Numerical investigation on the thermo-electro-mechanical behavior of HTS tapes

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Abstract

This work extends to second generation (Re)BCO tapes an experimental procedure previously developed to analyze the impact of double bending at room temperature on the performance of BSCCO tapes. The modified procedure is applied to measure the critical current of a commercial (Re)BCO tape subjected to bending around a cylindrical mandrel first on one side then on the other side, followed by the cooldown to cryogenic temperature. In the bending loading phase, mandrels of decreasing diameter are used to identify the minimum curvature leading to a significant reduction of the tape critical current. Furthermore, a novel numerical model is developed to interpret the experimental results and investigate the thermo-electro-mechanical behavior of the tape. The model simulates the double bending, the following straightening of the sample and its cooldown to cryogenic conditions. The coupled thermo-mechanical numerical model together with the temperature-dependent mechanical properties allow investigating the combination of thermal contraction effects and bending loads in every point of the domain of the problem. The experimental and numerical results obtained help to give a better insight in the distribution of the strain and stress components inside the (Re)BCO tapes and to evaluate their impact on the conductor electrical performance in relevant operating conditions.

The experimental procedure

Three experimental steps:
1) Critical current measurement at 77 K over a straight G10 support before double bending.
2) Bending procedure of the tape included between the voltage taps, on a mandrel of known diameter. The tape is released and subsequently bent over the same diameter on the other side. Afterward the tape is left free to recover the initial configuration.
3) Repositioning of the tape over the straight support and a second critical current measurement is performed.

A comparison of the critical current values found before and after the double bending is performed.

Different mandrel diameters are tested.

The numerical model

Finite Element model
Multi-layer shell elements, 4 nodes and 6 dof per node are chosen, with reduced integration (1 Gauss point in the mean plane) to avoid spurious modes. Out of plane composite layup-type section with 6 layers, 3 Simpson integration points per layer, to reconstruct in detail the stress and strain distribution across the thickness of the tape.

Finite strain analyses, with plasticity of material and contact on the mandrels.

Material characteristics
Material data are obtained from experimental tests performed at the University of Padova at 293 K and from SUNAM tests at 77 K.

Conclusions
A novel thermo-mechanical model of (Re)BCO tapes was developed, which allows computing the strain distribution in the tape volume under bending and thermal loading. The model was applied to interpret the results of critical current measurements performed after double bending tests at room temperature.

The critical bending diameter of the mandrel identified in the tests corresponds to peak strain values in the range 0.75 to 0.9% computed by the model, which exceed the irreversible strain limit of the tape. The abrupt performance drop found in the experiments suggests a possible rupture of the (Re)BCO layer.

References
[2] IEC 61788