Introduction

High current cable made with REBa2Cu3O7-coated conductors will enhance a new generation of compact high field, high current density magnets due to the smaller influence of the magnetic field and temperature on the critical current density of the superconductors.

Among the cabling options, the HTS Cable-in-Conduit Conductor developed at ENEA is particularly suited for high-field applications.

The cable consists of:
- Aluminum core with five helically slotted channel
- A stack of 20 SuNaNAM tapes in each channel
- Aluminum spacers
- Aluminum jackets, wrapped around the core and drawn to reduce gaps

Finite element analysis was used to evaluate the strain distribution and ultimately the critical current degradation on the REBCO tapes in the cable caused by: compaction of the aluminum jacket (1), bending (2), and thermal cooldown (3).

Finite Element Model

A three-dimensional finite element model was developed in ANSYS to replicate the assembling process and testing of a five-channel HTS CICC cable.

The model is composed of three steps:
- Step 1: Compaction of the aluminum jacket (50 mm)
- Step 2: Cable bending (full twist pitch, 500 mm)
- Step 3: Thermal cooldown to 77 K (50 mm)

Model Details:
- Tape modeled using SOLID910 structural solid-shell elements.
- Surface-to-Surface contact pairs between adjacent tapes and the support structure.
- Bilinear stress-strain curves (elasto-plastic behavior) at 77 K and 295 K.
- Coefficients of thermal expansions (CTE) to predict residual thermal strain from cooldown.

Assumptions made to capture the overall behavior and reduce the computational time:
- One slot full of tapes, no jacket
- Spacers merged to the core

Compaction

**Boundary conditions and loading**
- External ring (rigid body) positioned around the jacket to apply displacement
- Radial displacement of 325 µm (measured) applied to the ring
- α and β nodes constrained vertically
- One end of the jacket constrained longitudinally

Bending

**Boundary conditions and loading**
- Multipoint constraint coupling (pilot node) used to control the cable ends.
- Equal and opposite displacement and rotation applied to pilot nodes

Cooldown

**Temperature gradient from 295 to 77 K.
Some boundary conditions as compaction**

Data Analysis Technique

The average critical current in each tape was calculated combining experimental Ic vs. axial strain data from literature and the strain distribution obtained from ANSYS

von Mises strain was used instead of axial strain for a multiaxial loading scenario (more conservative approach, but similar results)

<table>
<thead>
<tr>
<th>von Mises strain % ε</th>
<th>Axial strain #20</th>
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<tr>
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- Von Mises strain collected at 80 locations across the width of each tape at 72 location along the length of the cable

Results: Bending

The normalized critical current is calculated by considering the total strain from compaction, bending and cooldown. The results are very sensitive to the friction utilized in the model.

- Highest degradation observed with μ = 1
- Frictionless model (μ = 0.02) match well with experimental data and PSM analytical model

Results: Compaction

- For small bending diameters the outer tapes of the stack experience significant higher degradation
- The same behavior was observed experimentally for the top and bottom tapes of the stack
- Compaction is believed to be the major cause of this behavior (almost frictionless model)

Conclusion

A finite element model was developed to predict the strain generated in an aluminum slotted core cable-in-conduit conductor filled with five stacks of SuNaNAM tapes.

- Strain caused by the compaction of the jacket can affect the electrical performance of the tapes
- Two design modifications were proved to reduce the strain caused by compaction
- The strain due to cooldown is significant for the top and bottom tapes of the stack
- A good agreement was found between the bending model (which include compaction and cooldown strain) and experiments, when defining a friction coefficient of 0.02.

Future work

- Investigate the impact of compaction with a designated experiment to validate the model
- Use the optimized FEA tool to investigate possible changes to the cable design with the goal of reducing the critical current degradation

References