Karlsruher Institut für Technologie

Progress on HTS Roebel cable at KIT

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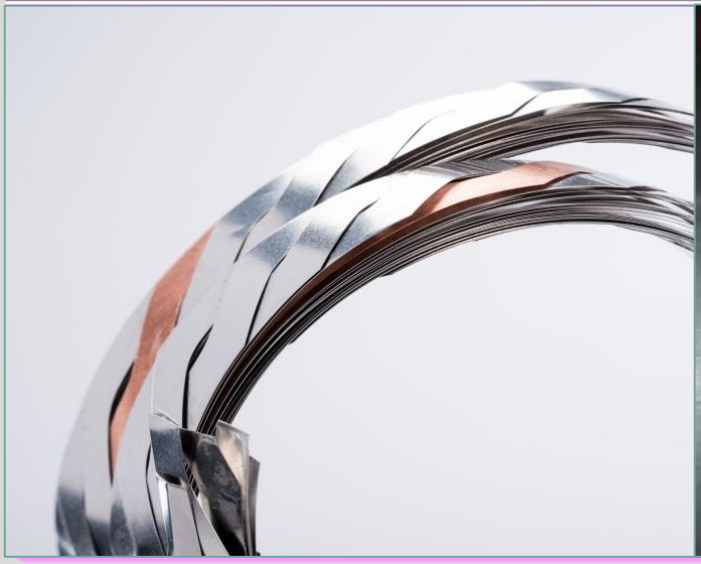


Introduction

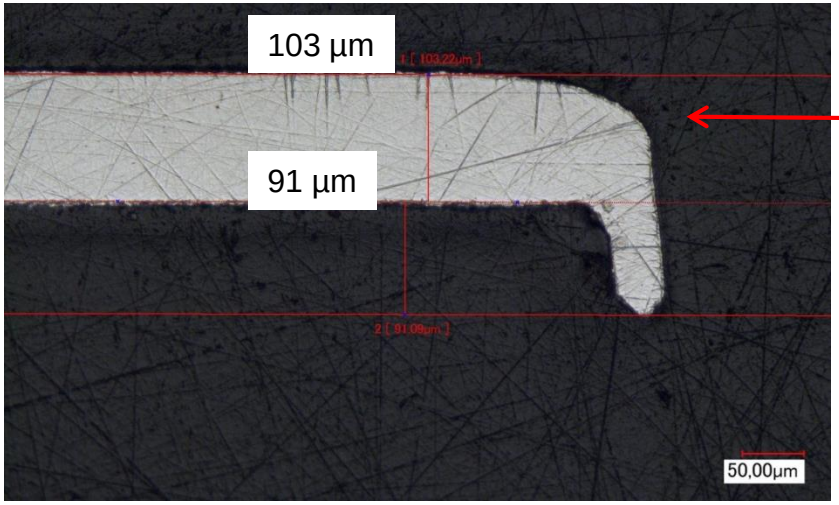
- Central issue is to have a reliable punching result for each tape being considered for application. Important aspects are:
- Dimension accuracy of tapes (cross section) to match the tool !
- Straightness of the tape (adjustment in the tool)
- Tool optimized for material (Hastelloy, SS) and thickness
- Focus on the preferred Punch&Coat process for perfect sealing
- Optimized Cu plating process for good cross section tolerance
- Monitoring delamination effects
- Investigating reliability of impregnation and transverse stress restistance
- Analyzing real bending conditions as in lead section of winding

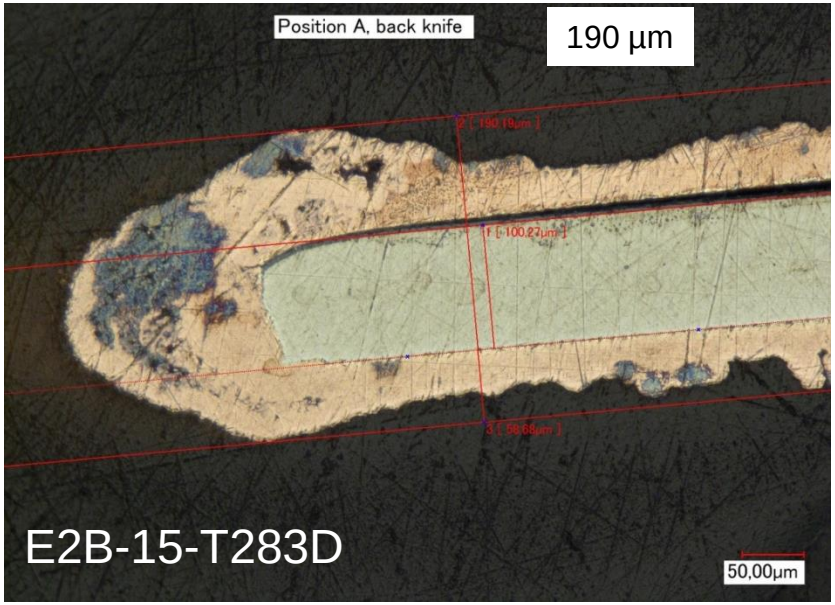
Bruker tapes for punching and coating :

- Problem with punching tool – new tool ordered commissioning December
- Punched tapes:

  E2B-15-T283D – 30 +4 m

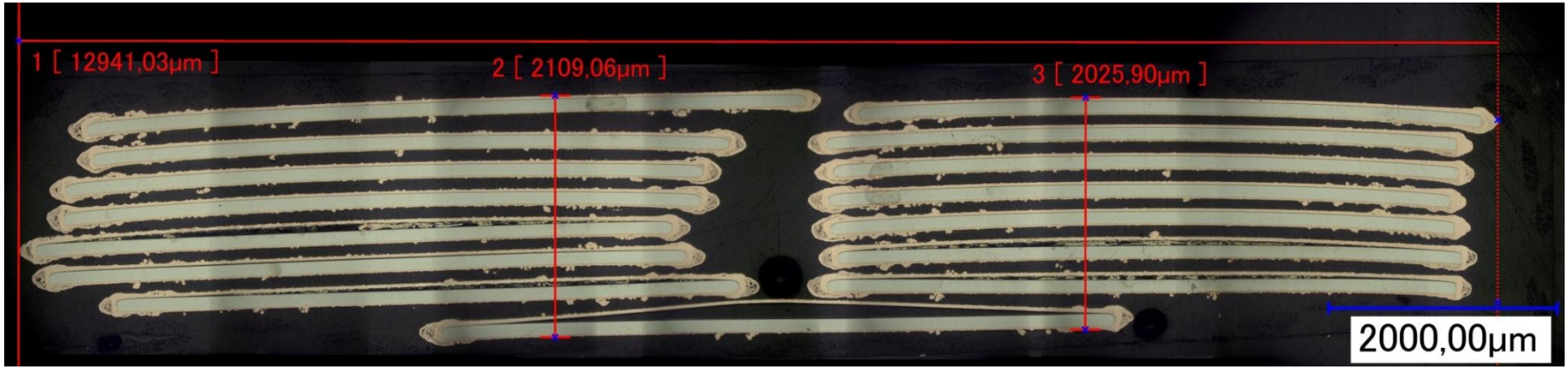
  E2B-15-T284D – 25 m
- Burr removed at Bruker
- Roebel strands from tape 283D electroplated at Bruker
- No delamination from edge side observed





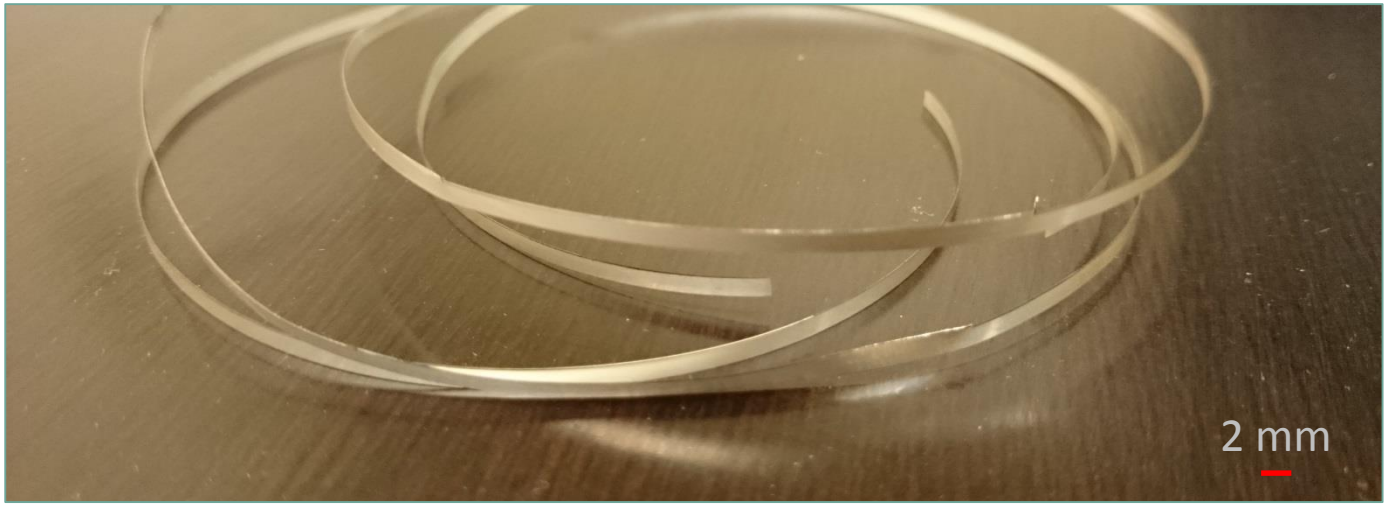
FRESCA cable (2 m):

- Roebel cable: 226 TL, 15 strands
- Punch + Coat
- Assembled
- 2 m long
- 283 D tape



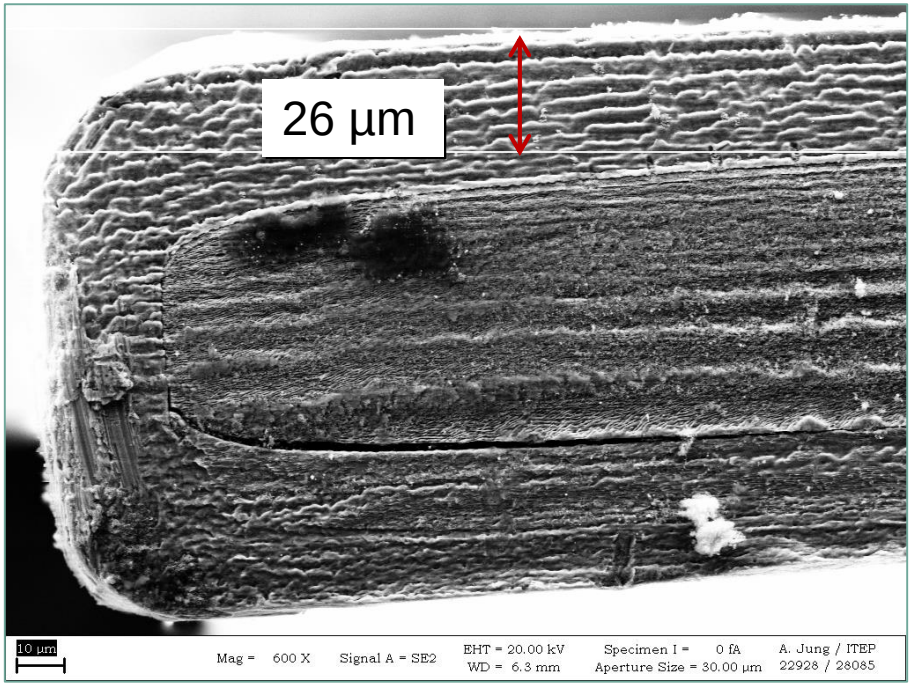
- Rough surface is problem for dense packing and resin flow
- Delamination is caused during grinding/polishing of cross-section preparation

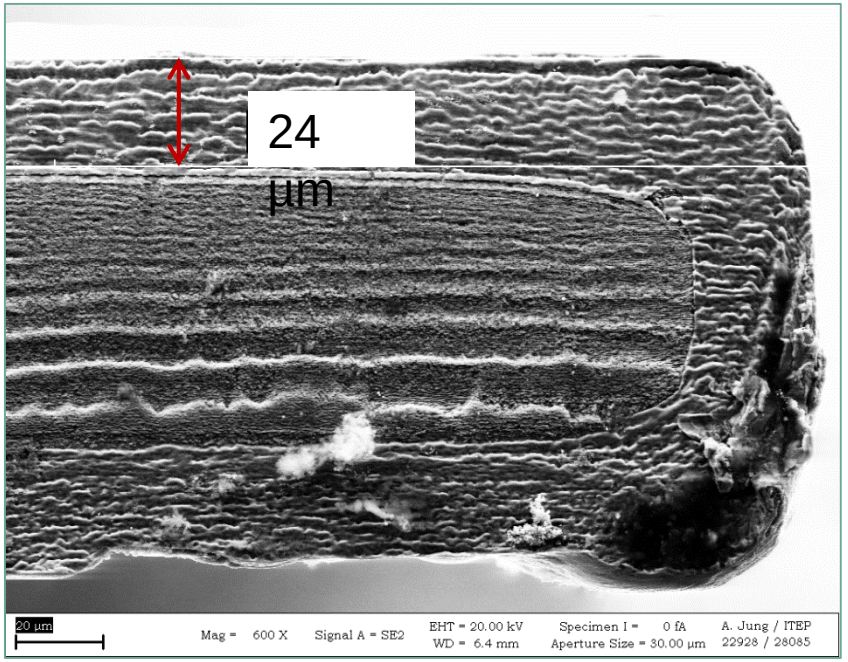
Bruker 4 mm tape slit to 2 x 2 mm width:

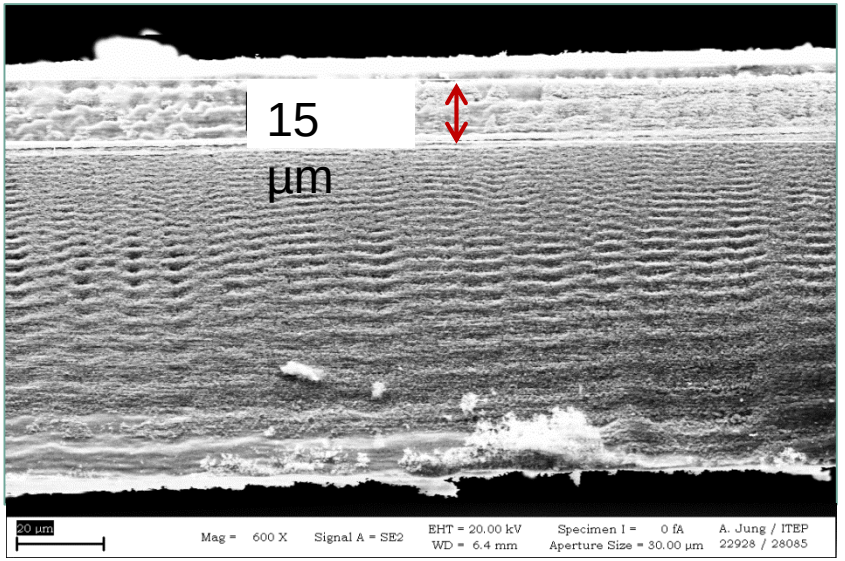


- 4 mm tape slit using laser into 2 x 2 mm
- Sent to Bruker for copper plating 4 x 50 cm + 1 x 45 cm -> 8 + 2 samples
- For quench experiments at U. Twente
- Tape 275D-A – Ag
- 4.2 K, 5 T, BIIc – I_c = 576 A
- KIT psec IR-Laser has negligible heat generation !

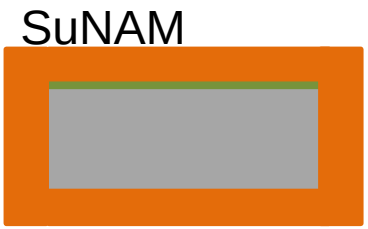
Copper plating - SuNAM







- Homogenous copper layer



Cu 20 µm
*RE*BCO 1-3 µm
Hastelloy 60 µm
Cu 20 µm

SuNAM- CERN:

Dimension

Item	Spec	Data				Result
		$\bar{X}$	σ	Max	Min	
Width (㎜)	12.1±0.1	12.1	0.01	12.1	12.1	OK
Thickness (㎛)	110±15	105	1.4	107	103	OK
Bare Substrate Magnetic Properties	-	non-magnetic				OK

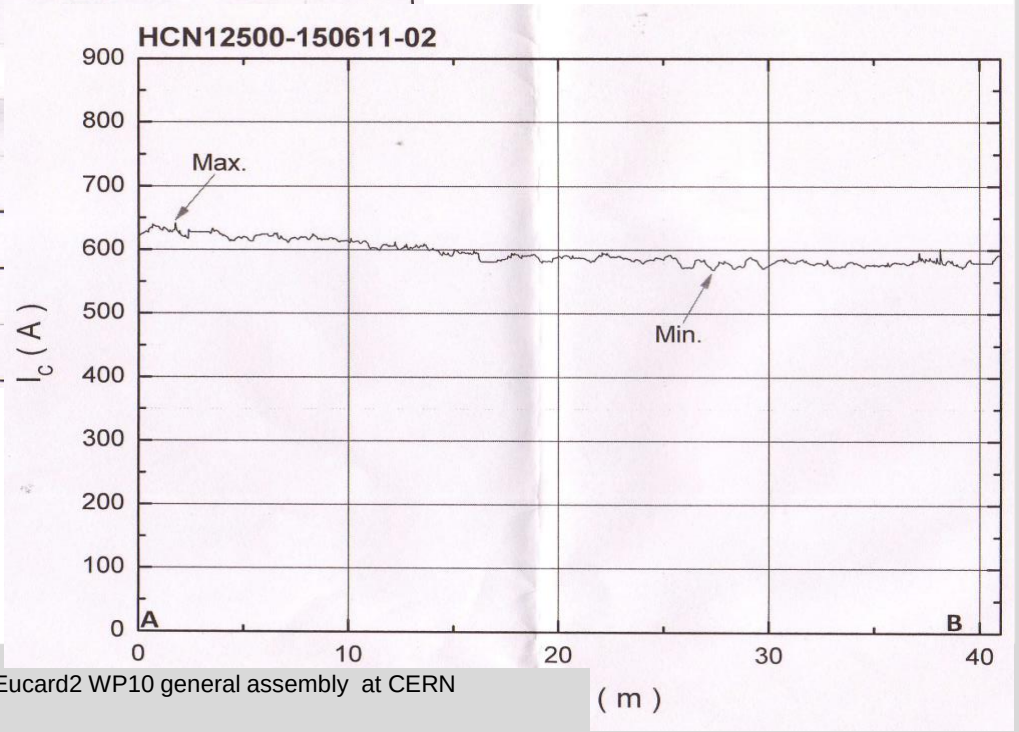
2G HTS Wire Properties

Item	Spec	Data				Result
		X	σ	Max	Min	
T_c (K)	-					
Critical current (A)	≥ 500	595				
Je (4.2 K, 20 T) estimated	> 200 A / mm²					
COV(coefficient of variation)	< 10					

Appearance

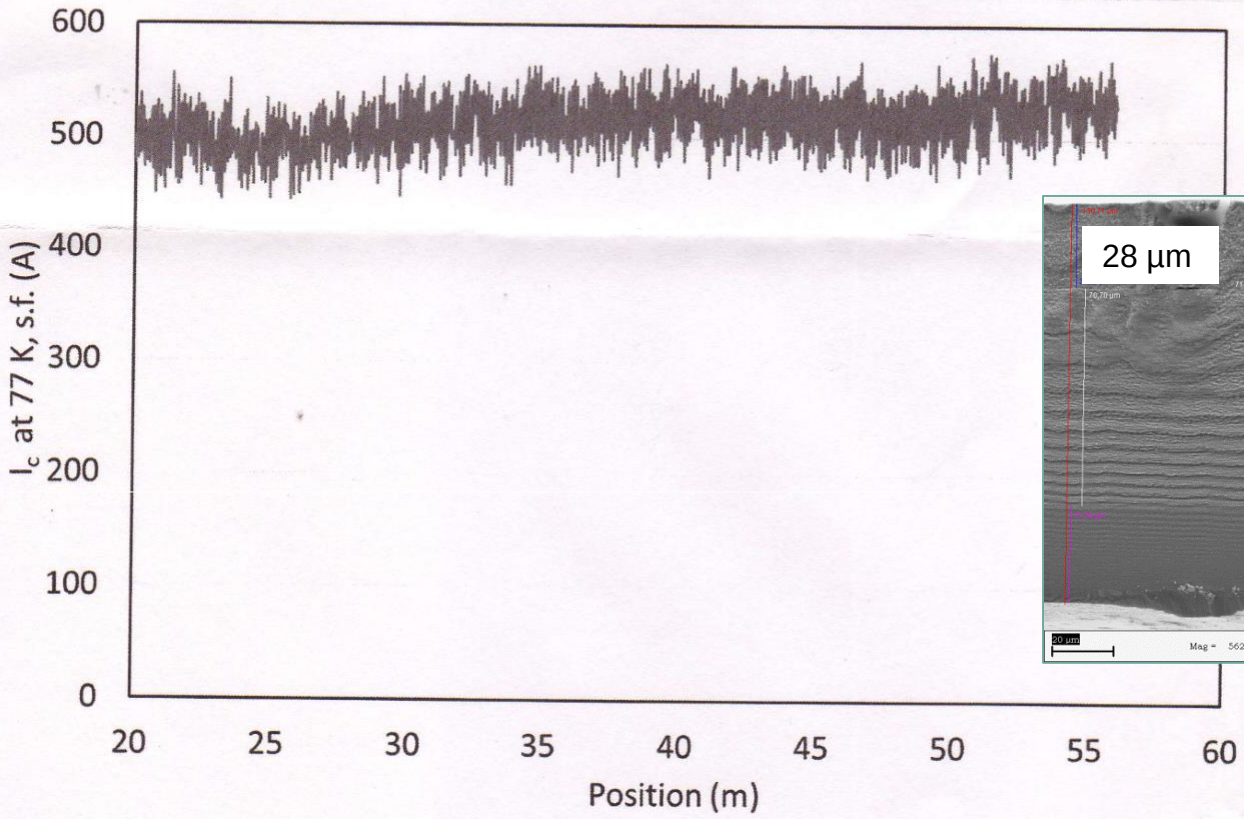
Item	Spec
Visual (Scratch etc.)	Free

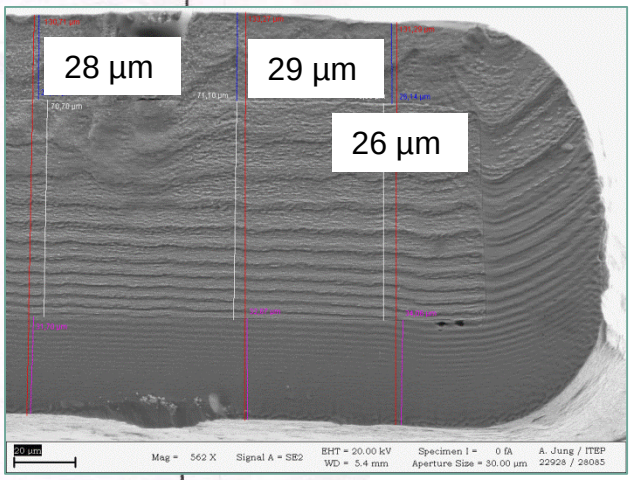
- Delivered from CERN to KIT for punching test 40 m
- Change in punching tool needed (tape width)



SuperOx- CERN:

Substrate	Hastelloy C276 (nonmagnetic), 60 µm
Min. I_C (77K, s.f.)	450 A
Width	12 mm
Length	36 m
Silver layer	2 µm
Copper surround layer	20 µm





*cross-section of one of the previous samples

Fujikura – Ag – KIT:

Model Number FYSC-S12(Substrate75um)
Serial Number 15-0024

■Tape Thickness(Reference value)

Parameters	unit	Thickness	Note
Ni-based metal alloy	μm	75	Hastelloy C-276 equiv.

■Tape Dimension

Parameters			unit	spec	Data
length ※1			m	–	3.1
width ※2	Insulated wire	No.1	mm	–	12.04
		No.2			12.04
		average			12.04
thickness ※2	Insulated wire	No.1	mm	–	0.088
		No.2			0.082
		average			0.085

※1 Tape length is only superconducting wire.
Superconducting wire is wound on the reel so that the Ag layer is located outside.
About 2m SUS tape is connected to both ends of the superconducting wire.
※2 The width and the thickness of the wire shall be measured at the representative points including the end of the wire and the average value shall be described in the test report.

■Critical current measurement

Parameters	unit	Spec	Data
Ic ※3	A	–	642

※3 Measured in short sample method from one side of wire at 77K, Self field, 1μV/cm

*RE*BCO 3-6 μm
Hastelloy 75 μm
Ag 10 μm

- Possible to punch this geometry with our tooling
- Samples provided by Fujikura.

Fujikura – Cu – KIT:

Model Number FYSC-SCH12(Substrate75um)
Serial Number 15-0025

■Tape Thickness(Reference value)

Parameters	unit	Thickness	Note
Cu	μm	20	Electroplate copper
Ni-based metal alloy	μm	75	Hastelloy C-276 equiv.

■Tape Dimension

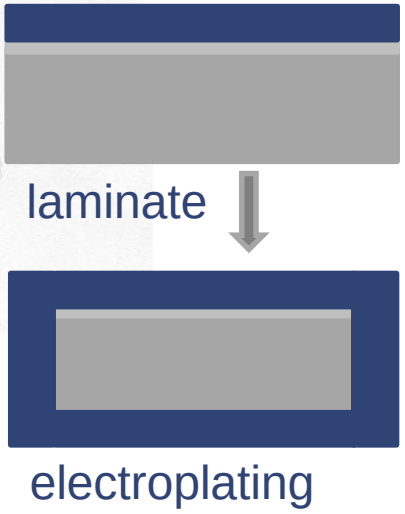
Parameters			unit	spec	Data
length ※1			m	–	3.0
width ※2	Insulated wire	max	mm	–	12.17
		average			12.13
		min			12.12
thickness ※2	Insulated wire	max	mm	–	0.131
		average			0.124
		min			0.122

※1 Tape length is only superconducting wire.
Superconducting wire is wound on the reel so that the Ag layer is located outside.
About 2m SUS tape is connected to both ends of the superconducting wire.
※2 The width and the thickness of the wire shall be measured at the representative points including the end of the wire and the average value shall be described in the test report.

■Critical current measurement

Parameters		unit	Spec	Data
Ic ※3	Average	A	–	626

※3 77K, Self field, 1μV/cm
The distance between the center of the voltage terminal is 5.0m.
The distance between the inside of the voltage terminal is 4.7m.
0m is reel inside.



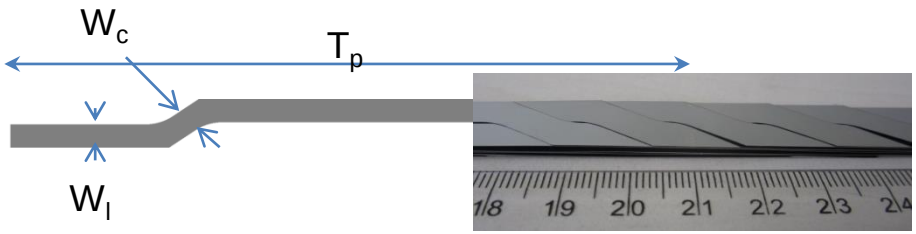
Cu 20 μm
*RE*BCO 3-6 μm
Hastelloy 75 μm

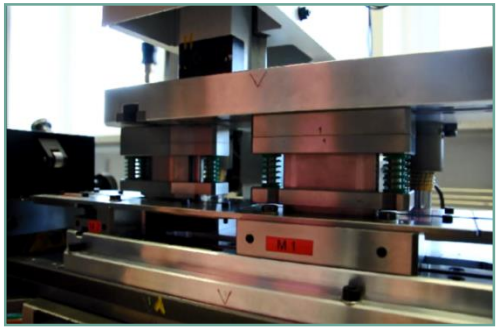
Cu 20 μm
*RE*BCO 3-6 μm
Hastelloy 75 μm
Cu 20 μm

- Samples provided by Fujikura.

Available punching options:

Transposition lenght (mm)	Strand width (W_l)/ Bridge width (W_c) (mm)	Tape width (mm)
126	5.5 4.7	12.1 (SP, SOx) 12.4 (Bruker) 10.1 (old Fujikura)
226	5.5 4.7	12.1 (SP, SOx) 12.4 (Bruker) 10.1 (old Fujikura)
300	5.85	12.1 (SP, SOx)
426	5.5 4.7	12.1 (SP, SOx) 10.1 (old Fujikura)





Roebel cable for transverse stress at U. Twente:

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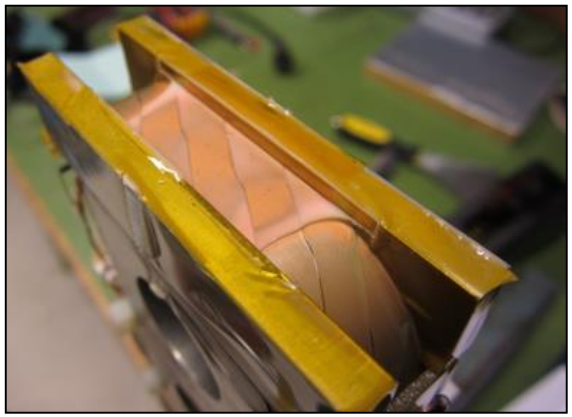
Roebel cable: 226 TL, 15 strands:

1. SuperPower CC + KIT impregnation
2. SuperPower CC + CERN impregnation
3. Bruker CC + CERN impregnation

CERN: delivers resin and glass fibre to UT

KIT: Bruker (ready) and 2 SuperPower cables (in preparation)

UT: experiments planned 2016

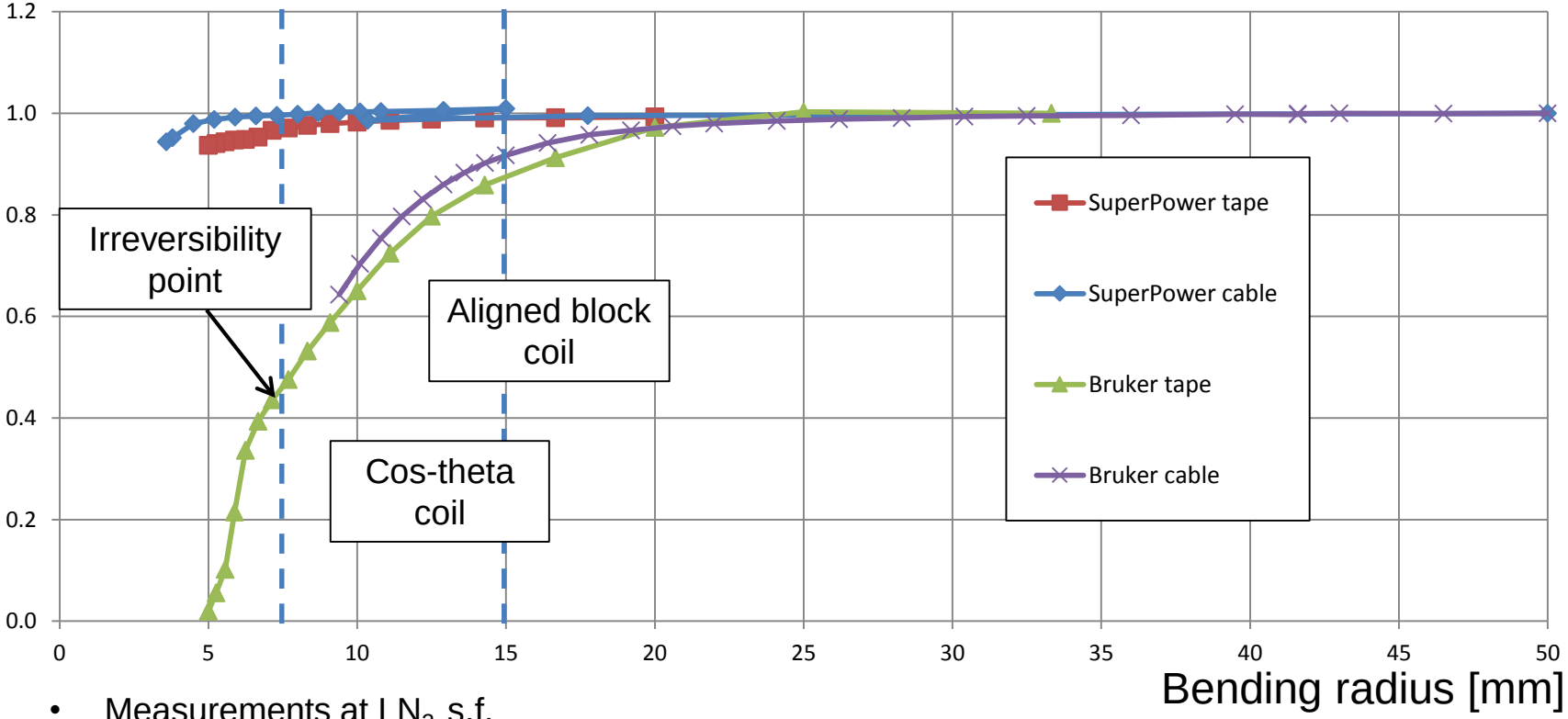


Old experiment:

- Roebel cable: 126 TL, 10 strands
- SuperPower tape, 20 µm Cu (per site)
- KIT impregnation

Out-of-plane Roebel cable & single tape bending:

Reduced critical current



- Measurements at LN_2, s.f.
- *RE*BCO inside / compressive bending
- I_c of the Roebel cables:

  SuperPower: 1427 A

  Bruker: 658 A

<u>SuperPower</u>

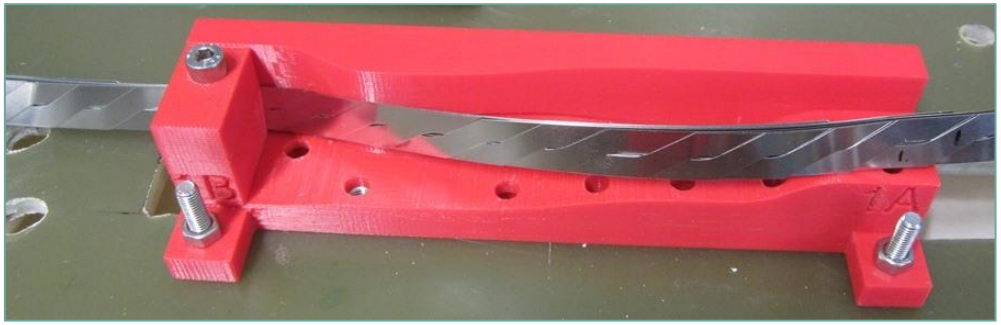
- 20 µm Cu, 50 µm Hastelloy

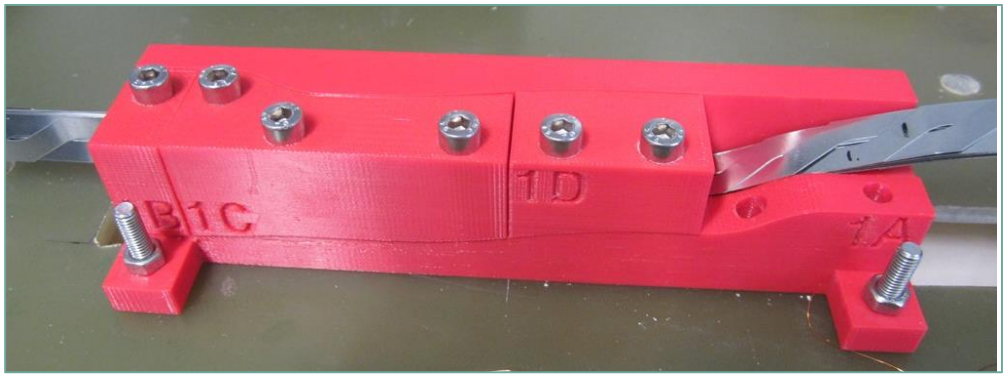
<u>Bruker</u>

- 20 µm Cu+, 100 µm SS

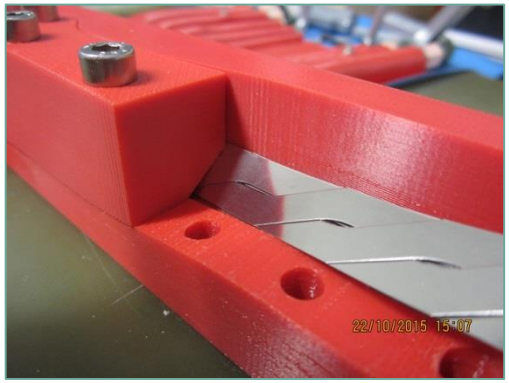
Mechanical test of the cos-theta coil end geometry (CEA Saclay + KIT):

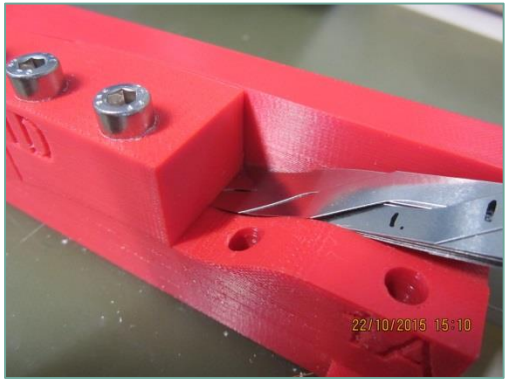
Courtesy of M. Durante



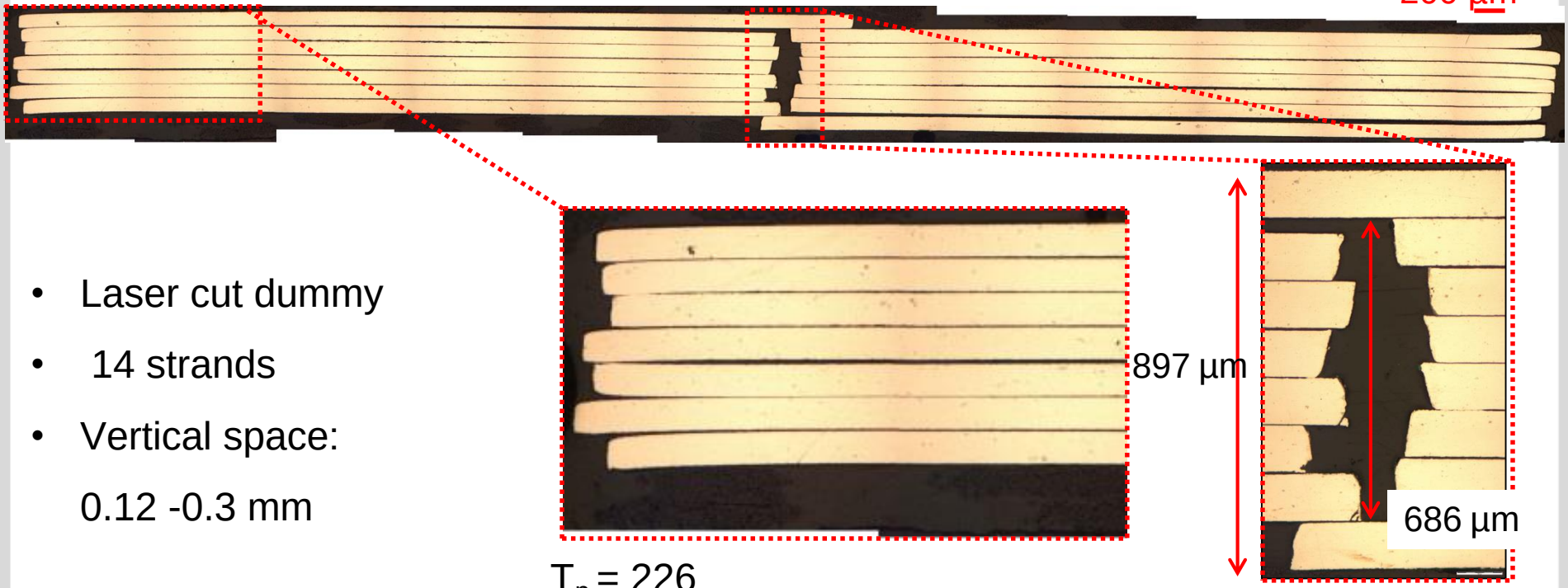


- Forseen January 2016
- Test at KIT (77 K, s.f.)
- CERN-3D form print



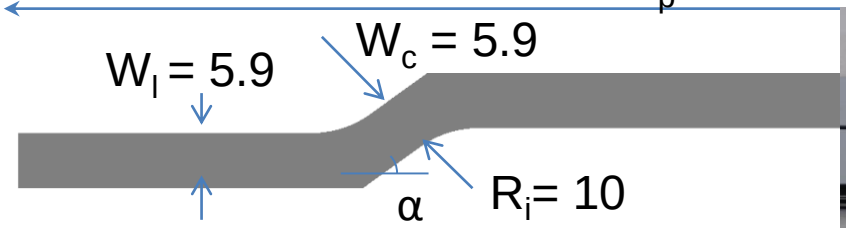


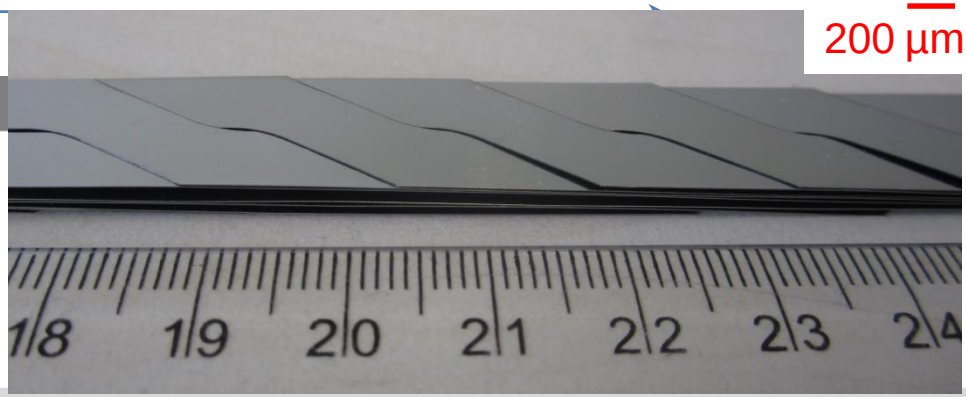
Roebel with reduced central space – changed strand geometry:



- Laser cut dummy
- 14 strands
- Vertical space:

  0.12 -0.3 mm





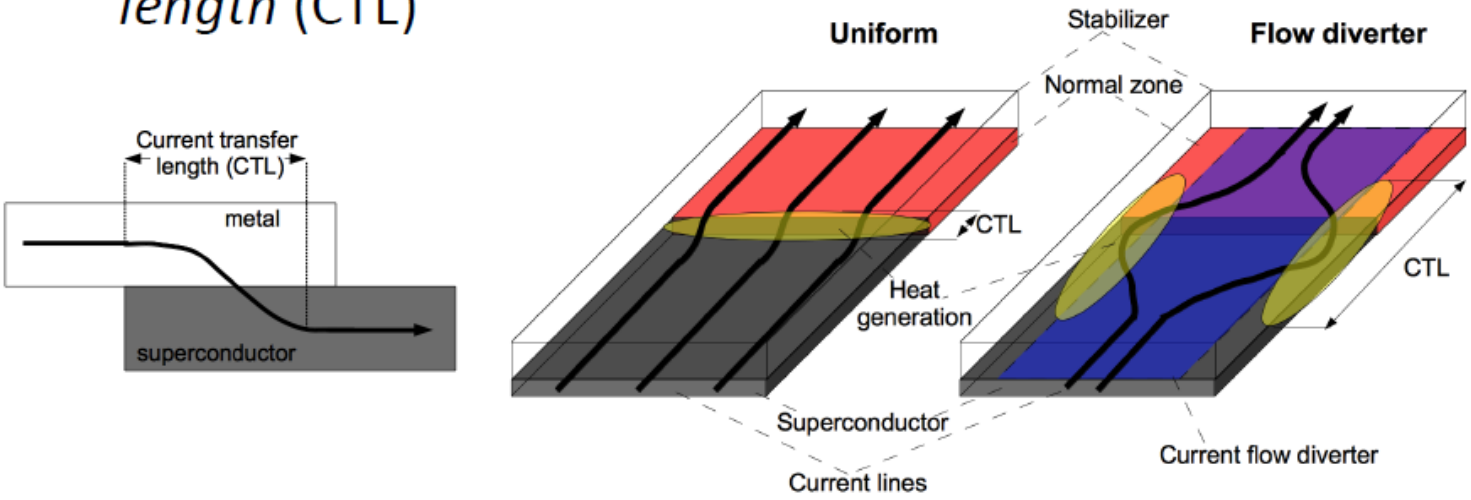
Outlook on developments on CC and Roebel cables parallel and beyond Eucard2 at KIT

- Upgrade of the Roebel cable to a double-core-cable (24 mm width): Dummy, short sample and numerical modeling,
- Focus on doubled current for larger magnets !
- Integration of a quench detection system in the cable (matter of patent appl.)
- Modeling and experiments on quench dynamics (F. Grilli; R. Guraki)
- Quench accelerator (NZPV) systems bei modeling and experiment (F. Sirois + Student)
- Frederic Sirois (Ecole Polytechnique Montreal) joins KIT for 1 year (2016) !

Quench management via CC material conditioning

Current Flow Diverter (CFD) concept[1]

- Highly resistive layer that **partially** covers the HTS-Ag interface to increase the *current transfer length* (CTL)



- Increases the NZPV by an order of magnitude for a given interface resistance (R_i)

[1]Lacroix *et al. SUST* 27, 035003 (2014)