Long Term Test of ZerRes HTSC Current Leads

M. Garber and W. Sampson
Brookhaven National Laboratory
G. O. Zimmerman and Y. Z. Negm
ZerRes Inc.

For the past several years ZerRes, Inc. have produced a cryogenic current lead based on the so-called "1-2-3" type of high temperature superconductor (HTSC). Early in 1993 engineers at the SSC project expressed interest in using these leads provided a rigorous life test could be passed: unattended operation at rated current for at least one month. It was proposed that this test be performed at BNL as part of the CRADA program, utilizing the laboratory's expertise in cryogenics, instrumentation and superconductivity. A series of preliminary measurements showed that:

- unattended operation for one week at the rated current (100A) posed no problems
- the critical current at zero field and 4.5K was greater than 220A
- the quench protection technique used for conventional superconductors works well with the new material

In July 1993 the grant was awarded; a few months later, the SSC project was terminated. Interest in HTSC leads was and is, sufficiently great that it was decided to continue the study with emphasis now placed on determining properties of the leads under realistic operating conditions rather than on the longevity. Apparatus was designed to determine the heat leak of the leads and the critical and quench currents as a function of temperature. By the end of the grant in 1994, the current - temperature dependence was determined and extended operation near the optimum heat leak at the rated current of 100 amps was demonstrated.

The ZerRes HTSC lead consists of an HTSC rod 25 cm long by 1 cm overall diameter, capped at each end with a brass ferrule which holds a group of flexible copper wires at one end and a high current low temperature superconductor at the other. Electrical contact to the HTSC superconductor rods is made with a special low melting temperature solder which wets the HTSC material. The lead design and the special solder are proprietary to ZerRes, Inc. Nominal operating parameters are: maximum warm end temperature of 77 K (corresponding to liquid nitrogen) and steady state current of 100 amps. Higher current ratings are achieved simply by paralleling conductors.

Measurements have been conducted using a 500 liter LHe storage dewar. This has made it possible to run for long periods of time without having to stop for He refills. In order to determine the heat leak due to the leads, the helium boil-off was measured with and without the leads. Fig. 1a shows the arrangement of the neck plug used in determining the heat leak due to the dewar itself. By observing the level over a period of several days it was determined that the loss rate was 4.6ℓ/day, corresponding to a heat leak of 0.14 watts. (Without the neck plug the dewar boil-off is 5.7ℓ/day or .17W). Fig. 1b is a schematic representation of the lead test; only one lead is shown for clarity.

Figure 1a. The plug forces boil off gas to heat exchange with the cryostat neck reducing the conduction heat leak into the liquid helium.

Figure 1b. When the HTSC current leads are in place the boil off gas is divided between the space around the neck plug and the leads.

One of the lead elements was wrapped with a bifilar stainless steel foil heater as shown in Fig. 2. A diode temperature sensor was glued into a notch in the warm end and the whole assembly wrapped with a thick layer of masking tape for thermal insulation. This simple arrangement worked very well: the temperature could be varied from 4.2K to over 100K with relatively small heater currents when immersed in liquid helium. It worked well in liquid nitrogen also with the measurements at 77K in the helium bath matching nicely those in nitrogen. Fig. 3 shows V-I curves for different temperatures using one of the copper wires at the warm end as one voltage tap. In nitrogen the mechanical tap at the cold end is used to minimize the correction needed for the LTSC wire. The measurements were made by increasing the current slowly and recording the voltage drop across the HTSC element until the voltage was not stable (i.e., increased with time at fixed current). This happens slowly enough that the current can be reduced when this point is reached without actually quenching the element.

Figure 2. Experimental arrangement used to measure the temperature dependance of the current carrying capacity of the HTSC leads. The whole assembly is immersed in liquid helium and the heater power adjusted to vary the lead temperature.

Figure 3. The voltage current characteristics of HTSC leads at three temperatures. The diagonal line represents an effective lead resistance of one micro-ohm. The voltage drop across the lead can be used to regulate the gas flow up the lead to maintain optimum operating conditions.

This maximum stable current is shown as a function of temperature in Fig. 4. Also shown is the current at which the effective resistance is equal to one micro-ohm as determined from the diagonal in Fig. 3. The maximum stable current at 4.2K is about 220A. The warm end temperature corresponding to 100A is approximately 65K.

Fig. 4. The temperature dependence of the current for ZerRes Inc. HTSC elements. The upper curve represents the maximum current for stable operation. At higher currents the lead resistance will increase rapidly with time leading to a transition to the normal state or quench. The lower curve is the current at which the effective lead resistance is one micro-ohm. The optimum operation region is shown by the shaded area. The points indicated by stars were measured in liquid nitrogen; all others were done in helium.

A pair of HTSC leads were operated continuously over a thirty day period. The gas flow up the lead assembly was varied from zero to full flow with no gas allowed to pass between the neck plug and the cryostat wall. The maximum continuous current that can be carried without gas flow is 55A since the warm end of the leads stabilizes above 70K. By adjusting the flow to distribute the boil off gas between the leads and the cryostat vent the operating current can be increased to the nominal operating value of 100A. The heat leak determined from the change in helium level was 8.6 liters/day. This heat leak is 4ℓ/day higher than that measured without the lead assembly and is due to conduction down the instrumentation leads as well as the HTSC leads themselves. The heat leak did not depend on the proportion of boil-off gas passing through the HTSC elements or the operating current. This is illustrated in Fig. 5 where the helium level is shown as a function of time. No measurable change in slope was observed when the gas flow through the leads was shut off and the current reduced to 55A. The level indicator represents a significant thermal input in this test and was only powered for a short interval each day. The current, gas flow, warm end temperature and voltage drop across the lead elements were monitored by a small computer during this long term test. The experiment was completely automatic and ran without incident.

Figure 5. Helium boil off during the long term test. The average rate of change of level corresponds to 0.26 watts total heat input. Most of this heat load is due to the cryostat itself and conduction down the instrumentation leads. When the cooling gas passing through the HTSC leads is shut off there is no significant change in the heat load but the maximum current is limited to 55A.

SUMMARY

The 100A ZerRes leads operated several times without event. Their low temperature properties appear to be undiminished over the year of testing. While HTSC's are mechanically fragile, only reasonable precautions were necessary in handling these leads. These tests have provided ZerRes with useful performance data for their product.