Beneficial effect of solid nitrogen on a BSCCO-2223/Ag composite tape subjected to local heating

Akira Sugawara [a,*], Hisashi Isogami [b],

Benjamin J. Haid [a], and Yukikazu Iwasa [a]

[a] MIT Francis Bitter Magnet Laboratory, Cambridge, MA 02139-4307, USA
[b] Mechanical Engineering Research Laboratory, Hitachi Ltd., Japan
Received August 26, 2001;

Abstract

This paper presents results of a quench/recovery experiment for a BSCCO-2223/Ag composite tape in the presence or absence of a thin layer of solid nitrogen on each side of the tape. Voltage and temperature data were recorded for a 20-**cm** long BSCCO-2223/Ag tape operating in the range 20-55 **K** and subjected to a heat pulse of a 10-600 **s** duration applied over a short distance at its midpoint. The data clearly show that solid nitrogen is beneficial to the stability of high-temperature superconductors (HTS) operating in this temperature range and subjected to transient heating disturbances.

Keywords: Solid nitrogen, Stability, BSCCO-2223, Critical current

1. Introduction

The stability and protection of high-temperature superconductors (HTS) are important design and operation issues.[1] The HTS magnet in a large system must maintain stable operation even when subjected to transient disturbances such as local heating in the winding. Also, because the HTS magnet is not self-protecting,[1-3] the only practical protection option is a magnet shutdown. For most systems, this "active" protection option should be the last resort, to be used only to save the magnet, because it disrupts the system operation. Is there a technique that enhances the stability of HTS to such an extent that the active protection will be needed in the rarest instances? Solid nitrogen as an integral component of the winding is a promising option to enhance the stability of HTS. Recognizing solid nitrogen as another stabilizer, the MIT group begun in 1999 studying possible beneficial effects of solid nitrogen for the stability of HTS magnets.[4]

Figure 1 shows heat capacity [$\mathbf{J/cm^3K}$] vs temperature plots of solid nitrogen and other substances in the temperature range 15-70 **K** [4,5]. Here silver represents the principal component of the HTS winding. In this temperature range, the heat capacity of nitrogen

*Tel.: +1-617-253-5548; fax: +1-617-253-5405.
E-mail address: akira@eng.niigata-u.ac.jp (A. Sugawara).

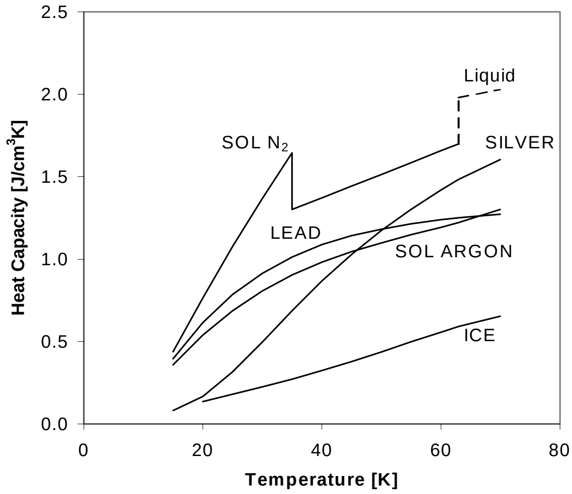

Fig. 1. Heat capacity *vs* temperature plots [5]

is the largest of these substances. Moreover, since nitrogen has the latent heat associated with structural change at 35.6 **K**, 63.25 **K**, and 77.35 **K**, its heat capacity is still large. It seems that solid nitrogen will cool local high temperature areas effectively. This paper shows preliminary results of a quench/recovery experiment performed on BSCCO-2223/Ag tape in the presence or absence of solid nitrogen.

2. Experimental Setup

The test sample (BSCCO-2223/Ag tape: Ag/SC ratio 3.0, 20-**cm** long, 9.0-**mm** width, 0.5-mm thickness) is shown in Fig.2. Nomex spacers, 0.38-**mm** thick, 3.2-**mm** width, are placed on each side of the tape every 12.7-**mm** in the azimuthal direction. Solid nitrogen occupies a 0.38-**mm** thick layer created on each side of the tape by the spacer gaps (Fig.2, top view). A quench-inducing heater of Manganin (0.127-**mm** in diameter) is wrapped around the tape over a 5-**cm** axial length centered at the midpoint of the test tape. Six voltage taps, each 2.5-**cm** apart, placed along and near the heater; two thermocouples, TC(a) and TC(b), are placed at the centers, respectively, of the heated region and Voltage B region (Fig.2 sideview).

Figure 3 shows the test chamber. The HTS tape is placed in a ring between the inner wall of the chamber and polyurethane foam filler. First, the test chamber is evacuated and cooled down to the temperature range

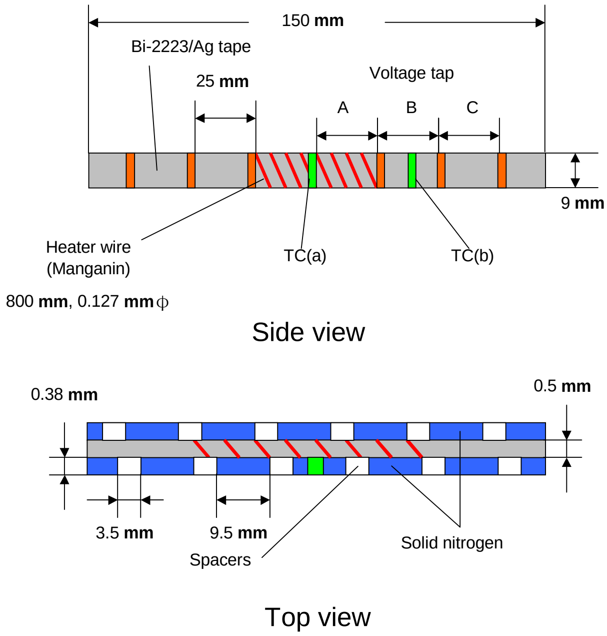

Fig. 2. Schematics of HTS test tape

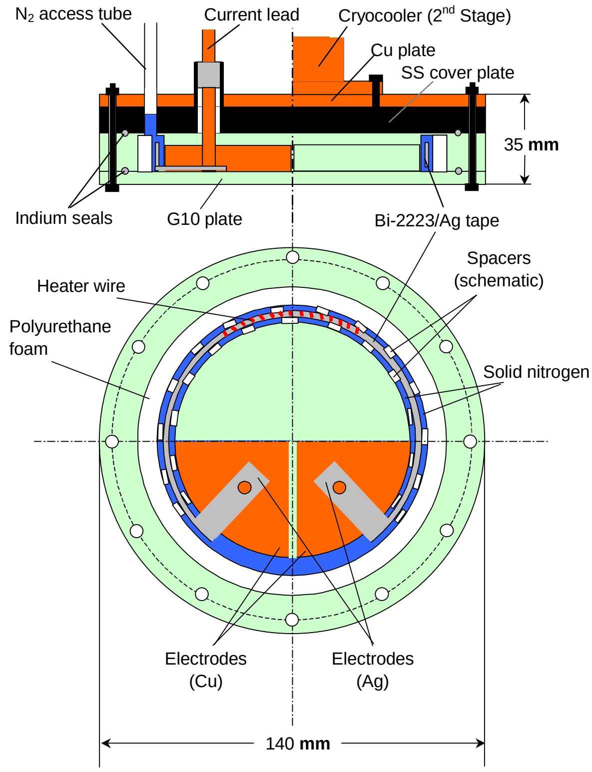

Fig. 3. Schematics of test chamber

64-77 **K** by a cryocooler. Nitrogen gas is injected slowly through the N_2 access tube into the chamber. As N_2 gas is liquefied, the liquid fills up the void space in the chamber. Subsequently, the chamber is cooled below 63 **K** to solidify the liquid.

A heater attached to the cryocooler's second stage controls the chamber temperature. The quench/recovery experiment on the test sample was performed at a constant current of 150 **A** in the presence or absence (chamber evacuated) of solid nitrogen. The quenching heater pulse is 0.3 **A** at 8 **V**, with a pulse duration of 10-600 **s**. The initial temperature T_{in} in the test chamber is 20-55 **K**. The voltages of the quenching heater, taps A, B, and C, and thermocouples TC(a) and TC(b) are measured and recorded by a data acquisition system with a sampling time less than 0.05 **ms**.

3. Results and Discussions

Figure 4 shows the measured critical current vs temperature data and a linear-fit curve of the test sample. Figures 5-8 show measured voltage and temperature traces. Figure 5, with an initial temperature of 48K, shows the traces in the absence of solid nitrogen (vacuum); Fig. 6, also at 48 **K**, shows corresponding traces in the presence of solid nitrogen. Similarly for Fig. 7 (at 35 **K** in vacuum) and Fig. 8 (24 **K** with solid nitrogen). In each figure, the dashed line is the quenching heater pulse applied at t=0. In Fig. 5 (48 **K**, vacuum) the HTS tape quenches at t = 8 **s** and the quenching ensues even after the heater pulse stops at t = 48 **s**. In Fig. 6 (48 **K**, solid N_2) the quenching does not begin until t = 60 **s** and despite a heat pulse lasting until t = 300 **s**, recovery begins immediately after the conclusion of the pulse heating. The TC(a) trace in Fig. 6 shows an anomaly at around 60 **K**, followed by a steady increase as the heating continues. This anomaly may have resulted due to the solid-to-liquid transition at 63 **K** taking place at the heater location. However, in the regions away from the heater, apparently there still is solid nitrogen, because the temperature falls rapidly after the heater pulse ceases.

Even in the vacuum environment, as shown in Fig. 7 the quench recovers, though slowly, because the initial temperature is low, 35 **K**. In the presence of solid nitrogen, as shown in Fig. 8, the voltage trace in the A

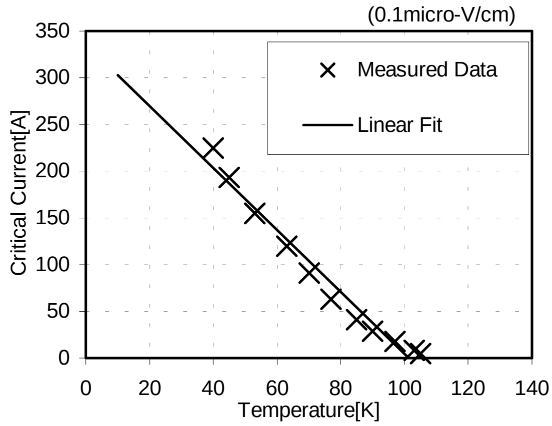

Fig. 4. Critical current

region increases very slowly even though the heating lasts 600 **s**, twice that in Fig. 6. Also note that in Fig. 8, the final voltage reached for a heating duration of a 600 **s** is ~14 **micro-V**, about 1/100 of that recorded in Fig.6 (300 **s**). Apparently, the low initial temperature kept Joule heating in the HTS tape to a minimum and hence the voltage to a microvolt level.

4. Conclusions

The quench/recovery behaviors have been measured for a 20-**cm** long BSCCO-2223/Ag tape in the presence or absence of a thin layer of solid nitrogen on each side of the conductor. The BSCCO-2223/Ag tape, at 20-55 **K** and carrying a constant current, is subjected to a heater pulse lasting 10-600 **s**. In the absence of solid N_2 (vacuum) at 48 **K**, as the HTS tape is subjected to a 110 **J** heating pulse, it is driven to a runaway quench. But in the presence of solid nitrogen, it recovers quickly even after subjected to a 750 **J** heating pulse. Moreover, at 24 **K** and in the presence of solid nitrogen, a heating pulse (600 **s**) of an equivalent energy input of 1500 **J** has little effect on the HTS tape, demonstrating beneficial effects of solid nitrogen on the stability of HTS operating in the temperature range 20-40 **K** and subjected to transient heating disturbances.

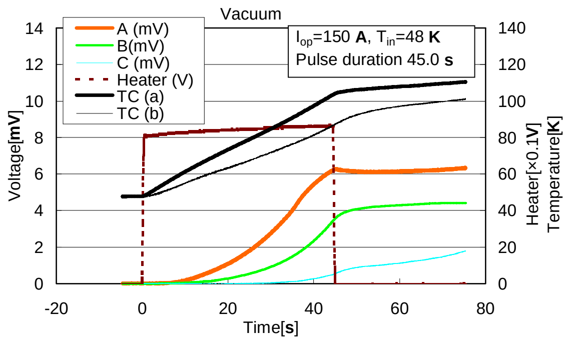

Fig. 5. Experimental voltage traces for I_{op}=150 **A** showing a runaway quench at 48 **K** in vacuum.

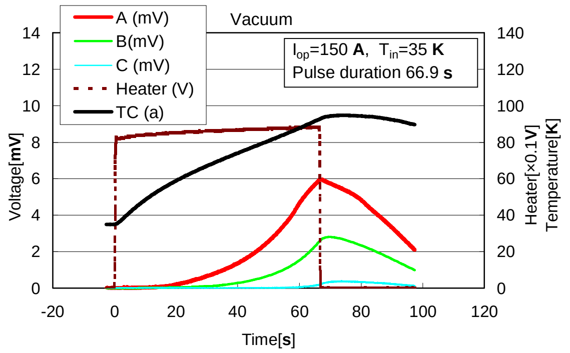

Fig. 7. Experimental voltage traces showing a quench recovering very slowly at 35 **K** in vacuum.

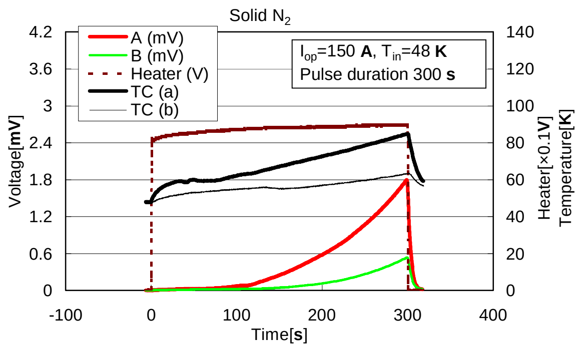

Fig. 6. Experimental voltage traces for I_{op}=150 **A** showing a recovering quench at 48 **K** with solid nitrogen.

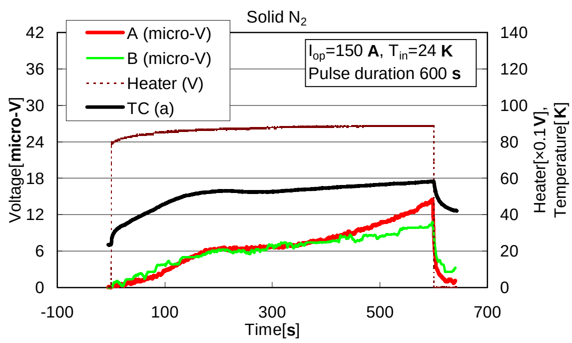

Fig. 8. Experimental voltage traces showing a quench recovering at 24 **K** with solid nitrogen despite a large heating energy of 1500 **J**.

Acknowledgements

The work presented here was supported by the U.S. DOE Office of Power Technologies, Office of Energy Efficiency and Renewable Energy.

References

[1] Y. Iwasa, "Case Studies in Superconducting Magnets," (Plenum Press, New York, 1994).

[2] R.H. Bellis and Y. Iwasa, "Quench propagation in high Tc superconductors", *Cryogenics* **34**, 129 (1994).

[3] Y. Iwasa and M.I. Yunus, "Spatial and temporal temperature and voltage signals of a silver-sheated BSCCO tape undergoing a quench: Experimental and analytical results", Inst. Phys. Conf. **148**, 447(1995).

[4] Y. Iwasa, "Protection in HTS windings, "Presentation at the DOE Annual Peer Review Meeting on Superconductivity Programs for Electric Systems (Washington, DC., July 1999).

[5] H. Isogami, B.J. Haid, and Y. Iwasa, "Thermal Behavior of a Solid Nitrogen Impregnated High-Temperature Superconducting Pancake Test Coil under Transient Heating", IEEE Trans. on Applied Superconductivity, **11**, 1852 (2001).