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2LPo2J-01

Flagship Project TransHyDE

Experimental Studies on an HTS DC Cable Prototype for Combined Energy Transmission with LH_2

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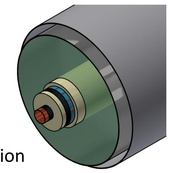
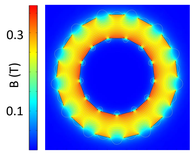
Motivation



Combination of HTS and LH_2 → efficient transmission of both electrical and chemical energy [1]

Proof-of-concept: construction of a demonstrator hybrid energy pipeline
→ requires testing of prototype components and their fabrication/installation

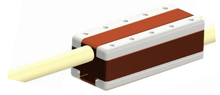
Cable design
→ 10 kA @ 25 K (+/- 10 kV) [2]



2-phase concentric
Cable core: Cu strands
HTS tapes: 3 mm
Inner radius: 7.4 mm
El. insulation: polyimide

→ $I_{c,Design}$ @ 30 K > 11.8 kA

Contact design
→ robust, simple, easy in-field installation



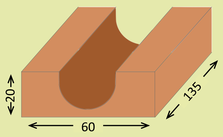
Concept:
Low-ohmic soldering of the cable ends in the contact blocks, bolted connection, current transport over high-quality surface pressing

Objective:
→ **Prototype testing in LN_2 (single phase)**
→ **Development of low-ohmic contact soldering: analysis and comparison of 3 different configurations**

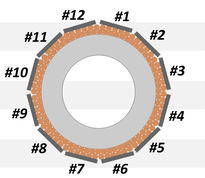
Prototype Fabrication

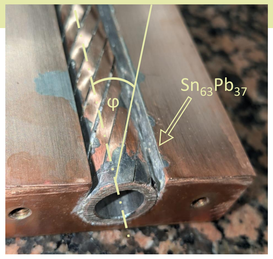
Main properties of HTS	
Manufacturer (model)	Fujikura (FESC-SCH03)
Substrate (Hastelloy®)	50 µm
Cu stabilizer	20 µm
Width x total thickness	3 x 0.11 mm
Critical temperature	93.5 K
Critical current @ 77 K, s.-f.	~ 94 A

Profile for soldering tests	
Material	Cu-PHC (H_2 compatible)



Cable samples (single phase)	
Core ⌀ (Steel pipe + Cu strands)	15.4 mm
Number of HTS tapes (single-layered)	12
Lay angle φ	20°
Twist pitch	133 mm
Strain on REBCO layer (compressive/tensile)	-/+ 0.11 % [3]
Length	~ 500 mm
Tape length per meter cable	12.8 m / 1 m
Expected current @ 77 K, s.-f.	~ 1.13 kA



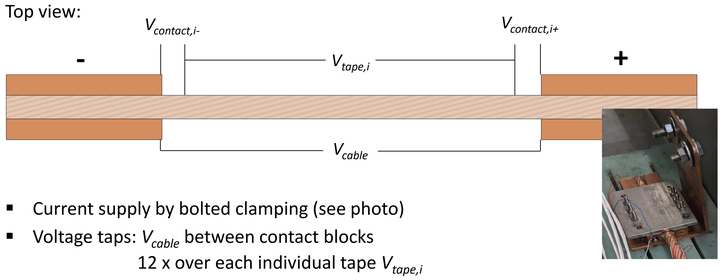


Preparation of 3 different samples

Sample **A**: no pre-tinning
REBCO layer facing *inwards*
Sample **B**: pre-tinning (Cu profile and individual tapes)
REBCO layer facing *inwards*
Sample **C**: pre-tinning (Cu profile and individual tapes)
REBCO layer facing *outwards*

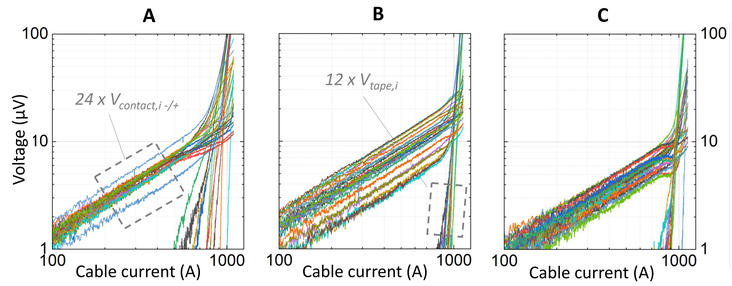
Experimental Set-up

Top view:



- Current supply by bolted clamping (see photo)
- Voltage taps: V_{cable} between contact blocks
  12 x over each individual tape $V_{tape,i}$
  24 x over individual solder resistances of each tape $V_{contact,i-}$ and $V_{contact,i+}$
- Measurement execution: ramping cable current (ramp rate 1 As^{-1})

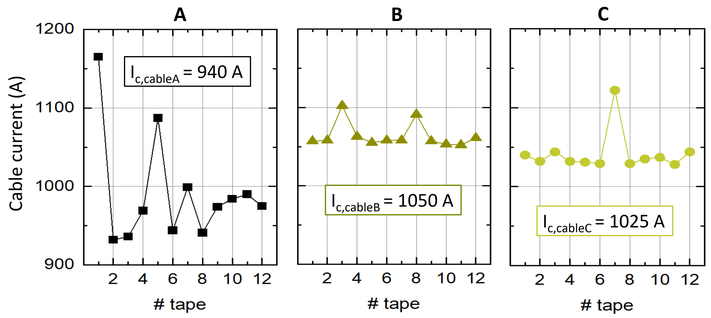
Measurement of Samples A, B, C: raw data



The figure shows all measured voltage signals of Samples A, B, C for comparison.

Results – Current Carrying Ability

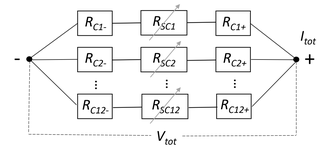
- Evaluation of critical current (criterion: 1 µVcm^{-1}) for each HTS tape related to the integral cable current
- Evaluation of the critical cable current $I_{c,cable}$ from V tap V_{cable} for Samples A, B, C



- Sample A: high range of $I_{c,tape,i}$, lower $I_{c,cable}$
  Samples B & C: lower range of $I_{c,tape,i}$, higher $I_{c,cable}$
  → Pre-tinning improves current distribution → higher total current
- Comparison with calculated $I_{c,cable}$ (1.13 kA): A lower by ~ 17%, B and C lower by ~ 8%

Evaluation and Modeling of Soldered Contacts

- Electrical model

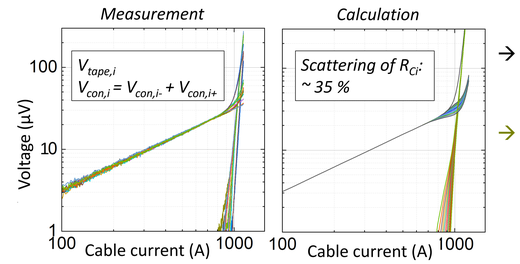


Assumption: HTS tapes in parallel

$$V_{tot} = V_{ci}\left(\frac{I_i}{I_{ci}}\right)^n + R_{Ci}I_i \qquad I_{tot} = \sum_{i=1}^{12} I_i$$

with $R_{Ci} = R_{Ci-} + R_{Ci+}$ for $i = 1 \dots 12$

- Approximation of variation in individual solder contacts by scattering R_{Ci} values to compare to measurement data (example: Sample B)



→ for $I < I_{ci}$: $V_{ci}\left(\frac{I_i}{I_{ci}}\right)^n = 0$
$V_{tot} = R_{Ci}I_i$

→ Scattering of R_{Ci} ~ 35 % delivers good results to model the soldered resistances of Sample B

- Integral contact soldering resistances from measurements (- and +):
  Sample A: ~ 29 nΩ
  Sample B: ~ 32 nΩ
  Sample C: ~ 18 nΩ
  → REBCO layer facing outwards reduces total soldering contact resistance (by ~ 40%)

Implications for operation @ 10 kA in LH_2 (hybrid energy pipeline)
Joule losses in soldered contacts of Sample C: $\dot{Q}_{contact} = R_C {I_{op}}^2 = 1.8\ W$

Conclusion & Outlook

HTS cable prototype designed to carry 10 kA in LH_2 was tested in LN_2 (single phase, 3 different samples).

→ **Current carrying ability of ~ 17% (Sample A) and ~ 8% (Samples B and C) lower than calculated ($I_{c,cable,calc}$ = 1.13 kA)**
→ **Low-ohmic contact soldering achieved with simple and robust soldering: pre-tinning and outwards facing REBCO layers reduce contact resistance by ~ 40%**
→ **Modeling of soldered contacts suggests low sensitivity to an individual resistance scattering of up to ~ 40%**

Next steps: experimental studies on clamping contacts, 2-phase cable testing

[1] 10.13140/RG.2.2.10355.75046
[2] M. Wehr et. al. – High Current HTS Cable Development for Combined Energy Transmission with LH_2 (EUCAS 2023)
[3] 10.1088/0953-2048/22/6/065013

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