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LHC Note 141

REDUCED SENSITIVITY OF Nb_3Sn EPOXY-IMPREGNATED CABLE TO TRANSVERSE STRESS

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Abstract

The critical current behaviour of an epoxy-impregnated Nb_3Sn cable exposed to transverse compressive stress up to 150 MPa was investigated. The field-dependent degradation of the critical current is completely reversible. The magnitude of degradation in the tested cable is much less than in single-wires subjected to same compressive loads.

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The behaviour of Nb_3Sn superconductors exposed to transverse load is a subject of considerable experimental interest, stimulated by the need to get more data for present day high field magnet design. The effect of transverse compressive stress on the critical current in multifilamentary Nb_3Sn wires has been thoroughly investigated [1, 2, 3]. In superconducting high-field accelerator magnets, however, candidate Nb_3Sn conductors consist of cables carrying currents in the range of 15 kA. It is advantageous to build such magnets by winding insulated unreacted cable, followed by reaction and epoxy impregnation in order to eliminate bending strain degradation and potential cable handling problems. Due to Lorentz forces and precompression during magnet fabrication, large transverse compressive stresses can arise in the windings. This note presents measurements of the effect of transverse stress on the critical current of a glass-mica insulated and epoxy impregnated Nb_3Sn cable.

The test apparatus is described elsewhere [4]. It was designed to apply and measure the compressive stress on a flat cable while one of its constituent strands carried a transport current. The compressive load is applied at room temperature and kept constant during the critical current measurement. The apparatus is placed in a liquid helium bath in the bore of a 12 T solenoid with the magnetic field perpendicular to the cable edge. With the apparatus, the critical current behaviour of a solder-filled Nb_3Sn cable, exposed to transverse loads up to 165 MPa, was investigated [4].

The conductor chosen for the present tests was a Nb_3Sn cable used in the 1 m long Elin-CERN dipole model magnet for LHC [5]. It is a 36-strand keystoned Rutherford cable made by Vacuumschmelze using the bronze technique. The wires of 0.92 mm diameter contain 20 000 filaments of about 2.5 μm each, with the stabilizing copper located on the outside of the wire. The cable is compacted to a size of $1.47/1.79 \times 16.81\ mm^2$.

The test sample consists of a central section, 13 mm long, where the compressive load is applied to the cable and two side sections, 25 mm each, where only the current carrying strand emerges from the cable. The current carrying strand in the central compression region includes one bent section that occurs at the thick edge of the cable. In this way, the effect of transverse compressive stress on both the straight and bent sections in a cable was studied. A series of samples insulated with glass-mica were reacted and then impregnated by epoxy resin. In order to fit the specimen thickness to the existing sample holder, the impregnated cable is sandwiched between two austenitic stainless steel strips of same type as the material of the sample holder. Figure 1 shows the final sample configuration. The ends of the current carrying strand were soldered to the current leads. In order to prevent premature quenches induced by movement of the specimen, the strands outside the compression region were bonded to an adequate support with a low temperature araldit. Voltage taps were attached to the sample at the points where the strand left the cable. A criterion of 1.5 μV/cm was used to determine the superconducting to normal transition.

Figure 2 shows the transverse stress dependence of the critical current for one of the investigated specimen at a magnetic field of 11.5 T. The results of a second sample were comparable with those presented here. The critical current values are normalized to the maximum critical current I_{cm}. The applied forces were converted to an equivalent pressure by dividing the force by the area of the top face of the cable.

As seen from Figure 2, in the first run little degradation is present. Upon unloading the sample for the first time from 150 MPa, the maximum load used in this experiment, an enhanced critical current was measured compared to its initial unstressed value. Subsequently, a new run was started by increasing the applied stress from zero. The measured I_c values were here normalized to the enhanced zero-stress critical current. In this second cycle, the critical current degradation increases monotonically with stress, reaching at a transverse pressure of 150 MPa nearly 6 % at 11.5 T. Up to this stress level, the effect was completely reversible. The increased zero-stress critical current on unloading the specimen was observed in all previous studies with this special sample geometry [4, 6] and is the result of the competition between the beneficial effect of the axial tensile strain still present in the partially deformed unloaded sample and the residual degradation due to applied transverse compression.

The current degradation effect was found to increase slightly with the magnetic field. For example, the reduction in critical current of the present sample subjected to 150 MPa increased from about 4 % at 10 T to nearly 6 % at 11.5 T.

Figure 3 shows a comparison of the present data obtained for the CERN cable at 10 T and the multifilamentary wire results of Ekin [1]. One reason for the very small degradation measured in cable compared to wire is that in the impregnated cable the load is uniformly distributed between strands. This results in a lower level of stress concentration on the imbedded wire compared to the single wire subjected directly to compressive load.

To study the effect of the transverse compressive load on the critical current of an epoxy impregnated Nb_3Sn cable, a cable section was selected where the current carrying strand crosses the cable face at the thick edge. The advantage of this choice is that the specimen contains both a straight and a bent section. This leads to a more representative test compared to a recent study of the same CERN cable where the current carrying strand was an entirely straight wire segment [6]. The results of the present experiment are consistent with those of earlier study. They suggest that at least up to 150 MPa, for the investigated cable, the bent section at the thick edge and the less compacted straight wire segments in the neighbourhood of this edge do not introduce more degradation than straight wire segments, as present in cables tested in [6], which are passing through regions of high compactions and may build up internal stress concentrations at crossover points. In other words, it seems that the bent sections at the edge of epoxy impregnated cables subjected to moderate transverse loads are not the major source of critical current degradation. Further study, however, will be required to determine whether strands in the highly compacted narrow edge region could be a source of enhanced strain sensitivity. Finally, measurements of cables supplied with the full transport current as reported in [7] should determine whether periodic current redistributions within the strand, induced by transverse compressive load, may affect the performance of long lengths dipole cables in magnet applications.

Acknowledgments

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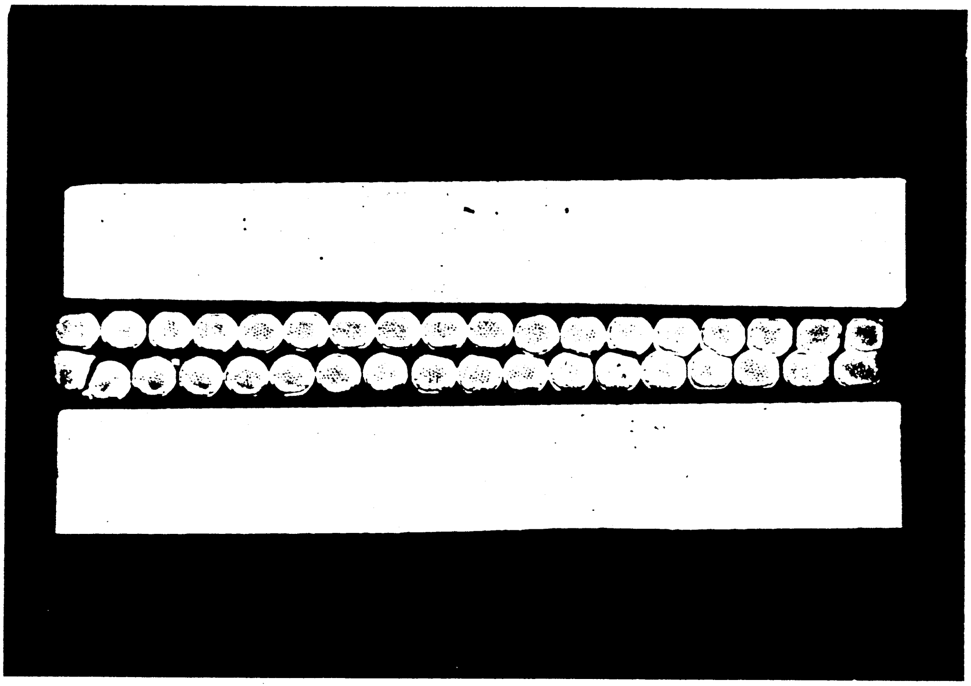

Figure 1: Cross section view of the test specimen

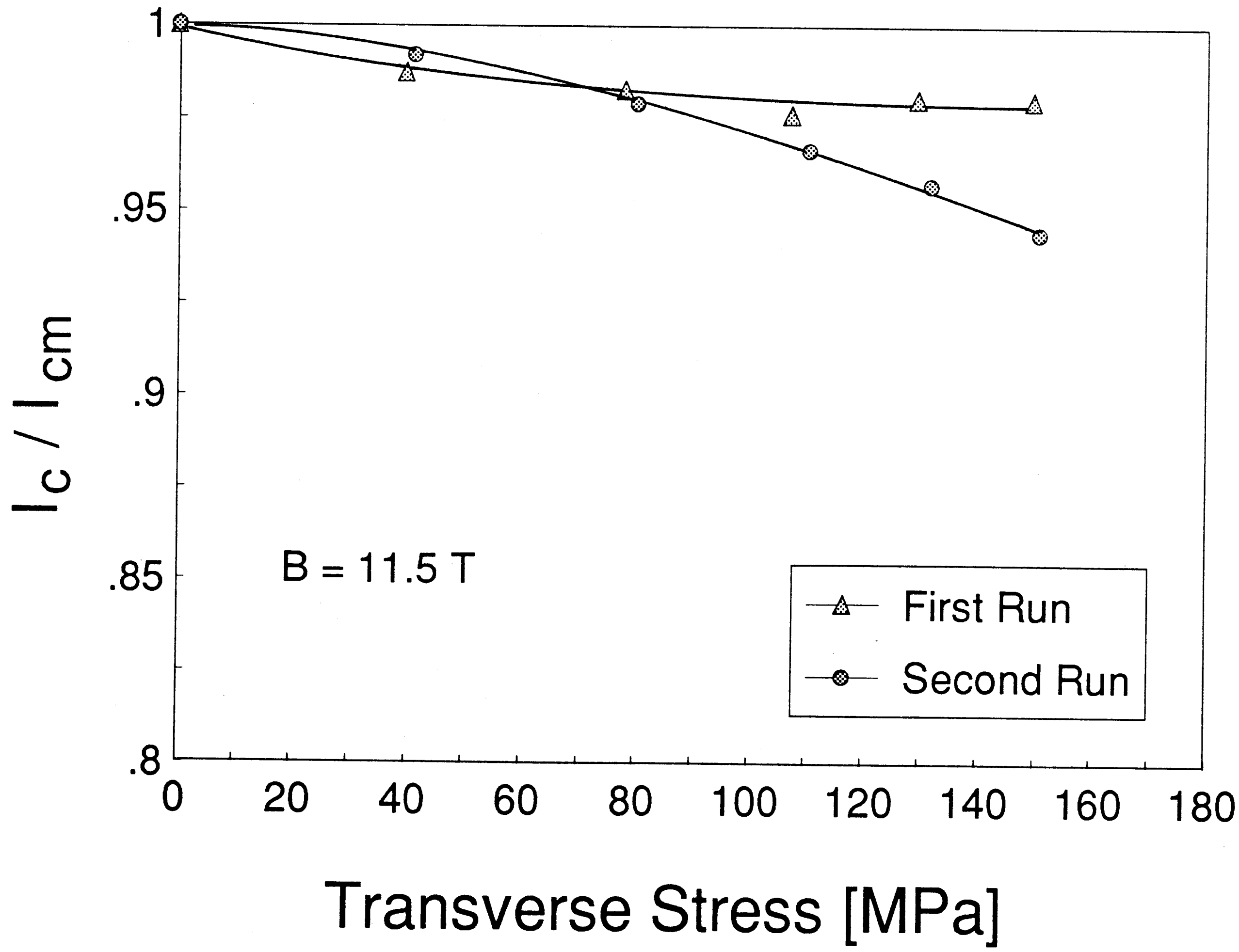

Figure 2: Effect of transverse compressive stress on the critical current of the epoxy-impregnated Nb_3Sn cable at 11.5 T

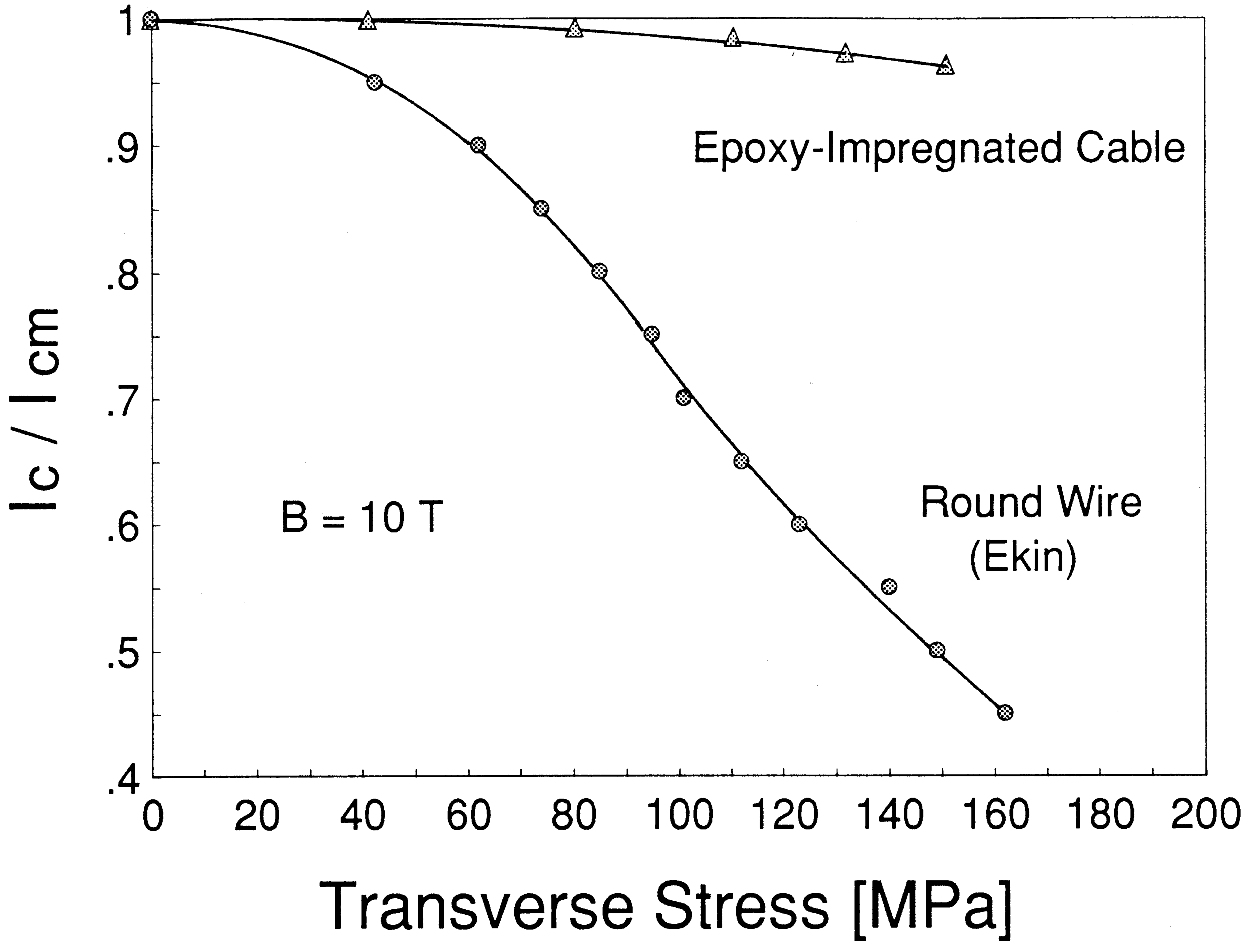

Figure 3: Comparison of critical current degradation in the epoxy-impregnated CERN cable and single wire at 10 T.
For the cable, the more relevant second run is given.

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