Computation of the Reversible Critical Current Degradation in Superconducting Nb$_3$Sn Coils

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Introduction

Strands:

Nb$_3$Sn strands are prone to critical current degradation under the effect of mechanical strains. This degradation can be produced with both axial and transverse strain. Axial strains measurements were used to define laws governing the critical current degradation due to the applied axial strain. It was shown that they can also be used for strands under transverse pressure.

Accelerator Magnets Coils:

The degradation resulting from high strains inside the windings may compromise magnet performances. However, clear limit conditions are not available. Magnet mechanics are simulated approximating the windings as a uniform block with averaged mechanical properties. An empirical equivalent stress limit of 150-200 MPa is used at the moment.

Critical Current Degradation

1. Effective Strain:

The strain computed in a detailed cable stack model has to be corrected considering the contribution of the differential thermal contraction of the strand components. The horizontal and vertical strain were also multiplied for a constant factor to account for the stress amplification at the filament level. The factor was found to be equal to 1.65. 3D models show that part of this factor (0.2) is due to the stress variation across the sample length.

2. Strain Function:

Because of the twist pitch of the cable, one can assume that all the strands will be subject to the same strains and field along the length of the sample. Also, since the filaments are twisted, one can consider that all the elements at the same distance from the strand center will be in turn subject to the same strain and field condition. The strain function was then averaged along the strand radius. For the PIT 2013 sample strain function values were: 0.93, 0.91, 0.88 and 0.85.

3. Magnetic Field:

The magnetic field inside the strand was computed as a sum of the background field and the self-field. As the strands are twisted, they will all be subject to the maximum field along the sample.

4. Critical Current:

Ramping the applied current one can verify if a critical condition is reached or not. Remarkable agreement was found with measured values. However, the computed values for the most severe load are slightly higher than the measured ones. This may be due to a small percentage of irreversible degradation.

Cable Stacks Under Transversal Pressure

Coils mechanical properties can be measured on stacks of impregnated cables.

A detailed stack FE model was validated against the measured data. Strands were modeled as concentric octagons of copper and Nb$_3$Sn. The geometry was defined compatibility to the filling factor and the copper to non-copper ratio definitions. Material properties were extracted from literature.

Conclusion

The procedure proposed demonstrated the possibility of reproducing the measured critical current degradation on cable stacks under transversal pressure in the reversible region. This required only one tweaking factor, reasonably justified by the problem mechanics. The result suggests for the first time that the exponential strain function can be applied also to Rutherford cables. As these cable stacks should be mechanically very similar to coil windings (at least in the straight section), the result should be applicable without major corrections also to accelerator magnets. The methodology has the great advantage of not requiring the modeling of the filaments, which could be prohibitive in a magnet winding modeling. Clearly, a direct validation on superconducting magnets would require extensive testing.

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