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Plenary

Monday Plenary

Special Tenth Anniversary Plenaries

Wednesday Plenary

High Current and Pulse Response of YBCO and BSCCO Junctions

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Abstract--**One of the crucial elements in the use of HTS materials as current leads between 77K and 4.2K is the nature of their contact to normal and LTS metals. We report here a set of measurements made on junctions of polycrystalline YBCO and BSCCO bulk rods to copper wires. The surface area and the nature of the surface, as well as the method of making the junctions, influence the junction's behavior. In a related measurement, high current short duration pulses were applied to HTS leads. It was found that the ability of the leads to withstand the stress of high current pulses depended on the previous history of the material.**

I. INTRODUCTION

Because of the highly developed technology of low transition temperature superconducting materials, (LTS), to magnet design [1], one of the most common current commercial applications of bulk high transition temperature superconducting materials, (HTS), is that of electrical power leads for magnets and machinery made of conventional LTS materials. Those electrical power leads, made of HTS materials, will play a crucial role in the application of superconducting technology even if HTS tapes and cables capable of carrying substantial currents in high magnetic fields are developed, since those will have to be operated at a temperature substantially below that of liquid nitrogen, 77 K. Several companies have announced the development of such electrical HTS power leads and their commercial availability [2-4]. (Only a few are mentioned here, without prejudice, since a complete enumeration is too extensive for this paper.)

The HTS electrical power leads have the capability of extending the LTS technology and of reducing the initial and operating cost of the LTS device. The greatest benefit in the use of HTS electrical power leads is achieved in cases where the LTS superconducting device cannot operate in a persistent current mode.

If the LTS device requires a permanent connection to a power source, the HTS electrical power leads provide an effective link between high and low temperatures which minimizes the heat input into the low temperature reservoir. That is the case because HTS materials have a thermal conductivity which is orders of magnitude lower than that of copper. In addition, the virtual absence of resistance eliminates joule heating. These properties not only save helium and extend the effective running time of magnets between servicing. They also enable LTS magnets to operate without liquid helium, cooled only by cryo-coolers [5]. This HTS application is an enabling technology whose full potential has not yet been tapped.

The last two sentences require elaboration. The materials used in HTS electrical power leads are not necessarily the ones whose electrical and thermal properties have been measured. Measurements are customarily made on idealized, single crystal materials available in small laboratory quantities. The materials used in HTS electrical power leads are those available in relatively large, commercial quantities. Those materials are generally polycrystalline, where the alignment between the crystals is variable and which contain weak links between the crystals. The alignment of the crystals, because of their anisotropic properties, and the nature of the weak links, play a crucial role in the critical current and magnetic field behavior of the HTS material used.

Two HTS materials are presently available in bulk commercial quantities. One of them is YBCO 123 or variations thereof with substitutions for the Y; the other is BSCCO 2223 or 2212. By nature, YBCO is more isotropic than BSCCO with the anisotropies in J_c of the order of 10^2 and 10^5 respectively between the a or b and c axes respectively [6].

Various melt cast processes have been developed for the preparation of both YBCO and BSCCO. In BSCCO [3], some of the melt cast processes have the advantage of aligning the grains which constitute the bulk material, while this is not the case with YBCO. The alignment generally leads to higher J_c. An extrusion process followed by sintering and annealing [7] has been developed for YBCO bulk rods which enables them to be manufactured in relatively thin long rods. Those, because of the high surface area to volume ratio, are particularly suitable for HTS leads because they provide a relatively low contact resistance, as shown below. (We will not consider here BSCCO metal sheathed tapes for HTS electrical power lead application because the metal adds a factor of 3 to 5 to the thermal conductivity of the lead. Moreover, as pointed out by Hull [8] [9], because of quenching considerations, the leads will be used in the low current density limit, approximately 500 A/cm^2.) It is therefore the contact resistance which is one of the important considerations in the application of HTS materials to electrical power leads.

II. CONTACT MEASUREMENTS

A. Samples

The contact resistances of YBCO and a BSCCO rod were measured by means of the standard four terminal method.

The YBCO HTS material elements were prepared by means of an extrusion method and were in the shape of rods of circular cross-section 1mm in diameter. This process is capable of manufacturing rods up to 25 cm in length. The length of the contact was 2.5 cm. The elements were then encapsulated so as to form a 100 A lead. A more complete description of the lead was given elsewhere [2]. A schematic of the lead is shown in Fig. 1.

The BSCCO rod material was prepared by means of a melt cast process. It was then cut into rods 15 cm long with a square cross-section 3 mm on a side. Smaller cross-sections proved unreliable because cracks developed easily during the cutting process. Again, the length of the contact was 2.5cm.

The contacts were made by the application of silver powder [10] to the surfaces, heating the powdered surface to 450^0 C and then using a low melting-temperature solder [10] for attachment to either copper wires or LTS wires. YBCO required reannealing in an oxygen rich atmosphere in order for the silvered ends to regain their superconducting properties while BSCCO did not.

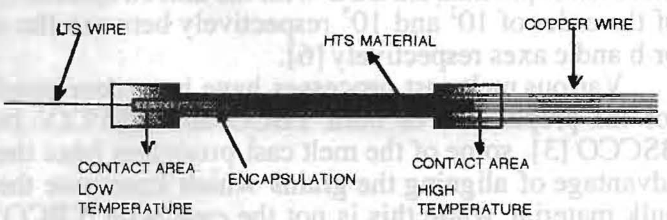

Figure 1
A schematic of an electrical power lead containing HTS material.

B. Results

The measurements were performed at liquid nitrogen temperatures, 77 K, since it is found that at the low temperature end the contact resistance is below $10^{-8}\ \Omega$ and thus negligible. Fig. 2 shows the V-I results for a nominal 100 A YBCO lead in the linear range, where the voltage was taken across the contact. In this case the contact area was 23.6 cm^2. The V-I line shows a resistance of 3.9 $\mu\Omega$ which translates to 90 $\mu\Omega$-cm^2 per contact area if we assume that the contact resistances simulate a parallel network.

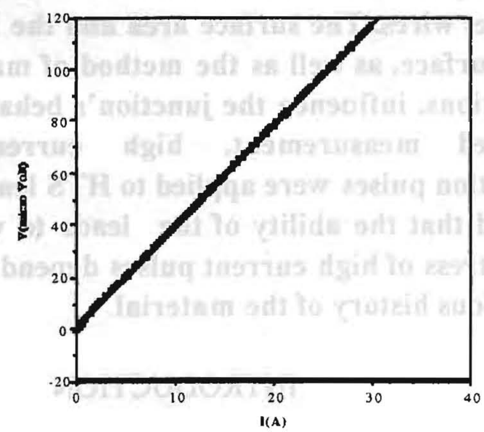

Figure 2
The V-I characteristic for a 100A YBCO containing current lead.

Fig. 3 shows the V-I results for a nominal 25 A BSCCO lead in the linear range, where the voltage was taken across the contact. In this case the contact area was 3 cm^2. The graph shows 3 measurements at magnetic fields of 5 G, 10 G and 15 G. Since no significant differences were found between the measurements, as expected, the resistance values were averaged. The average V-I line shows a resistance of 54 $\mu\Omega$ which translates to 162 $\mu\Omega$-cm^2 per contact area if we assume that the contact resistances simulate a parallel network.

While the YBCO lead contacts showed no deterioration upon temperature cycling, the BSCCO contacts showed considerable deterioration upon cycling, to the point of the contact peeling off the material.

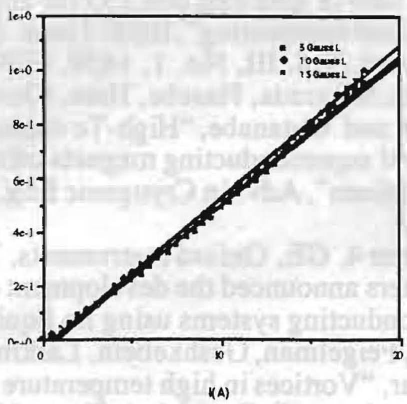

Figure 3

The V-I characteristic for a 25A BSCCO containing current lead.

Since the contacts were made by the same method in both cases, and the results shown above are reproducible through the many samples we measured, we tend to attribute both the magnitude of the contact resistance and the thermal cycling behavior to the structure of the two materials.

As shown schematically in Fig. 4, BSCCO bulk is made out of platelets which tend to align. The silver applied at the surface has a hard time penetrating into the interior and forming an integral network with the grains. Thus the silver contact tends to peel off when in contact with a solder to which it adheres better than the BSCCO surface. In YBCO, the more irregular grains allow the silver powder to penetrate into the interior of the bulk, thus allowing for a better contact with better mechanical, thermal and electrical properties.

In the schematic of Fig. 4, the silver is represented by the filled-in squares, while the BSCCO and YBCO are represented by hollow shaped forms.

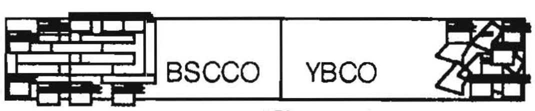

Figure 4

A schematic diagram of a possible microscopic view of the silver powder contact with BSCCO and YBCO.

C. Conclusions

With the contact method used in the leads described above, YBCO is superior as far as contact resistance per unit area, thermal cycling and mechanical stability is concerned. However, in the construction of an HTS lead many factors have to be taken into consideration. Although the contact resistance is a major consideration, the critical current, and its behavior as a function of the magnetic field has to be taken into account. So does the method of making contacts.

In our design, which is multi-filamentary, the ability to manufacture thin, long bulk rods out of YBCO material outweighs some of the advantages of BSCCO.

Another view of contact resistance would be to compare the contact resistance per 100 A in the above measurements. In that case the YBCO contact resistance per 100 A is about 4 μΩ at 77 K while that of our BSCCO is 13.5 μΩ worse by a factor of 3. A recent report [11] for contacts for BSCCO made by embedding silver in the bulk BSCCO during the melt cast process, with the bulk current density at 970 A/cm^2 at 77 K reports a contact resistance of 2 μΩ for a 500 A lead. Although the contact area is not reported, this works out to 10 μΩ for a 100 A capacity lead, which is comparable with the BSCCO contact resistance reported above.

III. PULSED CURRENTS

A. Introduction

To determine the ability of our HTS leads to withstand overload pulses for applications such as quench heater leads for the former SSC [12] accelerator magnets, quench heater leads for application in other accelerator magnets and short term overload applications for SMES and other purposes, we tested a pair of nominal 20 A HTS BSCCO containing leads.

B. Experimental details

A bank of capacitors was discharged through the HTS leads by means of a circuit controlled by an SCR. The leads were immersed in helium vapor at temperatures between 30 K and 40 K.

The procedure was to charge the capacitors to a certain voltage by means of a power supply and then discharge them through the leads. Voltages were monitored across the various circuit elements in order to determine the discharge current and its duration.

Typically, the current pulse consisted of a rise time and a decay time both of which were exponential. The typical rise time was about 1 μs while the decay time was 10 μs. The peak current varied with the initial capacitor voltage. The current was also limited by a limiting resistor.

C. Results

The pulses were administered over the course of a day.

Ten pulses with peak currents of 200 A, a ten fold overload for the nominal 20 A lead, had no effect on the leads. The peak pulse current was then raised to between 300 A and 320 A. The leads were then pulsed periodically. After the application of 13 pulses of this magnitude to the leads, one of the leads burned out.

D. Conclusions

The lead can withstand short duration pulses with peak currents ten times its rated capacity for an undetermined number of times. Pulses with peak currents 15 times of the rated capacity introduce stress in the lead which in time leads to failure.

The fact that the leads were able to withstand 12 pulses with peak currents of 300 A and failed on the 13th pulse attests to the induction of stress in the lead.

It is also interesting where the failure occurred. The lead burned through, ie. the HTS components and the encapsulation material fractured several millimeters below the warm temperature electrical contact. A dynamical thermal analysis of the failure is in progress.

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[12] These tests were conducted at the suggestion and the participation of Randy McConeghy who at that time was associated with the SSC project.