magnet behind it. The chrome wire heater was non-inductively wound and embedded within a GE 7031 varnish slab (see Fig. 1). One side of the heater was directly in contact with the matrix. The other side of the heater was thermally insulated from the liquid helium. The resistance of the heater was 1.14 ohm at 4.2 K and its effective length was 3.81 cm. The power source for the heater was a fast response pulser capable of supplying a perturbing energy of more than 20 J with pulse duration of 10 miniseconds. Seven potential taps and six thermocouples (chromel vs Au 0.07 at % Fe) were installed on the matrix and the stabilizer.

A ripple-free 5000 A / 100 V Transrex power supply along with two 2000 A / 5 V Hewlett-Packard power supplies were used as the current source for the sample conductor. The external field was provided by a home-made superconducting magnet which has a clear bore of 30.5 cm and generates a peak field of 7.5 T within the bore.³

Results and Discussions

Samples with void lengths of .63 cm, 1.27 cm, 2.54 cm, 6.35 cm, 25.38 cm, and 50.76 cm had been tested. Both the transient and the steady state characteristics were examined.

Transient State Test

In the transient state test, at 7 T and 4000 A transporting current, the superconducting matrix was heated with a square pulse of 10 ms duration and the amplitude of disturbance was varied. The time-wise variation of the potential drop across the void and the temperature of both the superconducting matrix and the copper stabilizer were monitored. Figure 4 is a typical recording of the test. After a square pulse with 10 ms duration and an energy of 15.12 J was injected into the sample with a void length of 50.76 cm, the temperature of the matrix and the potential drop across the void rose right away. However, the stabilizer temperature did not rise until a few tenths of a second after the heater pulse went off. Note that although the temperature of both the matrix and the stabilizer reached their peaks at about the same time, the potential drop did not reach its peak until about one second later. As indicated in Fig. 5, at the very beginning of an event, when a pulse was applied, there would be a high temperature peak on the matrix. Then as the time went by, although the high temperature peak dropped, the high temperature zone grew wider and thus the potential drop increases.

Because the conductor was well cooled and highly stable, it did not take much time for the stabilizer temperature to drop to the pool temperature. However, the matrix temperature did not recover unless the transport current was reduced to a certain low value. The recoverable transporting current is strongly dependent on the void length of the sample. As the temperature of the superconducting matrix approached its peak or its steady state value, the variation of the temperature

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became smaller and smaller. This made it very hard to tell the exact time for these events. Figure 6 shows the time needed for the matrix temperature to reach .63 of its peak and drop to .37 of its peak. Apparently, for the same pulse duration, the more the deposited energy the longer the time needed for the matrix temperature to reach its peak and drop to a steady state temperature. No matter what the void length was, as long as the deposited energy was the same, the time for the matrix temperature to reach .63 of its peak was about the same. But, the more the deposited energy the longer the time needed for the matrix temperature to drop to .37 of its peak. This is probably because the matrix temperature rose mainly due to the heat coming from the heater. The time needed for heat transfer depended on the amount of deposited energy. Both longer void length and higher deposited energy caused higher matrix temperature and longer time for the temperature to drop to a steady state level.

Steady State Tests

A steady state test was a hot end test. The steady state measurements were performed by passing sufficient high transporting current through a sample of given void length under certain external field.

Figure 7 is a set of normal transition and recovery electrical terminal characteristics. Figure 8 indicates the corresponding thermal characteristics. Note that the electrical terminal characteristics of recovery are marked with sudden transition. Samples with long voids could not completely recover until the transport currents were reduced to sufficiently low levels. A summary of recovery current vs void length at different external fields is shown in Fig. 9. For a sample with given void length, the recovery current increased as the magnetic field decreased. The shorter the void length the higher the recovery current. It is clear that in order for CFFF SCMS Grade A conductor to recover at 3675 A, the operating current of CFFF SCMS, the soldering void length should be shorter than 3.8 cm. Also note that a sample with 25.4 cm void length could only completely recover at a transporting current of 1500 A.

CFFF CONDUCTOR SANDWICHED WITH FIBERGLASS INSULATORS

Fig. 1 CFFF SCMS Grade A Conductor with its Insulator and Heater Configuration.

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Table I
Sample Conductor Parameters

Overall Dimension	.47 x 3.10 cm ²
Matrix Dimension	.23 x 1.03 cm ²
Specification	4500 A at 7.5 T
Operation	3675 A at 6.9 T
Cu/NbTi	23.7
Total Wetted Area	2.86 cm ² /cm
I ² R/Unit Length	.414 w/cm
Average Heat Flux	.145 w/cm ² (wet)

Fig. 2 A Round Micarta Plate Served as Sample Conductor Holder.

Fig. 3 A Completed Void Sample with the External Magnet Behind It

Fig. 4 Results of a Typical Transient Void Test

Normalization Constants Void Length = 50.76 cm
 $\Delta T_{sc} = 21.7K - 4.2K$ Perturbing Energy = 15.1 J/3.3 cm
 $\Delta T_{cm} = 7.1K - 4.2K$ Perturbing Duration = .01 sec
 $P = 1.5 MW$ Note base line of temperature is 4.2 K

Fig. 5 Temperature Distribution along the Conductor Changed with Time (t).

Fig. 6 Time Needed for Temperature of the Matrix Rose to .63 or Dropped to .37 of its Peak.

Fig. 7 Electrical Terminal Characteristics of 6.35 cm Void Sample.

Fig. 8 Thermal Terminal Characteristics of a 6.35 cm Void Sample (B = 7T).

Fig. 9 The Void Effect on the Recovery Current