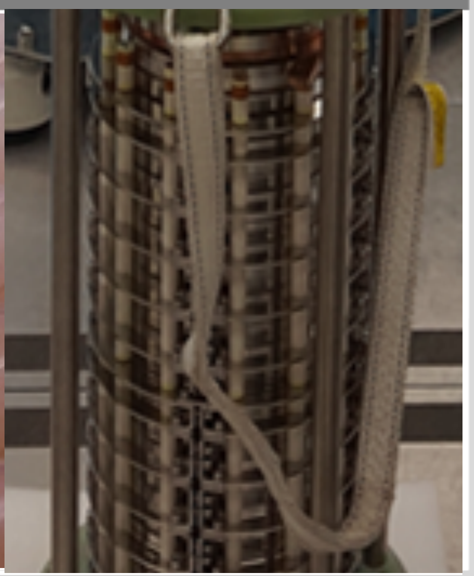
Karlsruhe Institute of Technology

Status of Industrial Coated Conductor Production and Properties

Bernhard Holzapfel, Institute for Technical Physics, Karlsruhe Institute of Technology,
EUCAS 2017, Geneva, 19th September 2017

Institute for Technical Physics





Motivation

- From SC materials to magnet and power applications

Material → Conductor → Application

- New Materials
- Basic Properties
- Improved Pinning
- Wire concepts

- Power Applications
- Magnets
- Rotating Machines

- Length, Homogeneity
- Economic Synthesis
- Upscaling
- Electrical stabilization
- Insulation
- Mechanical properties
- AC-losses
- Multi wire cable designs

Content

Coated Conductor Application Areas and required Properties

Industrial available Coated Conductors

- Top 10 main players and their Coated Conductors
- General aspects of electrical and mechanical properties
- Production issues

Assembled Coated Conductor and Outlook

Acknowledment

Karlsruher Institut für Technologie

- Market relevant Coated Conductor producer

SuperPower Inc.
BRUKER
SuNAM Co., Ltd.
上海超导科技股份有限公司
Shanghai Superconductor Technology Co., Ltd.
SuperOx
SUPERCONDUCTOR TO THE FUTURE
Fujikura
Shanghai Creative Superconductor Technologies Co., Ltd.
deutsche nanoschicht
amsc
THEVA

- Other sources:
  - CCA workshop 2016 Aspen
  - MT25, ASC 2016 contributions
  - ITEP internal documents

Coated Conductor Application Areas

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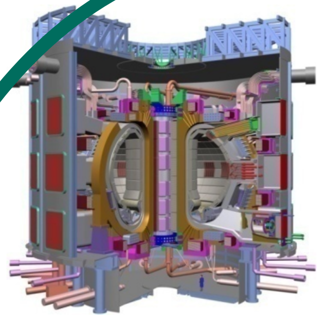
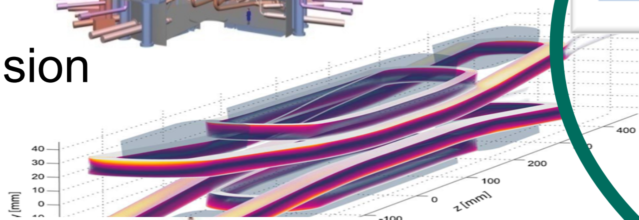


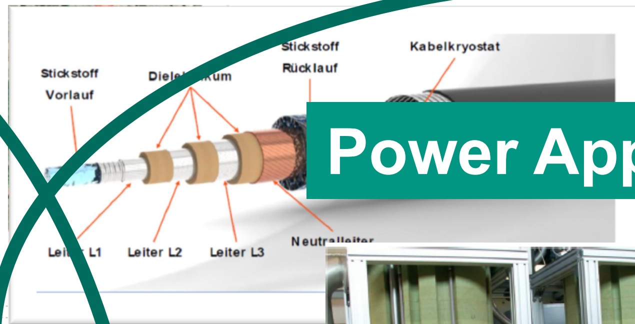
Fusion



FCC

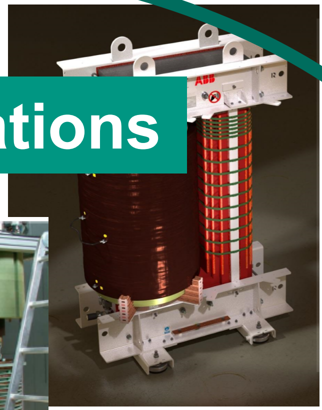
NMR/MRI

Magnets



AC/DC cables

Power Applications

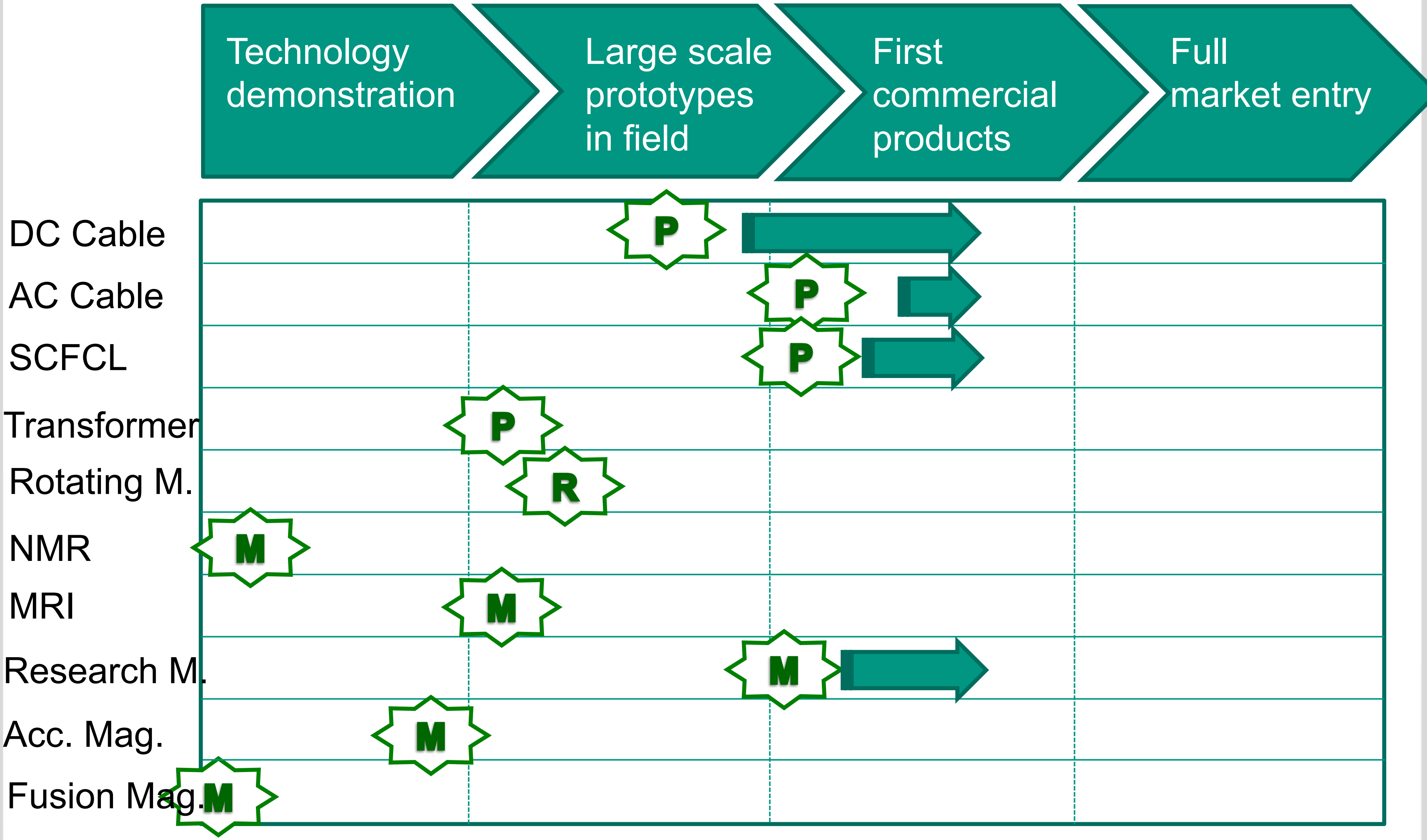


Transformer

FCL

Rotating Machines

State-of-the-Art CC Technology Development



Application based CC property requirements

- Power Applications
  (HT/LB properties, homogeneity, price, joints, insulation)
- Rotating machines
  (MT/MB properties, AC-losses, J_e(incl. insulation), mechanical, long piece length, price)
- Magnets
  (LT/HB properties, mechanical and electrical stabilization, joints, long piece length)
- Several high current applications require assembled multi wire cable concepts

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Assembled Coated Conductor and Outlook

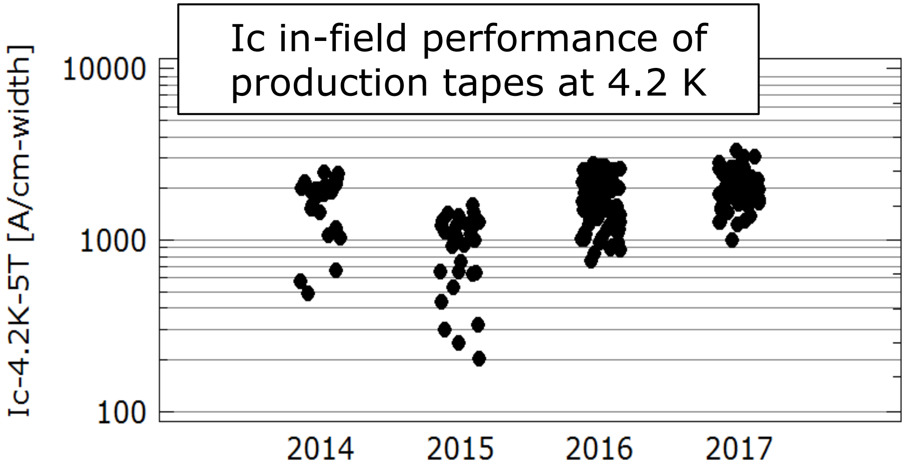
Overview on Industrial CC Producers

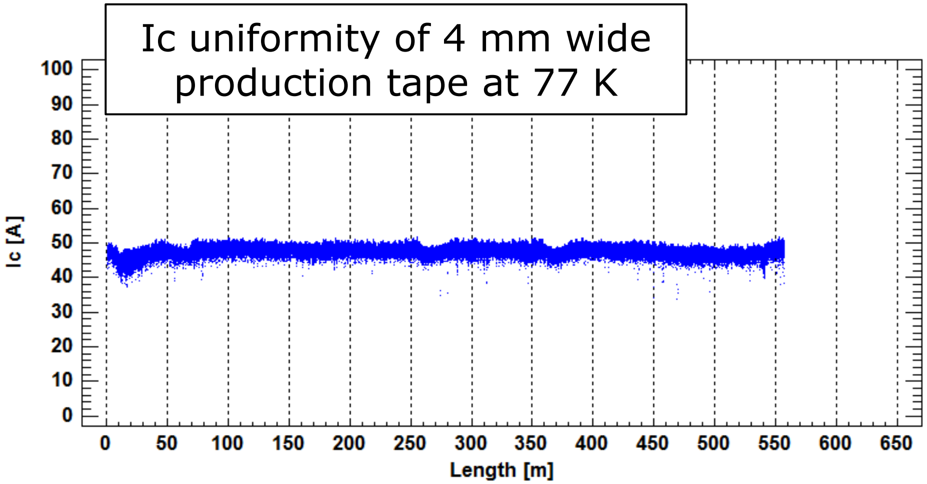
Company & Focus	CC arch.	Substrate + finish	Currents (77K, s.f.)	Dimensions	Remarks/ Specialty
AMSC full range	MOD Y(Dy)-123 RABiTS	Ni-W brass, Cu or stainless steel lamination Polyimide lam.	$I_c \approx$ 300 A/cm-w.	max. length: 500m max. width: 12mm min. thickness: 75µm	HT/LB + MT/MB clad conductor
Bruker In-house NMR	PLD Y-123 ABAD YSZ	Stainless steel Cu-plating	$I_c \approx$ 750 A/cm-w. 4.2 K / 30 T (B//c)	max. length: 600m max. width: 4mm min. thickness: 100µm	Advanced high field pinning at T = 4 K
D-NANO Low cost, pure tape supplier	MOD Y-123 RABiTS	Ni-W Cu laminate	$I_c \approx$ 300 A/cm-w.	max. length: 200m max. width: 10mm min. thickness: 60µm	wider tape clad conductor
Fujikura	PLD Gd-123 IBAD MgO	Hastelloy Cu plated Polyimide insulation	$I_c \approx$ 550 A/cm-w	max. length: 600m max. width: 12mm min. thickness: 75µm	Good in-field properties
Shanghai SC high field app	PLD Y-123 IBAD MgO	Hastelloy	$I_c \approx$ 300 A/cm-w @ 1km $I_c \approx$ 500 A/cm-w @ 100m	max. length: 1000m max. width: 10mm	

Bruker Energy & Supercon Technologies (BEST)

BRUKER HTS at a glance

- BHTS pilot-line plant (about 2000 sqm operation area), max. capacity 25 km p.a. (further ramp-up to 100 km p.a. possible within the plant)
- HTS tapes for ultra-high magnetic field application at intermediate and low temperatures, Ic at 4.2 K, 30 T, B//c exceeding 750 A/cm-width
- Tape width 4 mm and 12 mm (optionally 40 mm), the max. actual batch size for 4 mm is 600 m (max. tape length in 2014 was 200 m, production capability ramp-up to 600m started in 2015)





Industrial applications
DC bus bars

deutsche nanoschicht

- single copper laminate - HTS neutral fiber
  - Upscaling: wide tapes and production devices

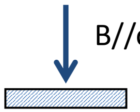
4x25m high temperature annealing furnace

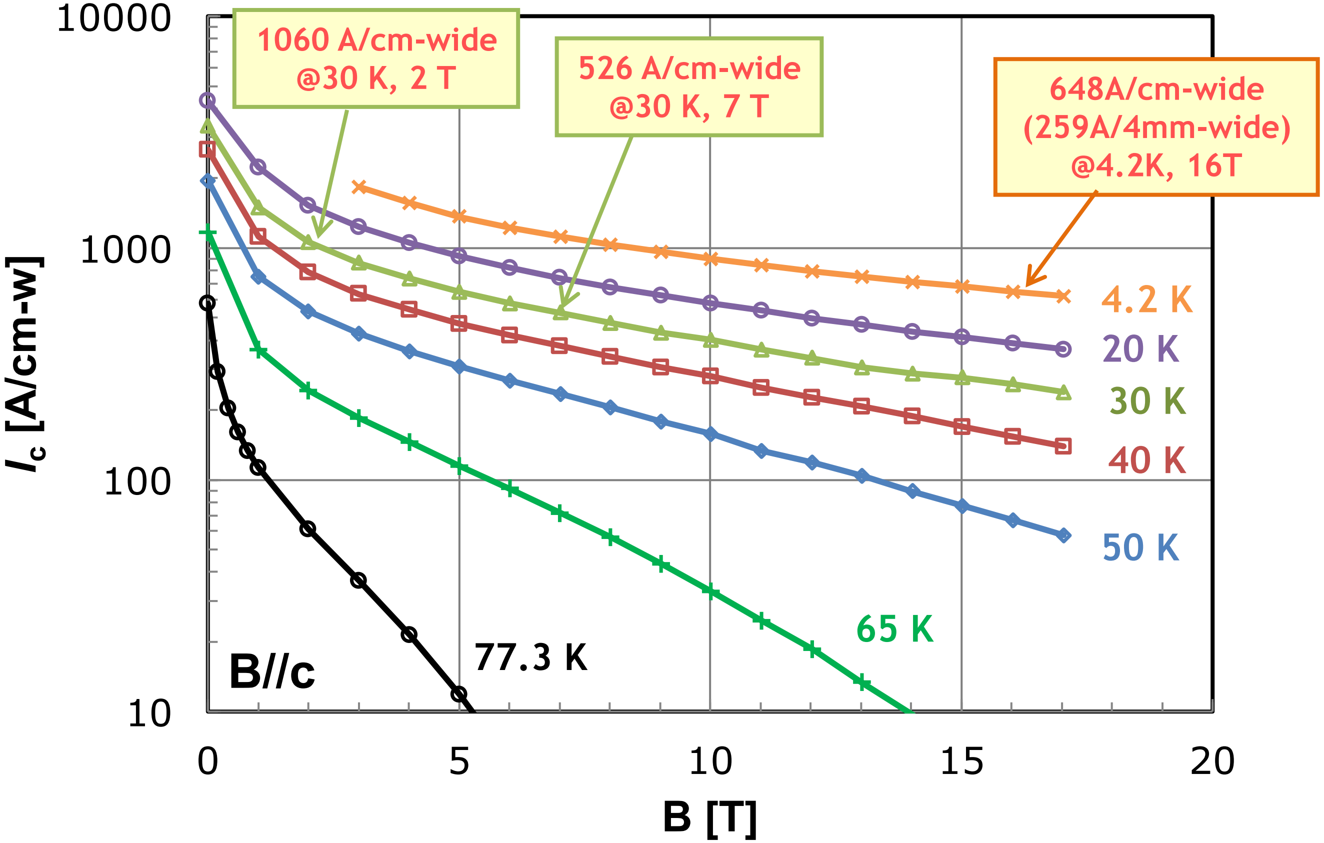
40mm fully buffered tape

M. Bäcker, 2MO4-06

Typical In-field I_c of a production wire

- Example data of typical production wire
- Sample : Ic = 573 A@77K,s.f. (cm-w)



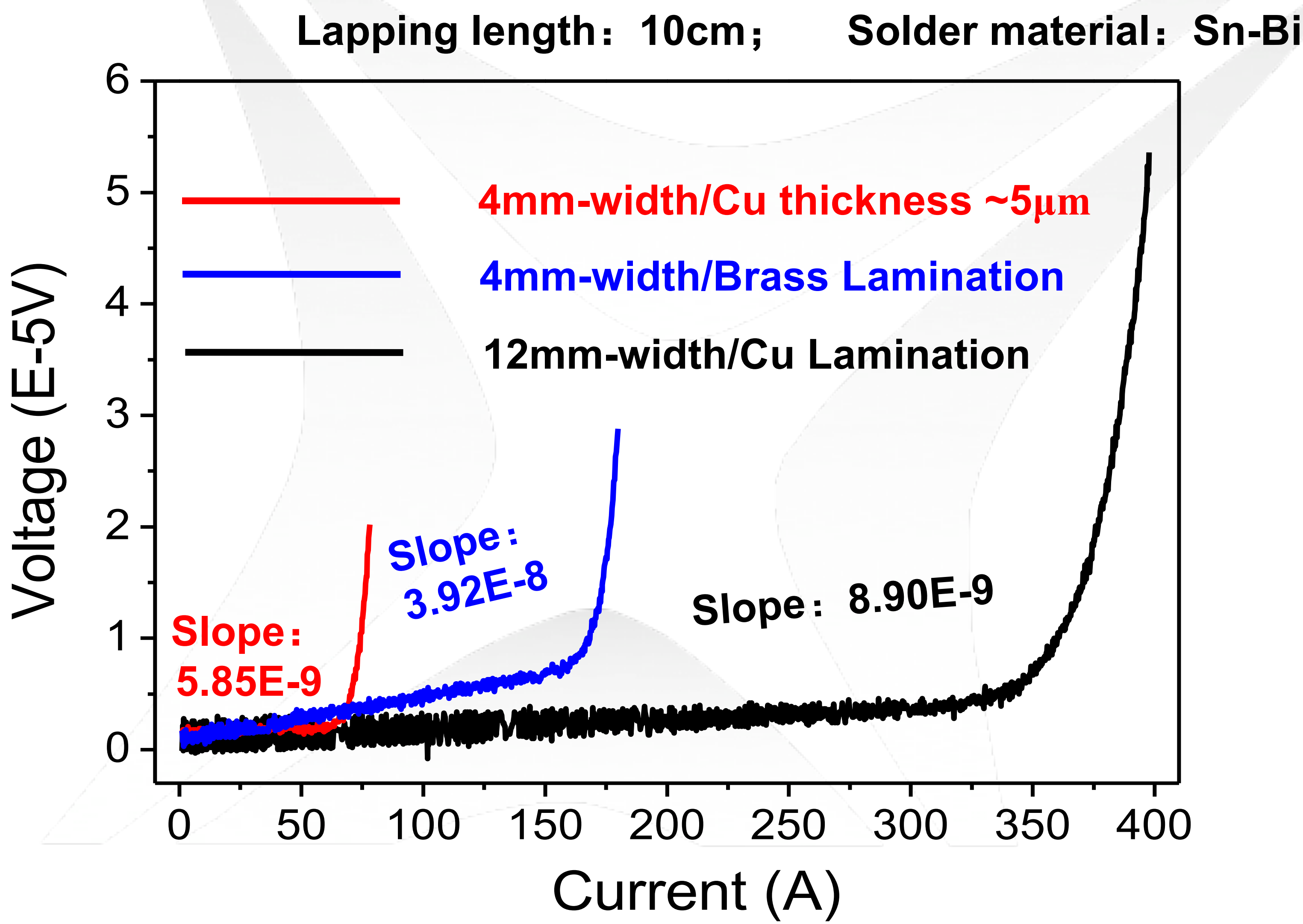


Fujikura

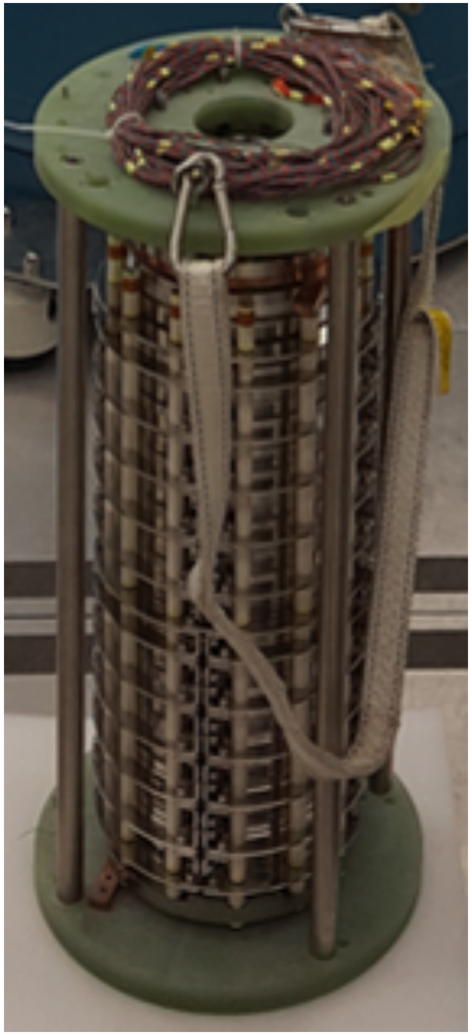
Overview on Industrial CC Producers

Company & Focus	CC arch.	Substrate + finish	Currents (77K, s.f.)	Dimensions	Remarks/ Specialty
Shanghai Creative SC	MOD Y(Gd)-123 IBAD MgO	Hastelloy Brass/Cu lam. Polyimide ins.	$I_c \approx$ 400 A/cm-w.	max. length: 500m max. width: 12mm min. thickness: 80µm	HT/LB + MT/MB Low resistance joints
SuNAM Tape sup. + magnets	RCE Gd-123 IBAD MgO	Hastelloy or Stainless steel Cu plating Brass lam. Ployimide wrap.	$I_c \approx$ 550 A/cm-w.	max. length: 1000m max. width: 12mm min. thickness: 105µm	Standard + LT/HB soon short delivery time
SuperOx Customized solutions, cables, systems (e.g. FCL)	PLD Gd-123 IBAD MgO	Hastelloy Cu plating Lamination, Polyimide coat. and wrap.	$I_c \approx$ 400 A/cm-w	max. length: 400m max. width: 12mm min. thickness: 60µm	HTS cables, 1mm square stacked cable filaments
SuperPower/ Furukawa pure tape sup.	MOCVD RE-123 IBAD MgO	Hastelloy Cu plating	$I_c \approx$ 450 A/cm-w	max. length: 500m max. width: 12mm min. thickness: 30µm	Highest J_e HT/LB + LT/HB Clad conductors
THEVA Economic route, coils	Gd-123 e-beam evap. ISD MgO	Hastelloy Cu plating or Cu lamination	$I_c \approx$ 500 A/cm-w.	max. length: 300m (600m demonstrated) max. width: 12mm min. thickness: 90µm	Lamination of Cu Low resistance joints

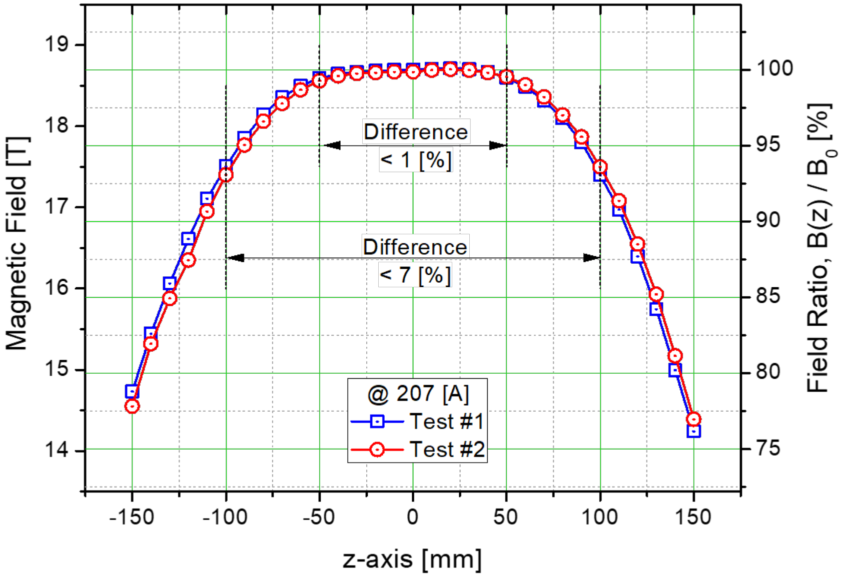
Joint Technology Development at Shanghai Uni. & SCSC



1st Commercial all HTS magnet system by SuNAM

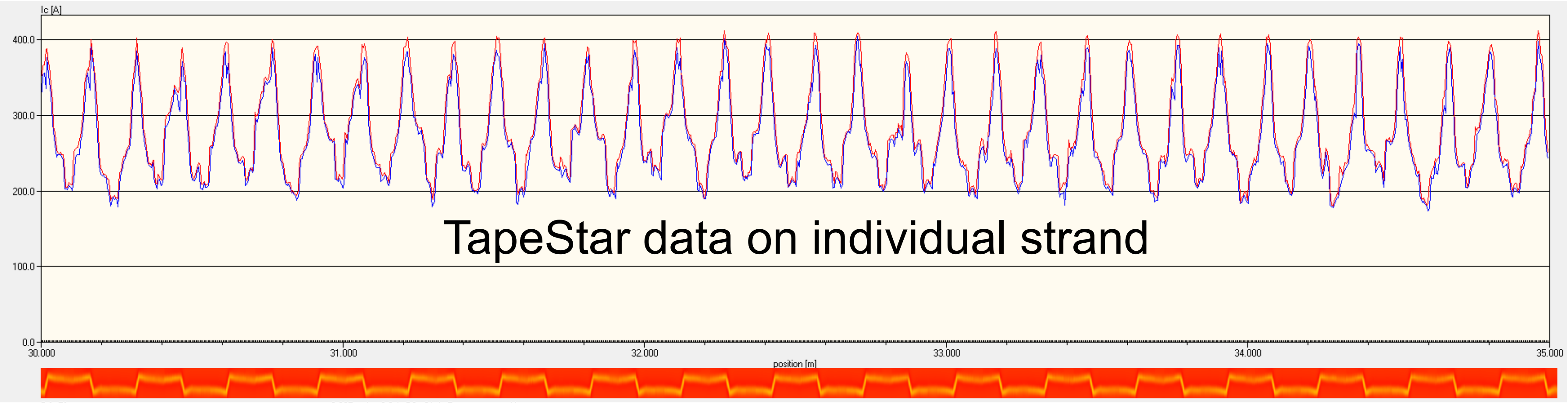


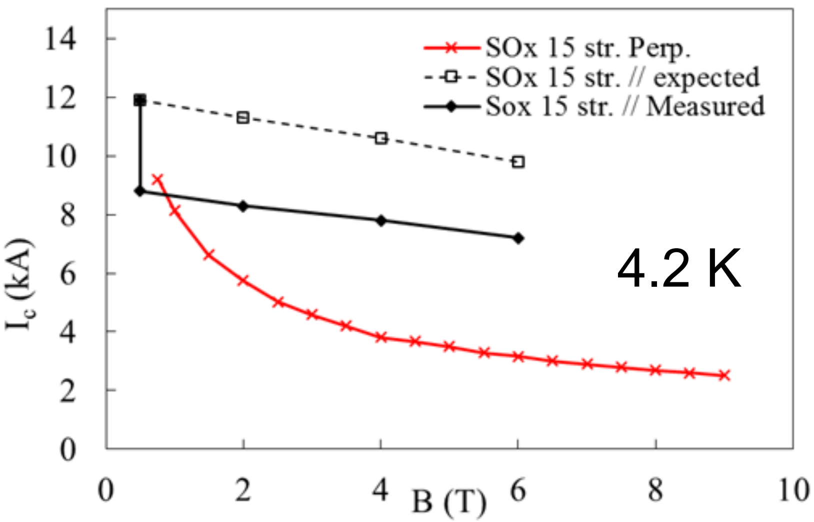
- Delivered to IBS (Institue for Basic Science) in Korea. (Aug. 2017)
- For "axion" detection.
- 18.7 T at 4.2 K, 70 mm clear bore.



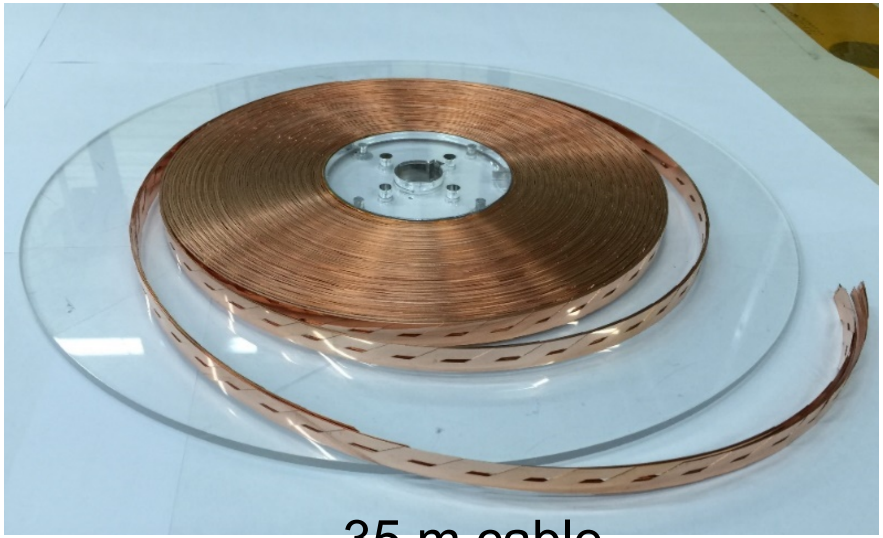
H. Lee, 2MO4-05

2G HTS Roebel cables





J. Fleiter et al. CERN Internal Note 2017_15, EDMS: 1757653



35 m cable

now in Feather 2 coil at CERN

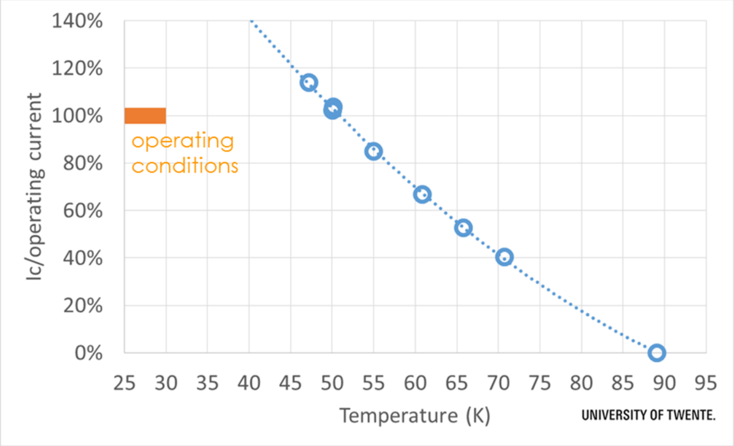
HTS coils

Coil winding and casting technology:

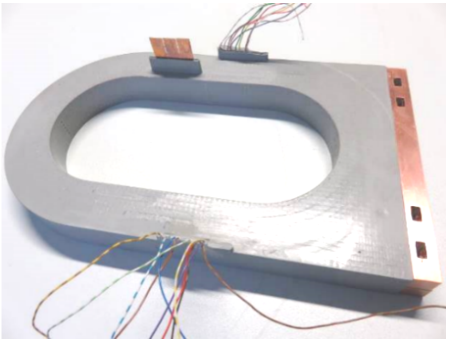
- Resin potted
- Double pancake coils
- About 200 turns
- Operating at 30 K
- For conduction cooling as well as cooling with liquids

Ongoing:
Small series production of more than 30 coils for a 3.6 MW windpower generator within the EcoSwing project

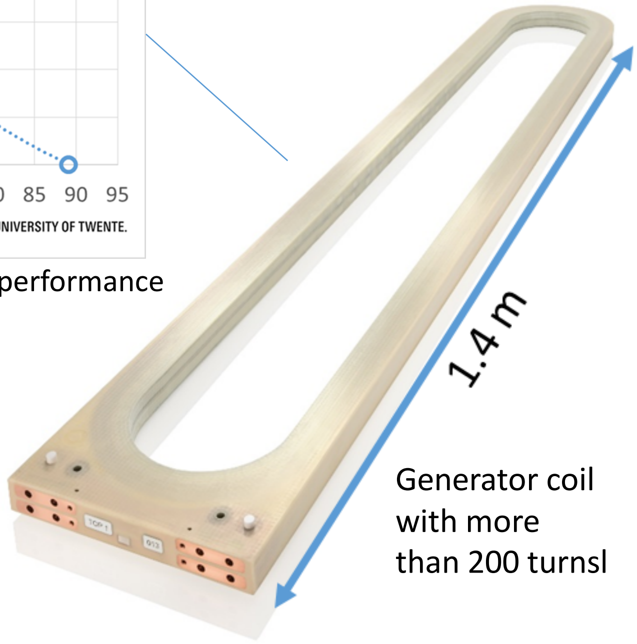
Technology can be adapted for different size, number of turns and wire width.



Type test of generator coil showing expected performance



2 x 87 turn coil



Generator coil with more than 200 turnsl

ecoswing

"EcoSwing has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 656024." "Herein we reflect only the author's view. The Commission is not responsible for any use that may be made of the information it contains."

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Electrical Properties

- For most applications sufficiently high J_c and I_c CC are available from industry
- Focus is currently on improving the engineering current density (where necessary) and transfering the exciting small sample advanced pinning properties into production
- In-field properties show a wide spread across producers and there is so far no general scaling of 77K data towards low T, high field properties possible
- Critical Current Anisotropy is quite different among tapes
- Public database on electrical properties
- Electrical stabilization properties (quench and recovery) including insulation are advancing but need to be investigated in more detail

Variability of J_c-Anisotropy

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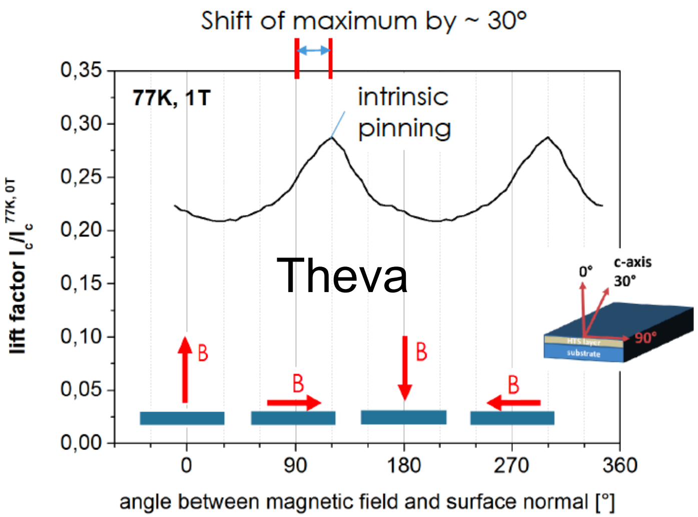
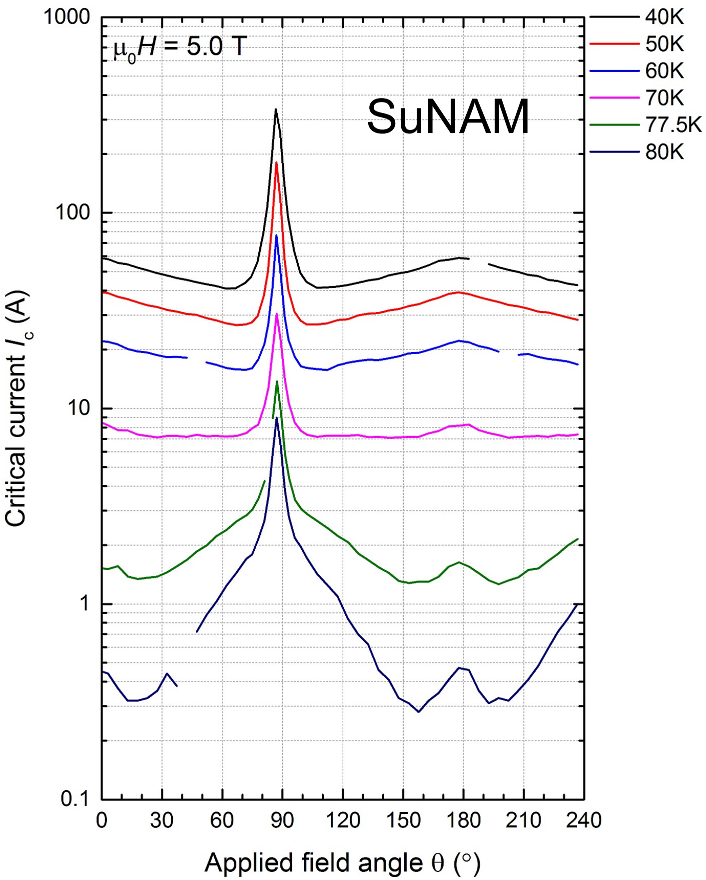


- J_c(BIIab) not always the max. J_c value



- J_c(BIIc) not always the min. J_c value

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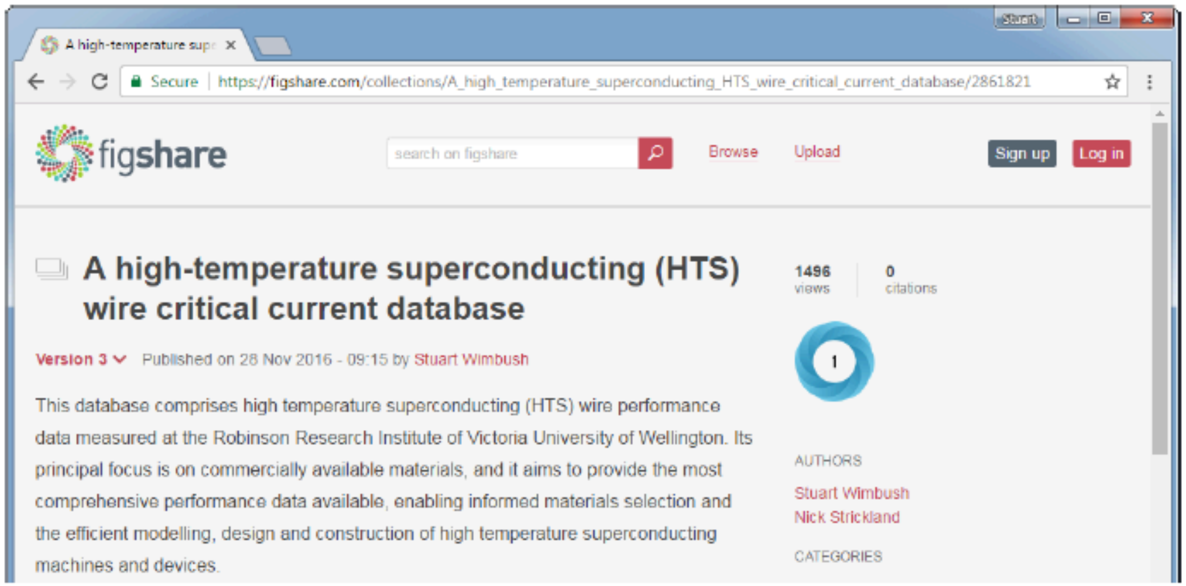
Public HTS wire critical current database

As high temperature superconducting technologies edge closer and closer to industrial breakthrough, the need for *detailed* wire critical current characterisation becomes greater and greater.



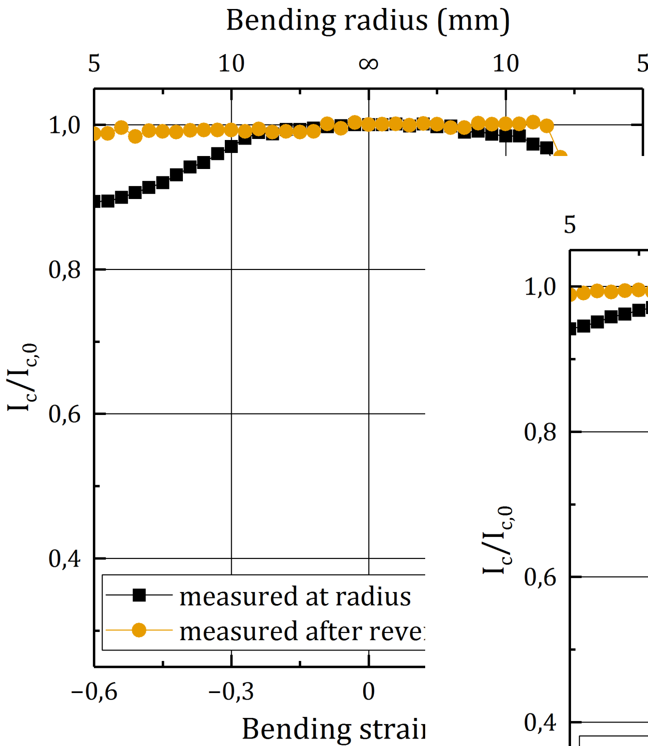
http://www.victoria.ac.nz/robinson/hts-wire-database

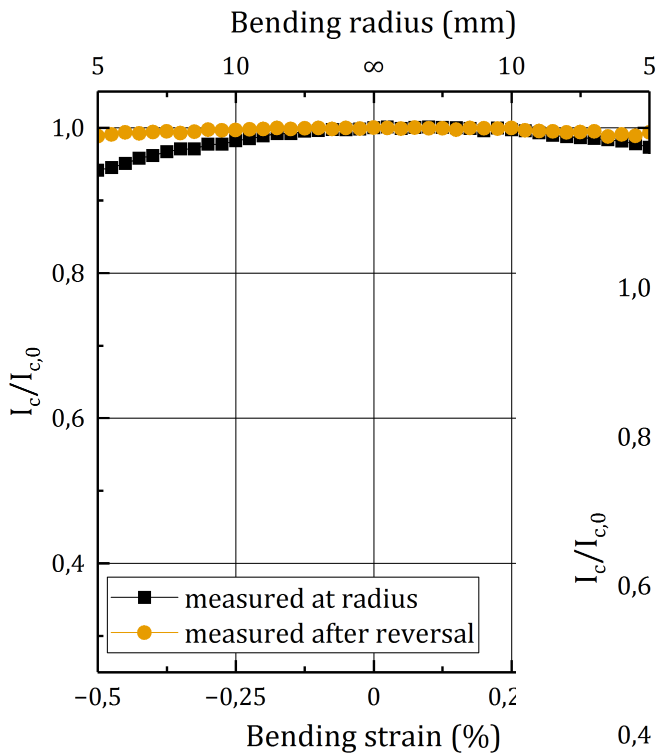
ICMC Focused Symposia on Materials for Electric Propulsion Transportation

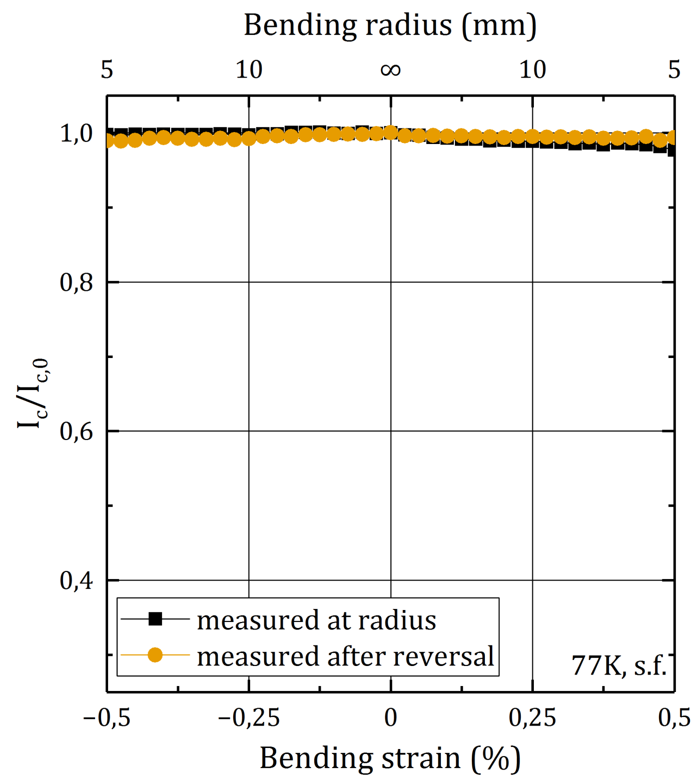
Wimbush and Strickland, *IEEE Trans. Appl. Supercond.* 27 (2017) 8000105.

Stuart Wimbush, Robinson Research Institute, Wellington, NZ, CEC-ICMC 2017

Mechanical properties show still strong variations







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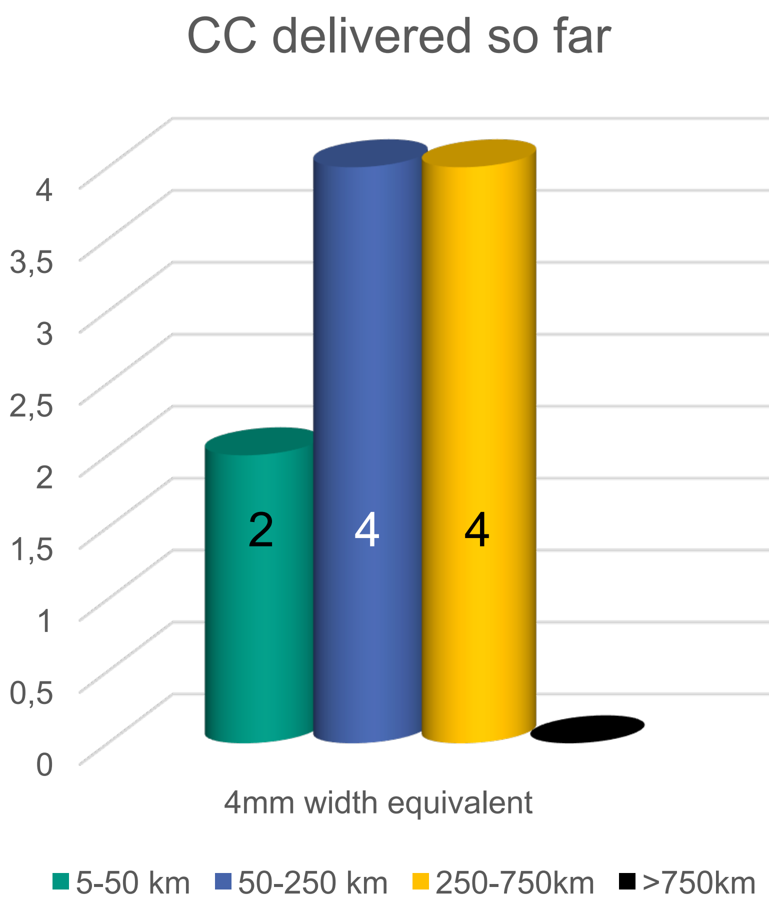
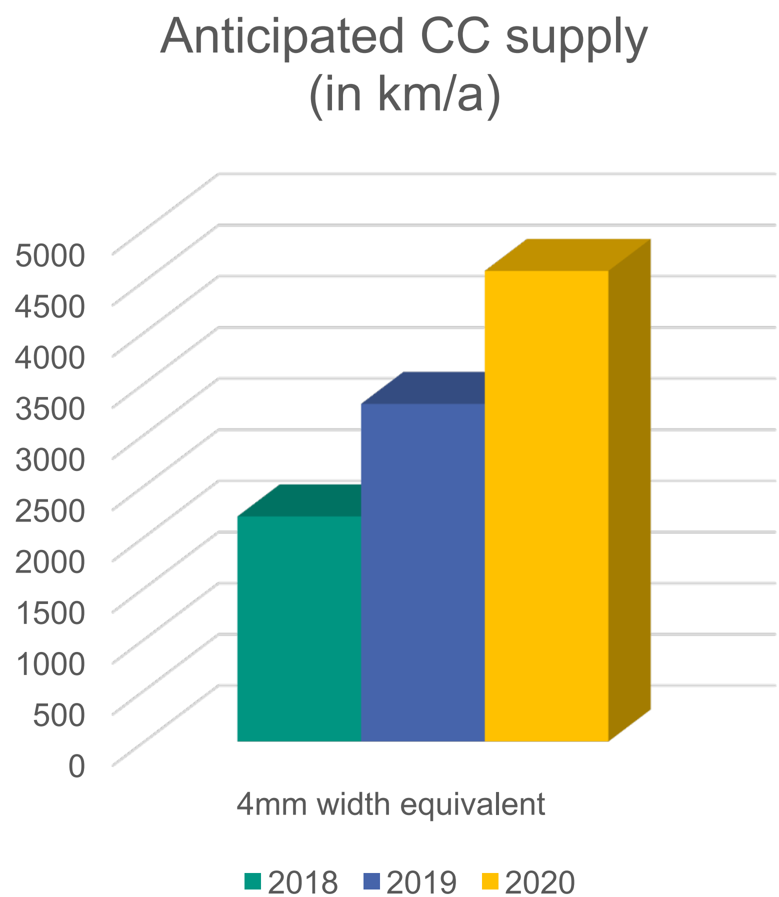
Assembled Coated Conductor and Outlook

General Production Developments

- Companies work hard to improve production stability and yield, e.g. by in-line inspection/analysis tools
- This has direct implications on CC homogeneity, available batch length, available volume and price
- Available batch length and yield is highly application specific (e.g. NMR vs. research magnets)
- Full range of electrical and mechanical stabilization concepts are realized and offered by CC producers
- More and more CC producers also develop system components (e.g. coils) and even full systems (FCL, magnets)

Coated Conductor Production Volume





Overall worldwide ever delivered CC volume ≈ 3000km

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Overview on HTS Multitape 2G Concepts

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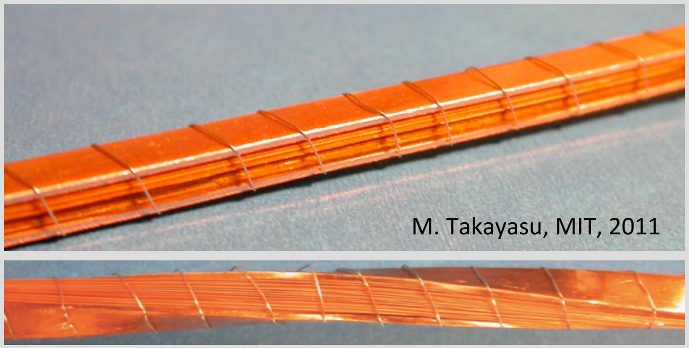
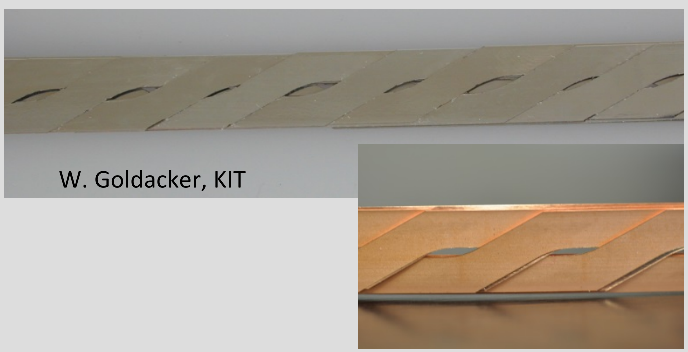
Stacks and Twisted Stacks

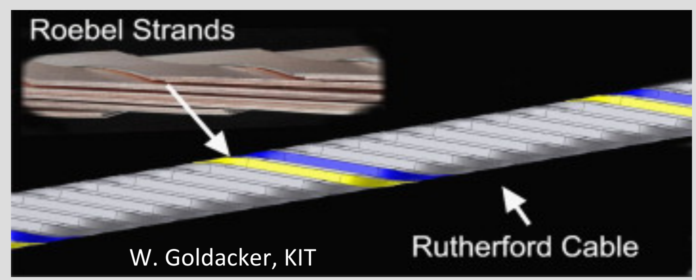


Cable on Round Core

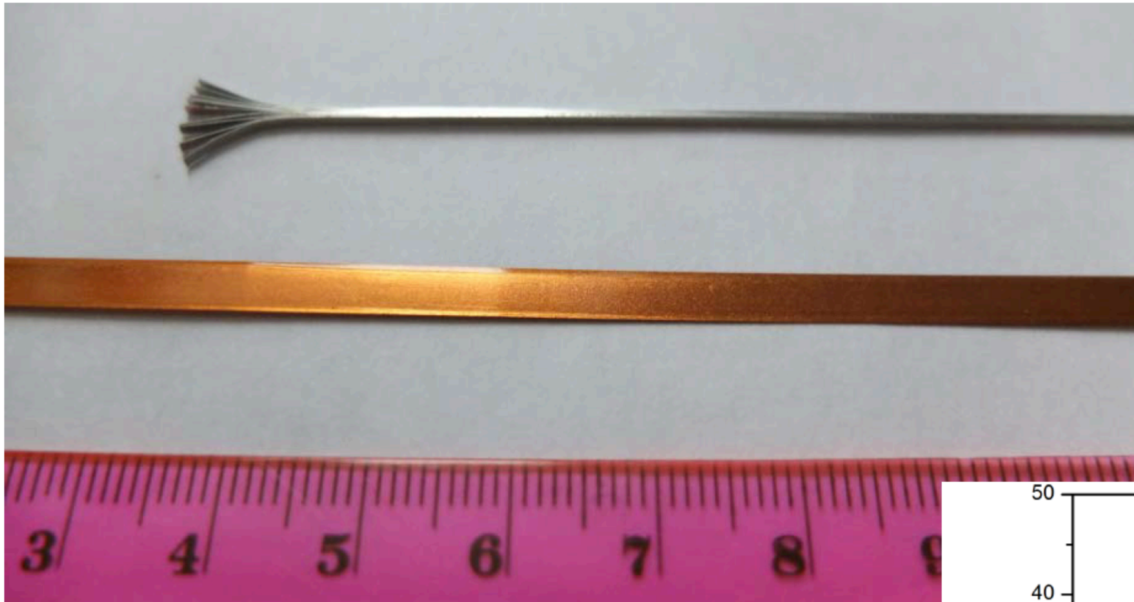
Roebel



Roebel-Rutherford

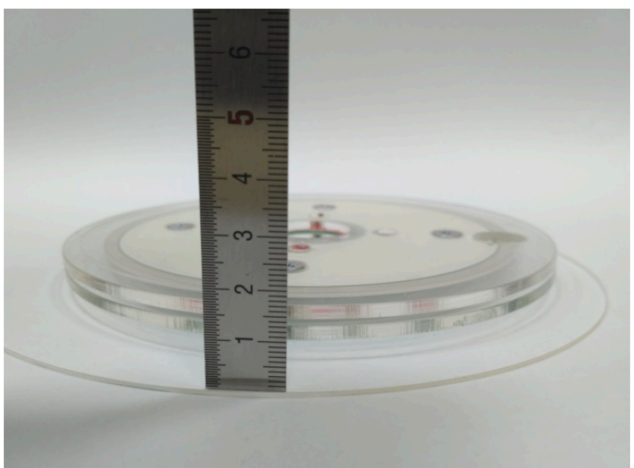


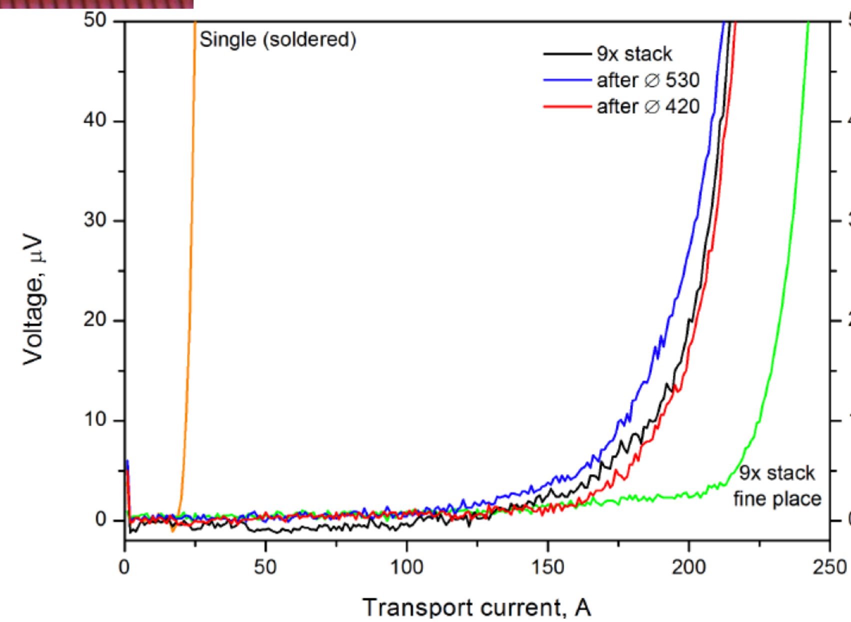
New 1x1-mm^2 combined 2G HTS conductors



1 x 1 mm 2G HTS conductor (new)

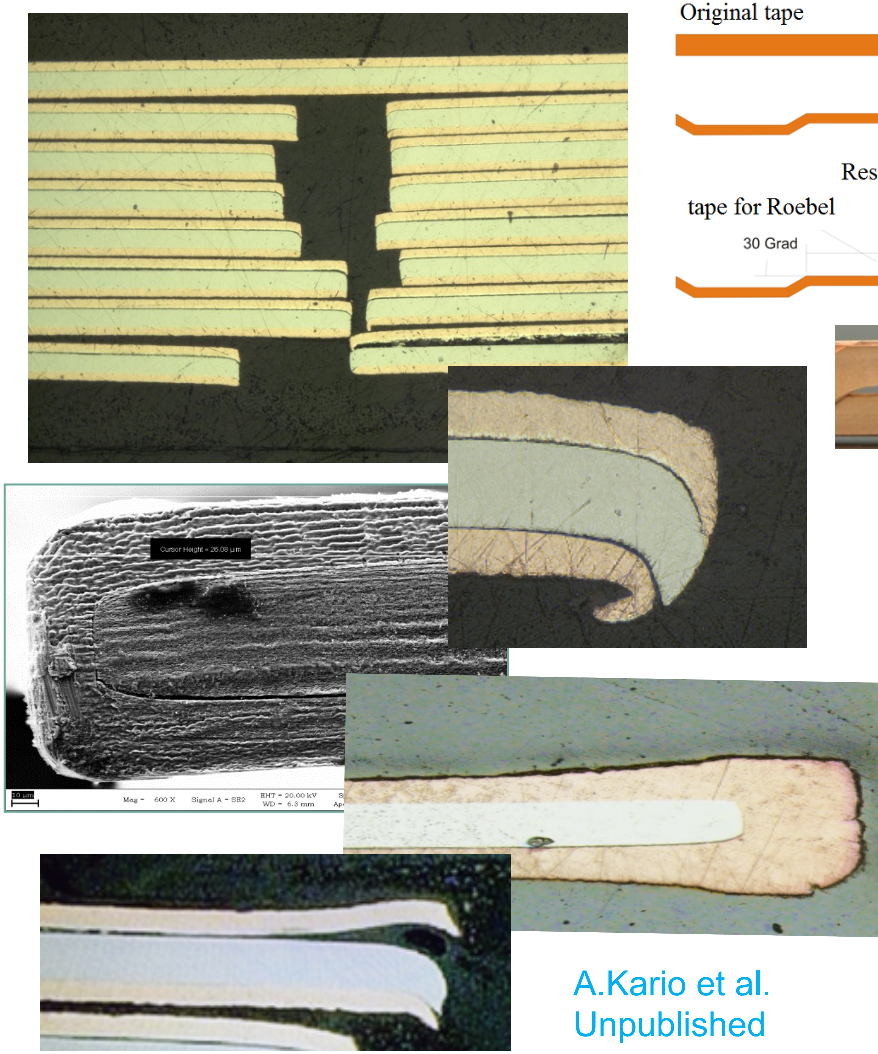
0.1 x 4 mm 2G HTS conductor (standard)

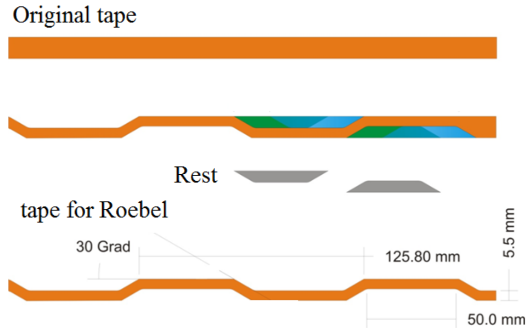


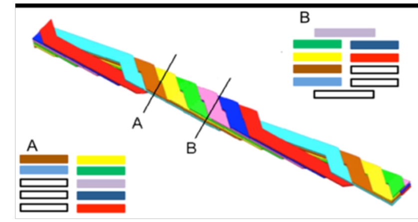


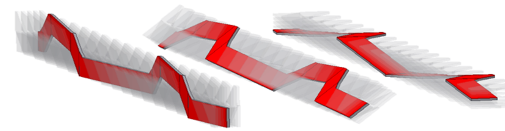
Preparation issues for HTS Roebel cables

Test of different coated conductors for Roebel approach (EUcard2-project)









A.Kario et al.
Unpublished

Key process: Strand punching !

- Dimension accuracy of CC (width, straightness, dog boning from Cu)
- Delamination sensitivity !!

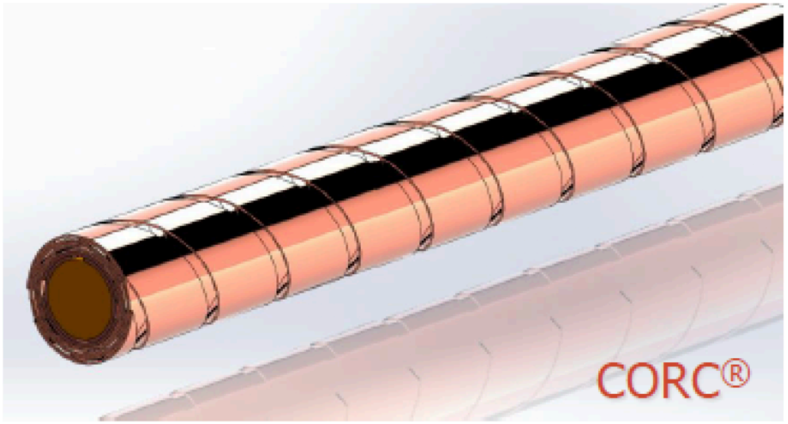
- High precision requires material specific punching tool (optimized gap tolerance)

- Switch to punch and coat process

CORC® wires using SuperPower tapes

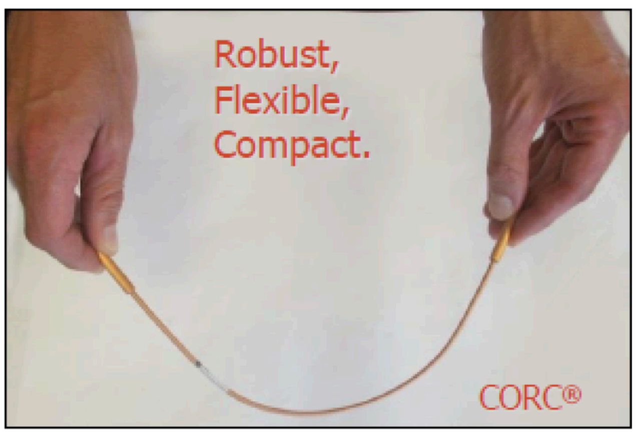
16 superpower tapes wound helically

- Copper core: 2.2 mm diameter
- 2 mm wide tapes with 30 µm substrate
- 6 mm twist pitch with partially transposed tapes for low AC loss
- Wire outer diameter: 3 mm
- Terminal diameter: 6.35 mm
- Nominal wire I_c: > 1,000 A (77 K)

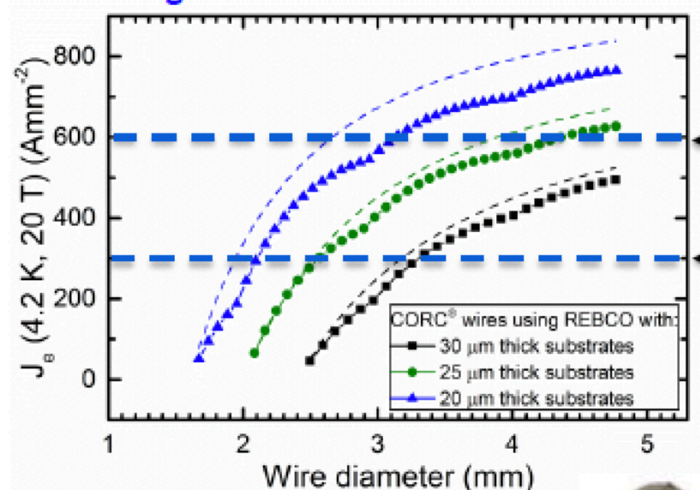


Applications

- High field magnets
- Accelerator magnets
- Fusion magnets
- High power density transmission



High magnetic field critical current density obtainable by increasing wire diameter and decreasing substrate thickness



Value desired for accelerator magnets such as CCT dipoles

Value desired for high-field research magnets

Advanced Conductor Technologies LLC
www.advancedconductor.com

Hisaki Sakamoto, MT25

Summary + Outlook

- Remarkable progress in CC quality, production stability and delivery, joints and cables
- Multiple suppliers for the various required conductor concepts exist
- A standard, full application ready CC available in long length incl. stabilization/insulation is still not routinely available
- Mechanical stability is often still an issue
- We will see soon broad availability of enough wire for first standard products
- Economy of scale has still to be worked out