Upgrade of SULTAN / EDIPO for HTS Cable Test

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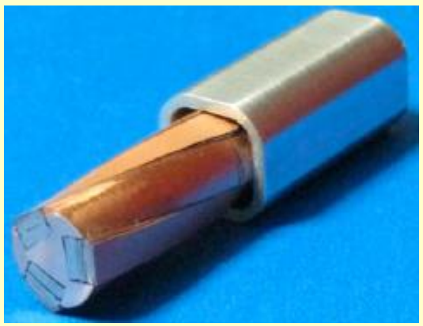
Motivation

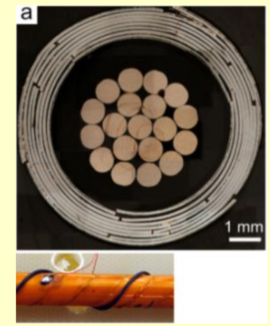
Significant progress in the manufacture of long 2G RE-123 coated conductors.
J_c at T = 77 K and B = 0 exceeds 300 A/cm-w in production tapes.

Development of high current cables utilizing RE-123 tapes with a high aspect ratio.

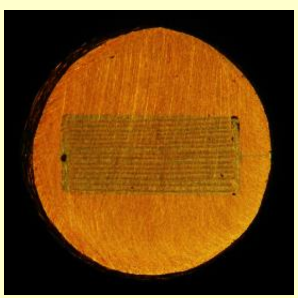


Twisted stacked-tape cable (TSTC), MIT, Takayasu et al., SUST 25 (2012) 014011.

Coated conductor Rutherford cable (CCRC), KIT, Schlachter et al., IEEE Trans. Appl. Supercond. 21 (2011) pp 3021-4.



Conductor on round core cable (CORC), van der Laan et al., SUST 24 (2011) 042001.



Twisted stack strand (CRPP)

Basic element for high current flat cables (Todays presentation of D. Uglietti et al.)

> **It is expected that there will be soon a demand for testing of high current HTS conductors in high magnetic fields and at elevated temperatures.**

Background

CRPP hosts the two unique test facilities SULTAN and EDIPO. They allow the test of large forced flow cooled superconductors under fusion relevant conditions.

	EDIPO	SULTAN
Peak field in test well	12.5 T	11.3 T
Length of high field region	1000 mm	450 mm
DC current up to	100 kA	

Upgrade of SULTAN / EDIPO facilities to allow the test of high current HTS conductors under fusion relevant conditions at temperatures between 20 and 50 K.

By the end of 2014 testing opportunities for high current HTS conductors will become available at CRPP.

Necessary Upgrades

In SULTAN / EDIPO sample currents up to 100 kA are supplied by NbTi transformers operated at 4.5 K. The temperature range of interest for testing the HTS conductor samples is between 4.5 K and ~50 K.

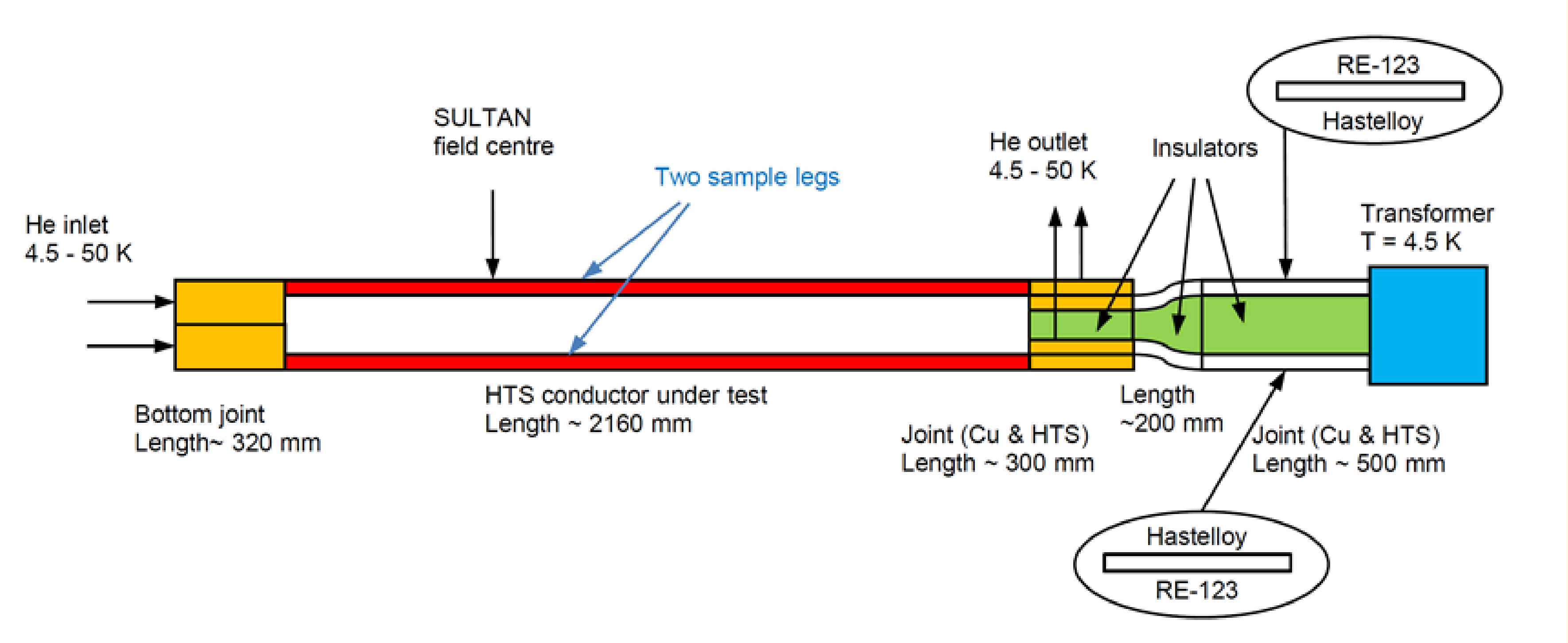
Limitation of the heat flux between NbTi transformer and HTS conductor under test to less than 10 W per leg by means of an HTS adapter, which is similar to the HTS module of an HTS current lead.

CRPP: Design and manufacture of a 100 kA class HTS adapter.

Supply of intermediate temperature helium for HTS conductor testing above 20 K. Intermediate temperature will be provided by a tube-in-tube counter flow heat exchanger (4.5 K He from the cryoplant and warm He leaving the HTS sample). The He temperature is adjusted with a heater.

M. Lewandowska (WestPomeranian University of Technology, Szczecin, Poland) performed the design calculations in collaboration with CRPP.

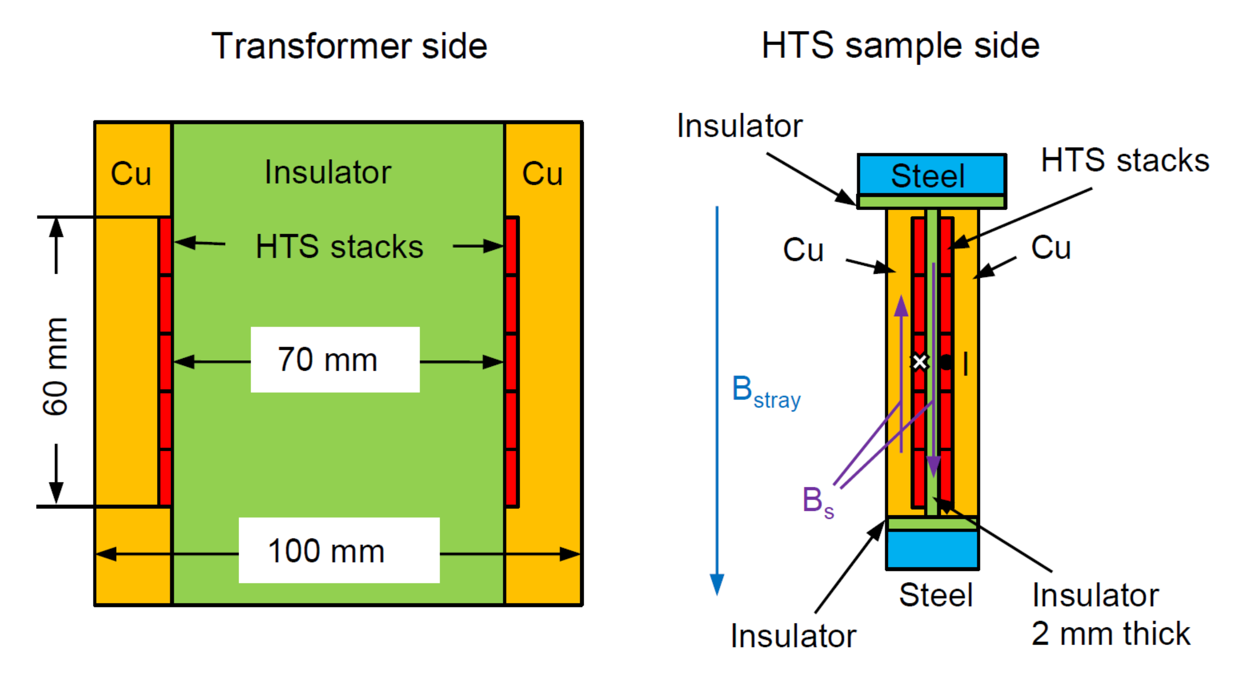
Straight HTS Sample Test in SULTAN



HTS conductor tests

- **Test up to 20 K ⇒ HTS bus bar & low resistance joints.**
- **Test above 20 K ⇒ Modified cryogenics & HTS bus bar & low resistance joints.**

HTS Adapter Design



Cross-sections of the HTS adapter at the transformer and the HTS sample side.

Stray field is parallel to the broad face of the RE-123 tapes.

In a large fraction of the conductor cross-section the self-field is parallel to the broad face of the tapes.

The calculated stray field at the position of the warm end of the HTS adapter is 0.19 T for EDIPO and 0.35 T for SULTAN. The peak field at a current of 100 kA exceeds 2 T.

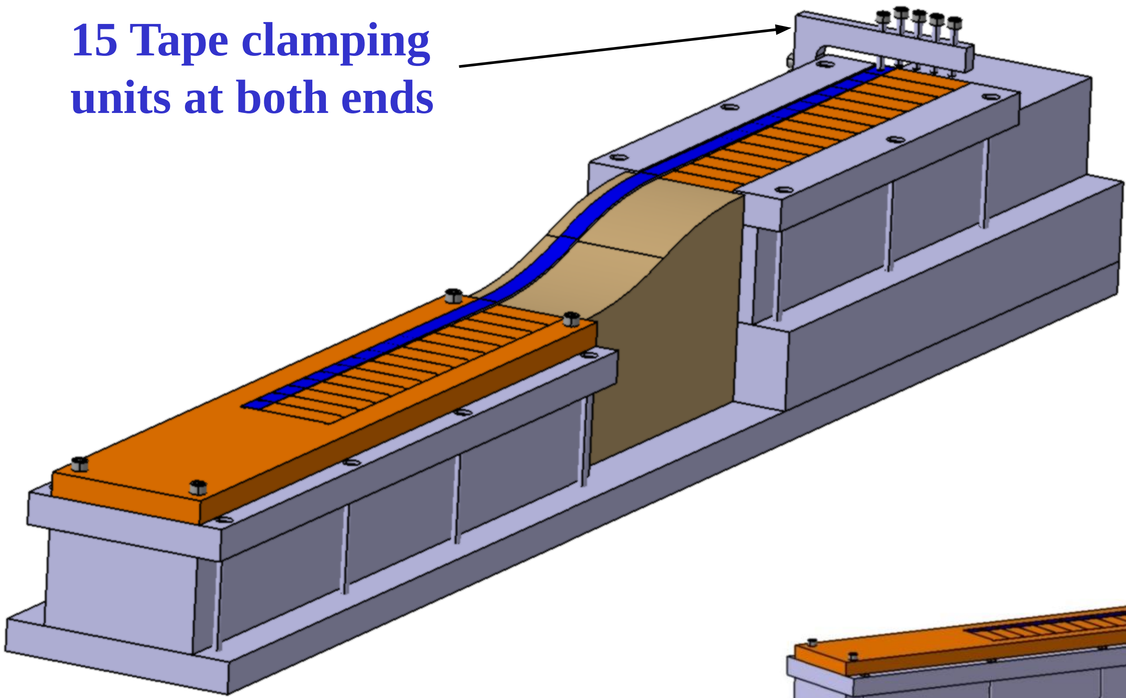
HTS Adapter Design

SuperPower tapes SCS12050-AP 2G wires	
Tape width (mm)	12
Tape thickness (mm)	0.071
Thickness of RE-123 (μm)	~1
Thickness of Ag (μm)	2
Thickness of Hastelloy® C276 (m)	50
Total length (m)	105
Minimum I_c @ 77 K, sf (A)	327
Reduced Cu stabilizer thickness (μm)	≈16

Main design parameters of the HTS adapter	
Parameter	Value
No of RE-123 stacks per leg	5
No of RE-123 tapes/stack	15
Total number of tapes per leg	75
Nominal length (mm)	200
Temperature at warm end (K)	≤50
Estimated heat flux @ T_w = 50 K (W)	~5
Estimated I_c at 40 K (kA)	≈100

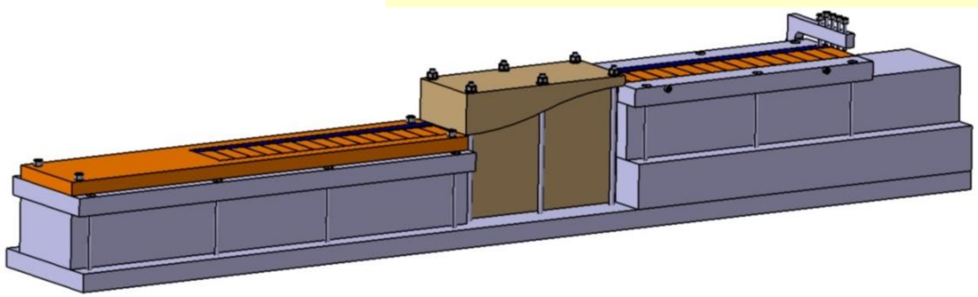
Manufacture of HTS adapter

- Pre-tinning of the RE-123 tapes
- Manufacture of a dedicated soldering device
- Manufacture of copper, stainless steel and insulator parts
- Assembly and soldering of the HTS adapters



Soldering device

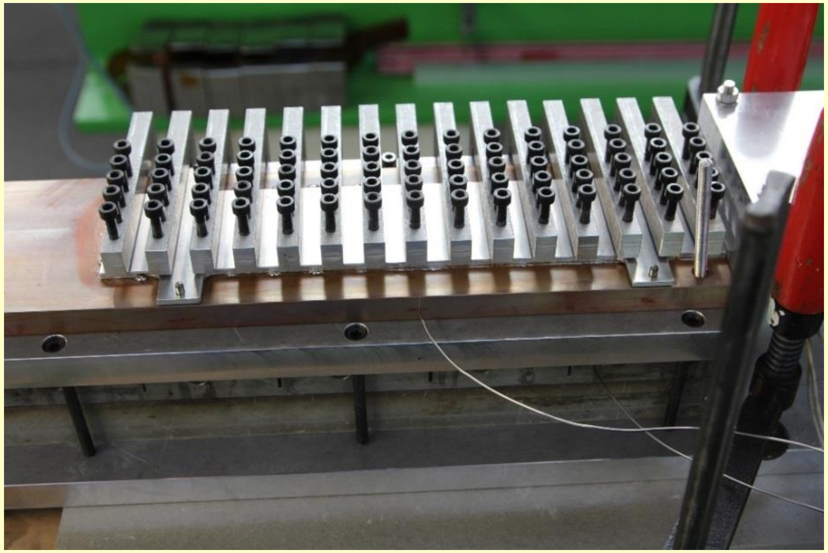
Each tape will be kept in position by the clamping units (5 x 15 screws) at both ends.



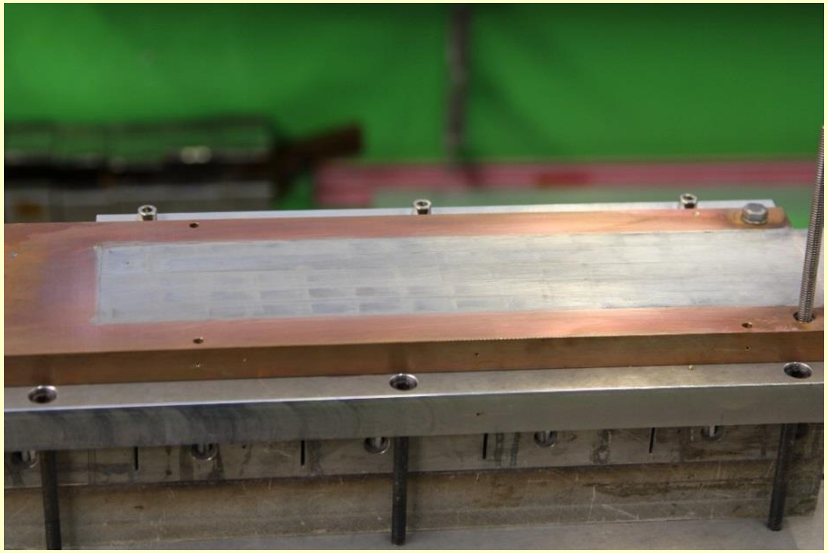
Manufacture of HTS adapter: Soldering

Soldering trial with a single stack
Measured joint resistance: 108 nΩ @ 77 K
For comparison, 10 kA HTS CL made of 11 eight-fold AgAuMg/Bi-2223 stacks.
Joint resistance: ≈70 nΩ @ 77 K

Here RE-123 and Cu in parallel, later two superconductors in parallel separated by a thin layer of copper, and hence a much lower joint resistance is expected.



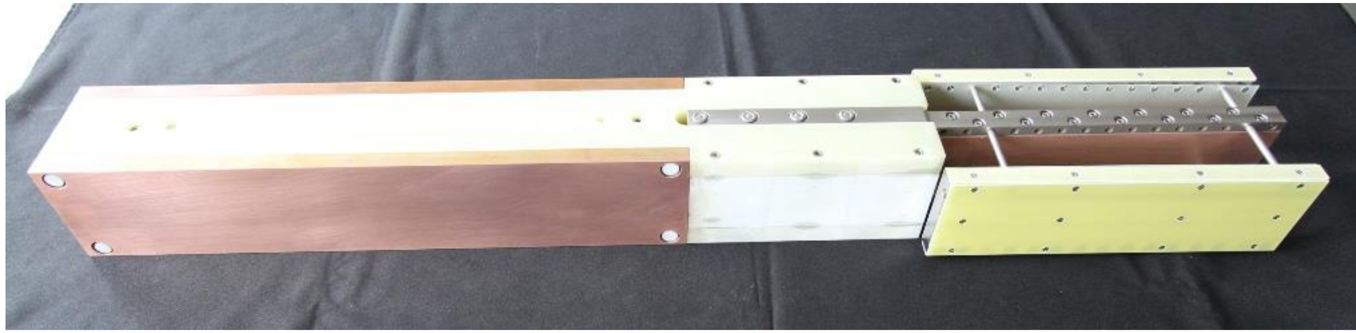
Stacks of RE-123 tapes after soldering to the copper end piece on the transformer side with stacks still clamped into position.

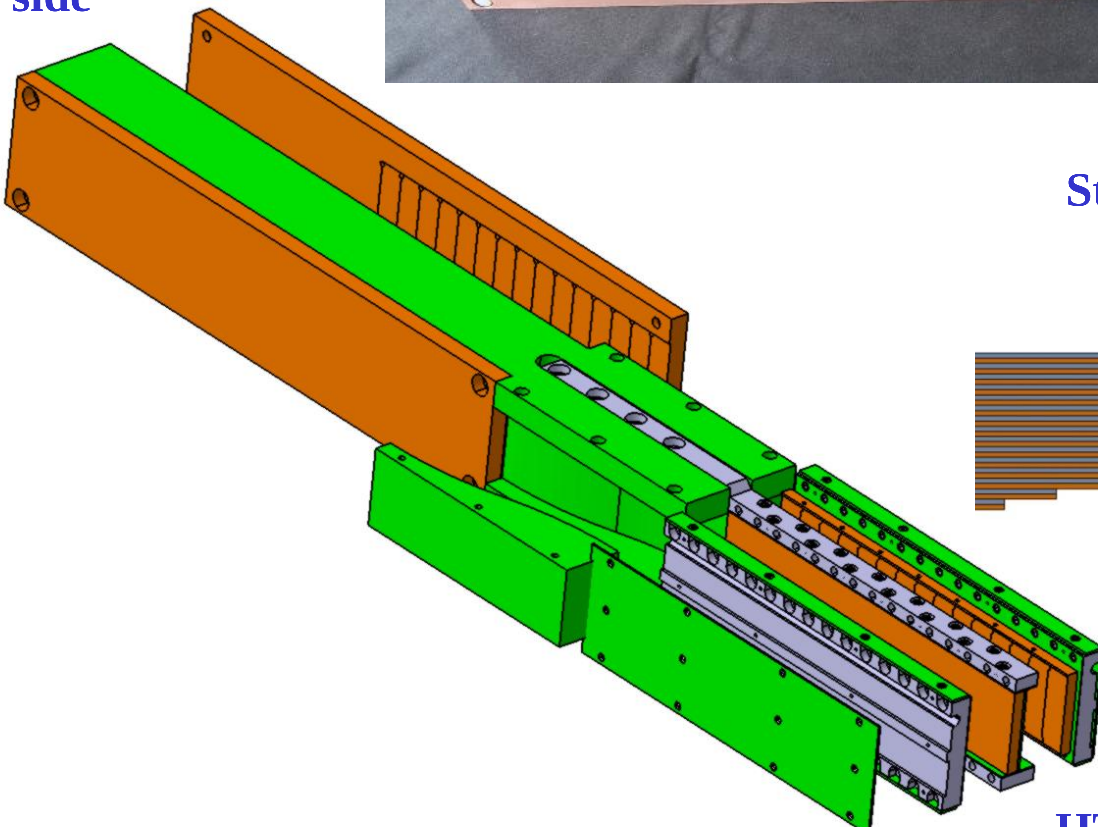


RE-123 stacks soldered into the copper end piece after removal of excess solder.

Assembled HTS adapter

Transformer side





Staggered end of RE-123 stack

Hastelloy side

RE-123 side

Transformer Cu shoe
HTS sample

HTS sample side

Design and Manufacture of the Heat Exchanger

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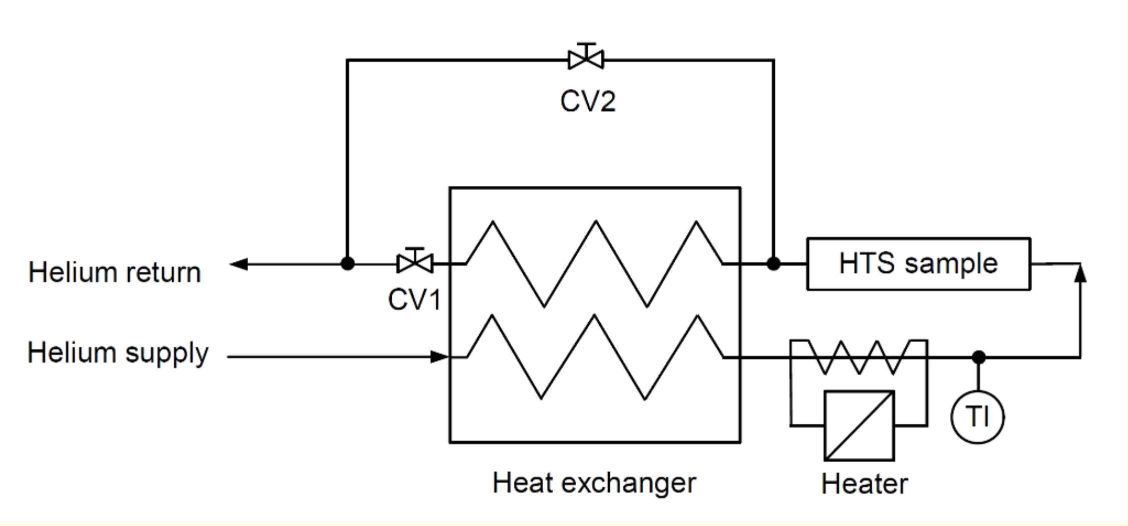
Assumptions in the design calculations

- Refrigerator provides 4 to 10 g/s helium of 4.5 K and 10 bar.
- Cold gas return to the refrigerator requires that the temperature of the helium leaving the HTS sample can be re-cooled to less than 20 K.
- Maximum temperature at the inlet of the HTS sample is 60 K.
- Tube-in-tube heat exchanger with an inner copper tube of 5-6 mm inner diameter and a wall thickness of 1 mm. Outer stainless steel tube with an inner diameter between 9 to 10 mm and a wall thickness of 1 mm.



Studied cryogenic circuit

He temperature is adjusted to the desired value by means of a heater before the inlet to the HTS sample

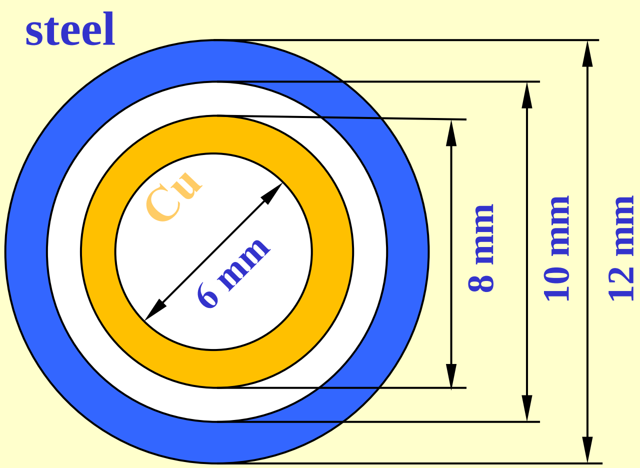
Tests at 4.5 K: He return via bypass (CV1 closed, CV2 opened).

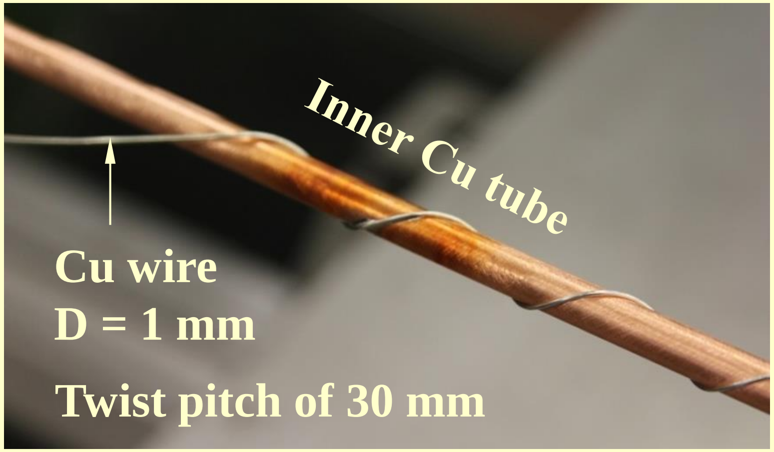
Design and Manufacture of the Heat Exchanger

Results of the study of M. Lewandowska

- A length of 5-6 m is sufficient to limit the return gas temperature to less than 18 K.
- The larger inner diameter is advantageous because of a reduced pressure drop.
- Warm helium in the inner tube provides a pressure drop reduction as compared to the option with warm helium in the outer tube.
- For all considered options, the required heater power was less than 1000 W.

Manufactured heat exchanger





Due to space restrictions the length of the tube is only ~4 m.

Conclusions

- HTS adapter for currents up to 100 kA at 40 K was manufactured at CRPP.
- Each HTS adapter leg is made of five 15-fold RE-123 stacks (RE-123 tapes of
- 12 mm width).
- Estimated heat flux of ~5 W per leg for temperatures of 50 and 4.5 K at the two ends
- Tube-in-tube heat exchanger for the supply of 20-50 K helium was manufactured at CRPP.
- The heat exchanger ensures a helium return temperature of less than 20 K even for 60 K helium supply to the HTS sample.

Commissioning of HTS adapter and heat exchanger is foreseen for the second half of 2014 in connection with the test of the CRPP 50 kA RE-123 flat cable (see presentation of D. Uglietti et al. this conference).

It is expected that testing of high current HTS cables in SULTAN / EDIPO will become available to users by the end of 2014.