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Publication Date

2000-09-10

Critical Current Variation as a Function of Transverse Stress of Bi-2212 Rutherford Cables

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***Abstract*—Transverse loading experiments on wire has shown that a significant drop in critical current occurs for stresses greater than 50 MPa. However, many high-energy physics applications require that the $Bi_2Sr_2CaCu_2O_8$ conductor withstand stresses greater than 100 MPa without permanent degradation. Therefore, a study of epoxy impregnated cables, identical to those used in accelerator magnet applications, has been performed. This work presents the first results of Rutherford cables of $Bi_2Sr_2CaCu_2O_8$ with transverse stress. The results show that the cable can withstand stresses up to 60 MPa with a strain of about 0.3 % for the face loading orientation and 100 MPa for the edge loading orientation**.

***Index Terms*—Bi-2212, cables, critical current, and stress.**

I. Introduction

For the production of dipole fields above 15 T, $Bi_2Sr_2CaCu_2O_8$ (Bi-2212) may be an attractive alternative to Nb_3Sn. The main advantage is the low field dependence of Bi-2212 in the 15-20 T range, where the critical current density of Nb_3Sn decreases rapidly. However, before this advantage can be realized, the engineering J_c must be improved and the J_c variation with transverse stress and strain behavior must be understood. Continual improvement in the critical current is presented at this conference in the paper by Aoki, et al. with I_c's greater that 250 A at 12 T and J_c's greater than 1750 A/mm^2 [1]. This paper describes some of the first experiments aimed at understanding the J_c variation with transverse strain behavior of Bi-2212 cables.

Manuscript received September 19, 2000. This work was supported by the director, Office of Energy Research, Office of High Energy and Nuclear Physics, High Energy Physics Division, U.S. Department of Energy, under Contract No. DE-AC03-76SF00098.

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II. Experimental Details

The testing procedure for the Bi-2212 cables presented in this paper was the same as that reported previously for Nb_3Sn cables [2]. Briefly, the cables are insulated with S-glass, placed in stainless steel test tooling, and vacuum impregnated with CTD-101 epoxy.

One cable used in this work, number 689 (fig. 1), contained 20 strands of Bi-2212 wire from billet number K288. It had a core of Ni-Cr 80 (6.3 mm by 0.1 mm) covered with two-layer wrap of MgO paper. The cable had the nominal dimensions of 2.240 mm thick and 8.890 mm wide. It was difficult to obtain a precise thickness measurement due to the soft MgO tape around the core. A thickness of 2.140 mm is obtained if the cable is firmly compressed during the measurement. Typically for Nb_3Sn cable the compacted dimension is used when the cable is assembled into the reaction and test tooling. However, this was not the case for the Bi-2212 cables. During reaction the cable was not confined to its nominal dimensions in a reaction fixture since the cable expanded during reaction. Therefore, the post-reaction cable dimensions were used so that the conductor would not be strained during assembly in the test tooling. The post-reaction thickness and width were 2.348 mm and 8.94 mm, respectively.

The cable was reacted on a large spool with a diameter of 300 mm to minimize any damage from bending the cable during magnet winding or preparing for these tests.

Fig. 1. Optical photograph of two cables of 689. The cross-section shows the potted cables as measure in face loading. The cable thickness and width were 2.35 mm and 8.94 mm, respectively.

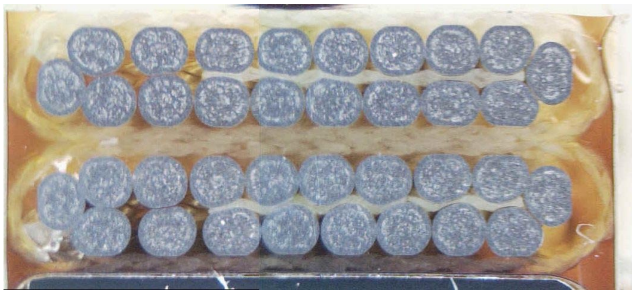

Fig. 2. Optical photograph of two cables of 734. The cross-section shows the potted cables as measure in face loading. The cable thickness and width were 1.47 mm and 8.13 mm, respectively.

Insulation was placed between the layers to prevent sintering of adjacent cable. The cable was taken off of the reaction spool and placed on a spool for shipment from Showa to Lawrence Berkeley National Laboratory. The cable was unwound from the shipping spool, straightened, and placed into the test tooling. The calculated bending strain that the cable sustained was less than 1%.

The second cable, number 734 (fig. 2) was produced with 18 strands with a pure Ag matrix. This cable only had an MgO tape core that extended about ¾ of the width of the cable as can be seen in Fig. 2. This sample was reacted straight in tooling such that it maintained the dimensions obtained during cabling.

A potential criteria of 1 μV/cm was used to determining the critical current of cable 689. Since the voltage taps on all of the cable are 17 cm apart the voltage criteria was of 1.7 μV.

III. Results and Discussion

The first measurements of the effect of transverse stress on the critical current of Bi-2212 wire has shown that the critical current dropped significantly for stresses as low as 10-20 MPa [3]. This paper reports the first measurements of transverse stress on Rutherford cable. Figures 3 and 4 show that a significant drop in I_c does not occur until the stress is greater than 60 MPa for the face

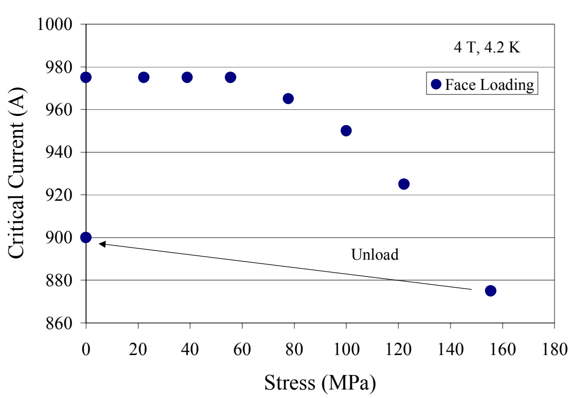

Fig. 3. Variation of the critical current (4 T, 4 K) with stress for a cable loaded on the broad face of the cable.

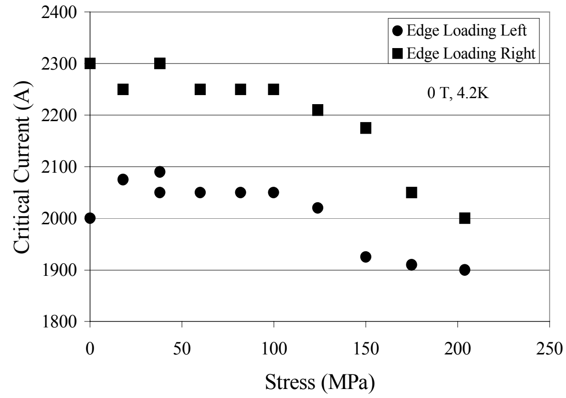

Fig. 4. Variation of the critical current (self-field, 4 K) with stress for a cable loaded on the edge of the cable.

loading orientation and about 100MPa for the edge loading orientation. It can also be seen in Fig. 3 that when the load is removed the I_c reduction is permanent.

The I_c of the cable measured in self-field (Fig. 4) is less than what one would expect from 20 times a single stand (i.e. 3,300 A). This decrease is more than one would calculate due to self-field effects in the cable, and the origin of the decrease is not known at this time. One source could be that the strands are damaged during cabling. However, previous results on strands that have been extracted from cable, heat-treated, and I_c measured have shown no loss in current carrying capacity [4]. Also, the V-I curves of fig. 5 suggest that the cables have not been damaged. The curves of fig. 5 give n-values of 7-12 that are low by Nb_3Sn standards but are representative of those observed in Bi-2212 conductors. The possibility of damage during assembly into the test tooling cannot be ruled out. The other possibility is that the cable is not uniformly heat treated due to its long length such that every section does not receive the optimum temperature for the appropriate time. These various factors can only be determined by measurements on future cables.

An estimate of the overall strain of the face loading cable stack can be obtained. Mechanical modeling of the cable stack in the face loading orientation for a load of

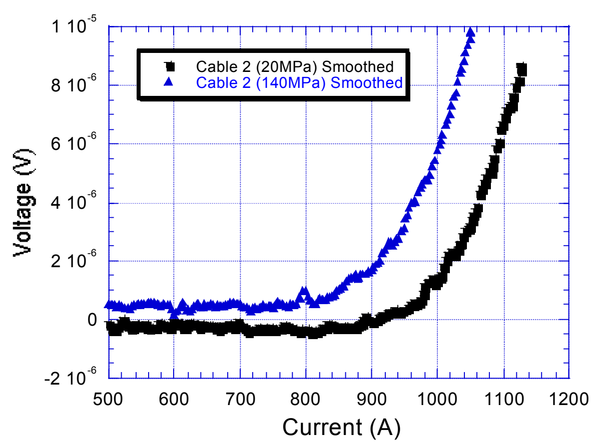

Fig. 5. Voltage-current curves at 4 T and 4.2 K of cable 689 for stresses of 20 MPa and 140MPa.

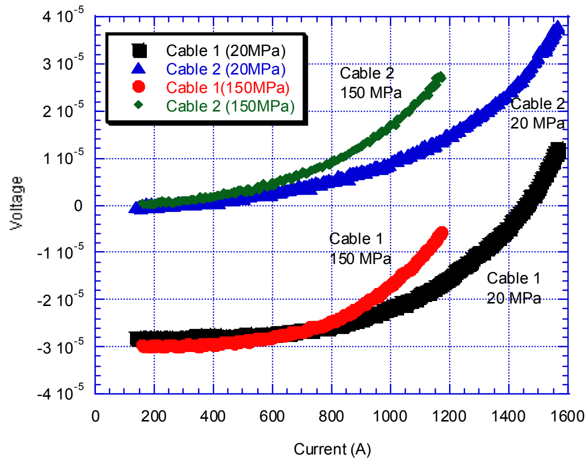

Fig. 6. Voltage-current curves at 8 T and 4.2K of cable 734 for stresses of 20 MPa and 150MPa. The top two curves are for cable 2 and the bottom curves two are for cable 1.

100 MPa gives a displacement of the steel beam into the cable package of about 25 µm. Using this value for the compaction of the stack and a stack thickness of 5 mm gives a strain of about 0.5 %. Therefore, at 60 MPa the strain would be about 0.3%. This is about the irreversible strain limit observed for Bi-2223 and Bi-2212 [5], [6]. Comparison of these results and the work on wires show that a better method to extrapolate wire data to cables is required. In the future precise measurement of the strain in wire and cable that are being loaded transversely should facilitate the comparison.

Unfortunately, cable 734 was damaged after reaction. This can be seen in the broad V-I curves of Fig. 6. Also, the I_c is about a factor of two less than an identical cable tested in parallel field [1]. Nevertheless, the results obtained show that this cable is also not very sensitive to stress. If one uses a criteria of 10µV the I_c (8 T, 4.2 K, 20 MPa) of cable 1 and 2 are 1,150 A and 1,050 A, respectively. The critical currents of the same cables measured at 150 MPa have I_c's of 925 A and 850 A, respectively for cables 1 and 2.

The newest Bi-2212 strand being produced has a much higher critical current than that obtained in these cables. Presently, the I_c of state of the art Bi-2212 wires produce I_c of 650 A in self field and 250 A at 12T. These results are being presented at this conference [1]. It has yet to be determined if cables made with the best material will also have low stress sensitivity or be less susceptible to I_c reduction with cyclical loading [6].

IV. Conclusions

These results show that Bi-2212 conductor can withstand large stresses as long as the strand is well supported in a fiberglass-reinforced epoxy matrix. The important design parameter, as well as the best parameter for comparing strand and cable results, is the amount of local strain the strand is subjected too, which is much less than that observed in an unsupported wire for similar stresses.

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