The Mechanical Analysis of the Rutherford Cable Subjected to Axial Tension and Cyclic Loading

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Introduction
- The main high field superconducting magnets of all existing large particle accelerators are based on Rutherford cables.
- Future Circular Collider (FCC) and High Luminosity upgrade of Large Hadron Collider (HL-LHC) are proposing new requirements of 16T.
- Nb3Sn Rutherford cables are designed to cater to the meet in the higher field for their advantage:
  - large filament dimensions
  - lower thermal and electrical properties of copper
  - the wind-and-react technique

Problem
- cable winding process:
  - Mechanical Loads: tension, compression, bending, torsion
  - Mechanical Instability: "pop-out", "protrusion"
  - Large Temperature Change: thermal residual stress
  - Magnets Running: the influence of electric field, magnetic field, and temperature field

Requiring a method to build up the Rutherford cable finite element model efficiently and simulate the mechanical behaviors during the whole process.

Model
- Geometrical modeling
  - strands number (n)  lay angle (α)  chirality (c)  strand diameter (d)  clearance (b)
  \[ D_d = d + b, \ R_d = 2D, \ \cos(\alpha), \ \tan(\theta), \ \theta = \frac{\pi}{3}, \ \beta = \frac{\pi}{2}, \ \kappa = \frac{2D}{\beta} \]
- The straight wires
  \[ x_i = \frac{n-2}{4} D, \ y_i = -R, \ z_i = k_1 \cos \kappa \cdot \frac{n-2}{4} Dk \]
- The helical wires
  \[ x_i = (R \cos \theta - \frac{n-2}{4} D) \cos \kappa, \ y_i = R \sin \theta, \ z_i = \frac{n}{2} t + \frac{n-2}{2} Dk \]
- Parametric equation of wire i
  \[ x = x_i, \ y = cy_i \cos \kappa, \ z = z_i + j \beta_i, \ \beta_i = (i-1)\beta_k \]

Mechanical modeling
- Representative volume element (RVE)
- Damage of filaments

Results and discussion
- Single strand axial tensile

- Rutherford cable axial tension and cyclic loading

Conclusions
- Develop a method to build up Rutherford cable’s geometry efficiently, considering strand numbers, lay angle, chirality and so on.
- Analyze the finite element model of Rutherford cable under axial tension and cyclic loading, while taking the friction and filaments damage into consideration.
- The axial tensile load during manufacture process may contribute to the “pop-out”.
- The friction has an obviously effect on Rutherford cable’s mechanical behavior when applied to tensile load.
- Rutherford cable’s structure and the strands’ hysteresis characteristics contribute to the hysteresis loops in the cyclic tensile loading.