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Two Methods of Fabricating Reliable Superconducting Joints with Multifilamentary Nb-Ti Superconducting Wire

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We describe two techniques for joining multifilamentary Nb-Ti superconducting wire. Both methods have achieved critical currents in vacuum at 4.2K comparable to the manufacturer's stated short segment rating. The techniques are simple and applicable to a wide variety of experimental apparati.

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1. INTRODUCTION

Small superconducting solenoids are commonly used to generate magnetic fields within the vacuum space of cryogenic apparatus. Typically these solenoids are equipped with a persistent switch consisting of a short section of the same wire as the solenoid windings to act as a shunt. The shunt is configured so that it can be locally raised above the critical temperature by contact with a heater. The joint between the solenoid, the superconducting shunt and the charging wire is usually found to be the element that limits the current that can be stored in the solenoid.

In our laboratory, junctions between superconducting wires are commonly fabricated by joining monofilamentary Nb-Ti superconducting wire comprised of a single inner superconducting wire of 0.04 to 0.05 mm diameter with CuNi cladding to a diameter of 0.1mm. Such a wire has a short segment critical current of about 5 A in magnetic fields below one Tesla at 4.2K. After being stripped of the copper nickel cladding with dilute nitric acid, exposed superconducting wires are twisted together and spot welded at points of contact. Such joints have critical currents of 0.4 to 3.0 amps in

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vacuum at 4.2K.

We wanted to find a technique that would not limit us to monofilamentary superconducting wire which typically has a lower current density than multifilamentary wire. There are techniques published in the literature[1,2] that describe the joining of such multifilamentary wire. The joints described in the literature are intended for use with large superconducting solenoids operated while immersed in liquid helium. We wanted to to develop superconducting joints suitable for use with small solenoids operated in a vacuum. The joints would be thermally anchored to the helium bath. The solenoid and the leads to it would be thermally anchored to parts of a 3He-4He dilution refrigerator operating below 0.1K. We have found that if the critical current was exceeded in joints produced with the methods described in the literature, the result was a subsequently diminished current carrying capability. We describe two techniques that produce joints suitable for operation in vacuum with 54 filament niobium-titanium wire, and have also been successfully applied to joints in 18 filament niobium-titanium wire.[3] This wire has an overall diameter of 0.14 mm, including a 0.015 mm thick Formvar insulation layer.

2. JOINING TECHNIQUE

In order to prepare the wire for joining we stripped off the Formvar insulation over a 1 to 2 cm length and immersed the wire in nitric acid (diluted 1:1 with water) to remove the copper cladding. Etching was continued until the individual filiments were visable. In order to make the small Nb-Ti filaments more manageable, the Formvar was left intact on the last 1-2 mm of the wire. The Formvar acted as a mask during the etch so that the copper was not removed on the very end of the wire and the filaments were held in place. After rinsing in water, the exposed filaments were immersed in a solution made up of equal parts of nitric and hydrofluoric acids diluted by 1:5 in water. The solution was sufficiently dilute so that when the wires were immersed for 5 seconds they were just barely etched.[4] After this step the wire was rinsed and joined within a few minutes by one of the methods described below.

The first technique involved spot welding the wires to a 0.13 mm thick niobium foil. The filaments were gently twisted and located on a section of the foil approximately 1 cm wide x 2 cm long. The filaments were then spot welded at 8 points over a 1.5 cm length, using pulses of 15-20 Watt-seconds.[5] During this step the wires were clamped gently between the tips of the spot welder's electrodes with enough force that they were firmly held in place. The second wire was joined similarly (Fig. 1a). This technique was repeated to make a second joint, this time omitting the hydroflouric etch. We obtained similar results.

The second technique employed a 6 mm long niobium sleeve with a 3 mm od and 1 mm id (Fig. 1b). The wires were threaded through the sleeve without twisting the filaments. In order to improve the mechanical stability of the wires, they were arranged so that a small section (<1 mm) of the still cladded wire was within the sleeve. With both wires in place, the sleeve was placed between two steel plates and crimped in a hydraulic press with 10000 lbs load applied.

All joints were tested while immersed in liquid helium in a storage dewar at 4.2K, and later in vacuum at the same temperature. In helium the crimp joint had a critical current, I_c, of 24 A, while the spot welds held 26 A. In vacuum the same joints had similar critical currents. In vacuum the critical current was signaled by a large increase in resistance across the joint, indicating the entire wire sample was driven normal. The critical current values that we measured approach the manufacturer's short segment current rating (28 A at 2T) closely. Since we were not using integration techniques[1] to test these joints, our measurements were not sensitive to small residual resistances. We estimate that at 10 A we could have detected a resistance of 3 nΩ.

Subsequent trials of these joints in vacuum showed some deterioration of the critical current presumably due to the effect of local heating generated when the current exceeded I_c and the joints stopped superconducting. We modified our technique to include a copper strip of 1 cm width x 15 cm long to which the wires were soldered after removing the Formvar (Fig. 1a). The strip and solder provided a shunt for the junction and had a resistance at 4K of less than 5 nΩ. The shunt enabled the joint to remain usable without deterioration of I_c after exceeding the critical current in five trials performed in a single day. Also, to render the assembly more rugged after joining and soldering, the superconducting joint and shunt were wrapped into a "jelly roll" and soldered to make it rigid (Fig. 1c). The shunt and joint could also be thermally anchored by clamping through a hole in a tab on the shunt (Fig. 1a) to the 4.2K flange of a cryostat, after electrically insulating the tab with Kapton tape.

We have constructed a solenoid using the spot welding technique which we have found to be particularly useful since the joints can be constructed in-situ on the cryostat, and since the technique works well without the hydroflouric etch. The solenoid will be used to apply a modest magnetic field ($\lesssim$ 0.5T) for experiments on ^{3}He superfluid. The current that this solenoid is operated at is only 5A and its inductance is approximately 0.25 H. In 36 hours we found that a 4.5A current had not decayed perceptibly (i.e. it was

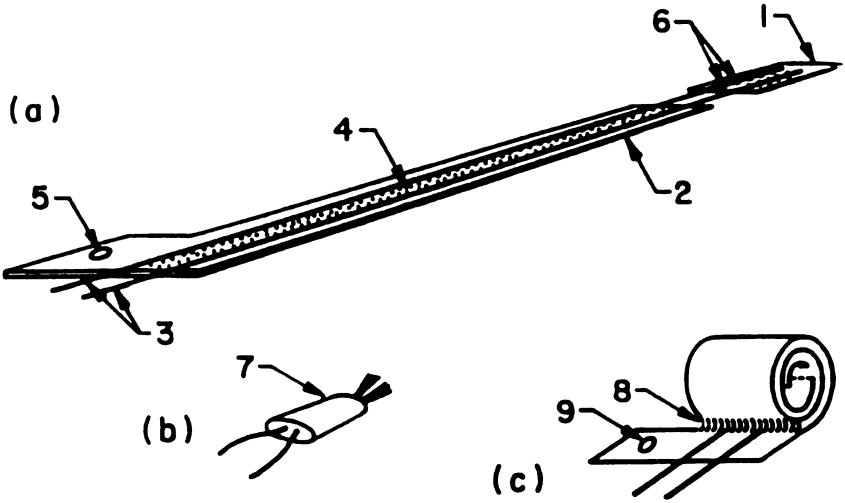

Fig. 1. We show the two wires soldered to the shunt and spot welded to the niobium foil. (b) shows the corresponding crimp joint, (c) shows the joint prepared for thermal anchoring. 1-niobium foil, 2-copper foil, 3-superconducting wires, 4, 8-solder, 5-tab for attachment, 6-spot welds, 7-crimp joint, 9-thermal clamp arrangement. The rolled configuration (c) is used for both the crimp and spot welded joints.

unchanged to better than 1 part in 10000, the resolution of our Hall probe). From this we conclude that the resistance of these joints is smaller than 250 pΩ.

3. CONCLUSION

In summary, we have described two successful techniques to make superconducting joints in multifilamentary wire. We also have describedthe incorporation of a low resistance normal metal shunt that serves to protect the joint in the event of the current exceeding the critical value. This shunt is particularly important in applications where the joint may have to be operated in a vacuum. In such applications, the shunt may also be used as a thermal anchor. The resistance of these joints has been measured to be less than a few nΩ at currents close to the short segment critical current specified by the manufacturer of the wire. In practice, at currents on the order of 10% of the manufacturers quoted critical current, the resistance has been found to be less than 0.25nΩ.

4. ACKNOWLEDGEMENTS

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REFERENCES

1. Leupold, M. J., and Iwasa, Y., *Cryogenics* 16, (1976), 215.
2. Li, J. D, Lin, L. Z., Han, S., and Wen, H. M., *Cryogenics* 34 ICEC Supplement, (1994), 497.
3. Supercon Inc., 830 Boston Turnpike, Shrewsbury, MA 01545. Wire used was #341E-5.
4. The solution was diluted so that bubbles were just barely visible on the surface of a niobium sheet after immersion in the solution for 5 seconds. The same concentration solution excessively weakened the much smaller niobium-titanium filaments exposed to it from a similar diameter wire as described in this communication but having 360 filaments.
5. Hughes Aircraft Company, 6155 El Camino Road, Carlsbad, CA 92008, Model # HRW250B. The pulse profile was the shortest duration available on this model.