Modeling superconducting inhomogeneities of commercial REBCO tapes with a 1-D electro-thermal model comparing two different constitutive laws

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Outline

Motivations: accurate simulations

1-D electro thermal model

Results inhomogeneity + constitutive laws

Conclusions & future work

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Silver 1-5 μm
REBCO 1-3 μm
Buffer layers <1 μm
Hastelloy 30-100 μm
Silver 1-5 μm

Nominal thickness
Real profile

\[ h_{\text{max}} \]
\[ h_{\text{min}} \]
\[ \langle h_{\text{av}} \rangle \]
Heat equation

\[ \rho_{m,\text{HOM}}(T)C_{p,\text{HOM}}(T) \frac{\partial T(z, t)}{\partial t} + \frac{\partial}{\partial z} \left( -k_{\text{HOM}}(T) \frac{\partial T(z, t)}{\partial z} \right) = Q \]

Step 1: Homogenized Heat Equation

\[ Q = EJ - \frac{2h \cdot (T - T_0)}{h_{\text{tot}}} \]

\[ k_{\text{HOM}}(T) = \frac{\sum h_j k_j}{h_{\text{tot}}} \]

\[ \rho_{m,\text{HOM}}(T) = \frac{\sum V_{\text{Vol}_j} \rho_{m,j}}{V_{\text{Vol}_{\text{tape}}}} \]

\[ C_{p,\text{HOM}}(T) = \frac{\sum m_j C_{p,j}}{m_{\text{tot}}} \]
Step 2: Equivalent electric circuit for tapes

Electric circuit

\[
I_j(T) = \frac{V_B - V_A}{R_i(I_i, T)}
\]

\[
I_{\text{REBCO}}(t) = I_{\text{tot}}(t) - \sum_{j=1}^{n_{\text{mat}}} I_j(t)
\]

\[
R_i(I_i, T) = \frac{\rho_{\text{el},i}(I_i, T) \cdot L}{S_i}
\]

\[
\frac{1}{R_{\text{HOM}}(I_{\text{tot}}(I_j), T)} = \sum \frac{1}{R_j(I_j, T)}
\]
**Step 3: 1-D electrothermal model**

1-D Homogenized Heat Equation for \( n \) sections

![Diagram showing the 1-D electrothermal model](image)

**Equivalent electric circuit for \( n \) short tapes**

\[
I_c(x) = \begin{cases} 
I_c(x_1) = 115 \text{ A} & \text{if } x_1 < x < x_2 \\
I_c(x_2) = 110 \text{ A} & \text{if } x_2 < x < x_3 \\
& \vdots \\
I_c(x_n) = 122 \text{ A} & \text{if } x_{n-1} < x < x_n 
\end{cases}
\]
Inhomogeneity implementation ($n = 100$ resistors sections)

THEVA tape, 12 mm wide

$\langle I_c \rangle = 683$ A @ 77 K s.f.
Validation & results: experimental measurements

65.9 cm

THEVA tape, 12 mm wide

$<I_c> = 683 \text{ A @ 77 K s.f.}$

Current source
Validation & results: Choice of the constitutive law (power law vs eta-beta law*)

\[ \rho_{PWL} = \rho_c \left( \frac{I}{I_c(T)} \right)^{n-1} \]

\[ \rho_{\eta\beta} = \rho_c e^{\left( \eta(T) \cdot \left[ 1 - \left( \frac{I_c(T)}{I} \right)^{\beta(T)} \right] \right)} \]

*A wide range E – J constitutive law for simulating REBCO tapes above their critical current*, N Riva, F Sirois, C Lacroix, F Pellerin, J Giguere, F Grilli and B Dutoit - *SuST*. 34 115014
- 30 ms DC pulse
  @1.2 \cdot I_c = 820 \text{ A}
- Homogeneous $I_c(x)$
Voltage along the length (inhom.)

- 30 ms DC pulse @1.2 \cdot I_c = 820 \text{ A}
- Inhomogeneous \( I_c(x) \)
Temperature profile (inhom.)

- 30 ms DC pulse
  @1.2 \cdot I_c = 820 \text{ A}
- Inhomogeneous $I_c(x)$
Conclusions...

1) Inhomogeneous $I_c(x)$ real data were used in a simple and computational efficient 1-D electrothermal model:
   A. Homogeneous $I_c(x)$ -> inaccurate simulations
   B. Inhomogeneous $I_c(x)$ -> \textit{eta-beta law} better reproduces measurements than the \textit{power-law} + realistic temperature profile along the tape length

2) Simple electrothermal model can be used to understand the role played in thermal runaways due to material inhomogeneity/defects

...and future work

- Improve agreement with measurements + further experiments
- Inhomogeneity layer thickness of materials (e.g., silver)
- Comparison with 2D/3D electrothermal models