

Progress in high-temperature superconducting CORC[®] accelerator magnet cable and wire development

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Introduction

Three major conductor challenges for >20 T HTS accelerator magnets

1. High engineering current density J_e (20 T) > 600 A/mm²
2. Small cable bending diameters 30 – 50 mm
3. Practical and low-risk means of making the magnets

CORC[®] cable principle

Winding many HTS YBCO coated conductors in a helical fashion with the YBCO under compression around a small former.



Initial CORC[®] cable development 2012-2015

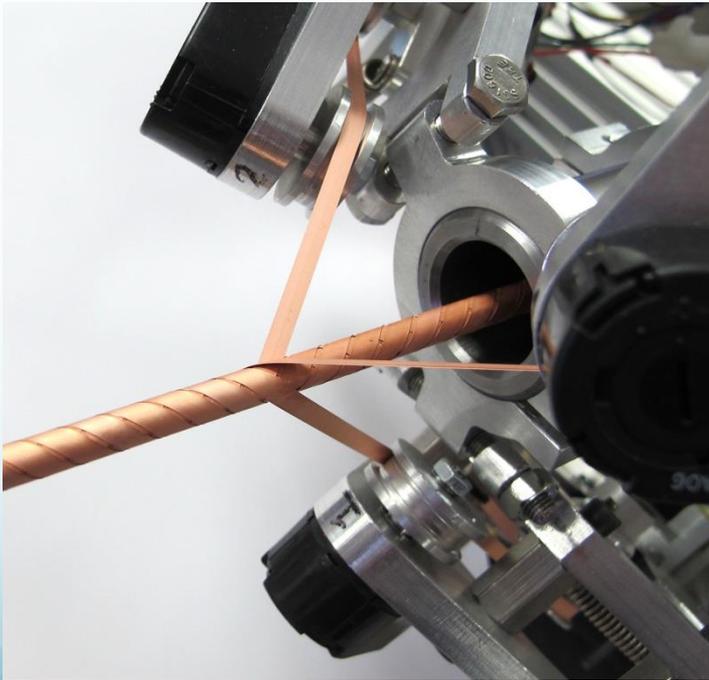
- Up to 50 tapes wound in 20 layers
- Tapes with 50 μm substrate and 10 μm copper plating
- Cable outer diameter 6-8 mm



CORC[®] cable machine

Winding of long CORC[®] cables with custom cable machine

- Accurate control of cable layout
- Winding tension control < 1 N
- Gap spacing variation < 0.1 mm
- Long cable lengths possible (> 100 meters)
- I_c retention after winding 95-100 %



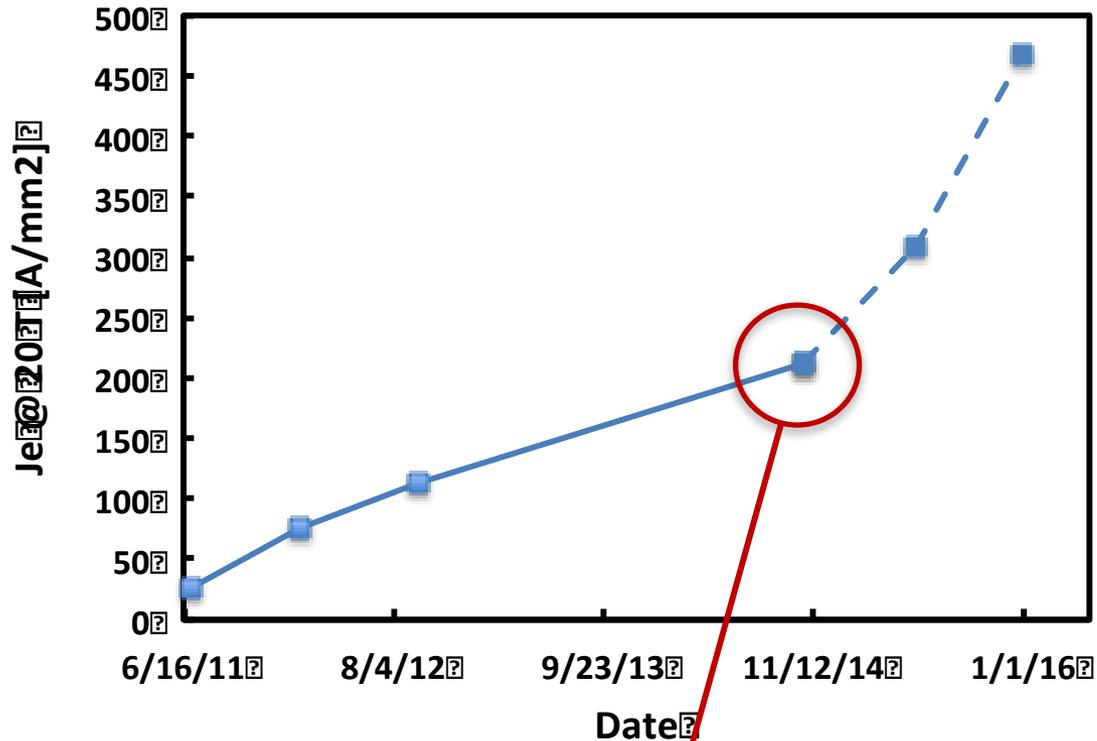
Commercial order from CERN

- 12 meter CORC[®] magnet cable
- Delivered August 2014



J_e projections as presented at LTSW 2015

Status of J_e (20 T) in CORC[®] cable presented at LTSW (Feb. 2015)



Large increase in J_e to 213 A/mm² @ 20 T

- CORC[®] cables wound with machine
- use of thinner substrate **38 μ m** instead of 50 μ m

38 μ m substrate

- higher tape J_e
- allows for thinner formers



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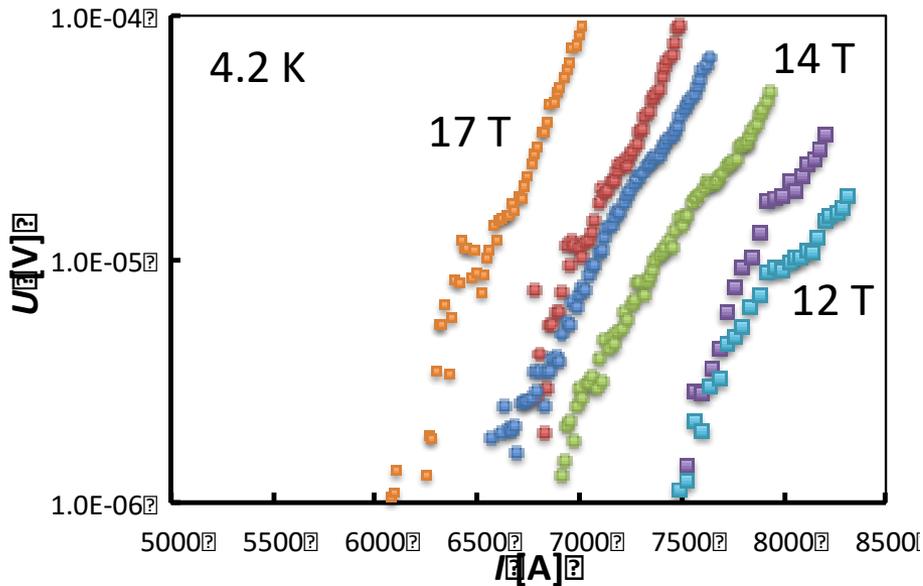
October 2015, CORC[®] cable with 30 μm substrate

CORC[®] cable



- 50 tapes with **30 μm substrate**
- 7.5 % Zr doping

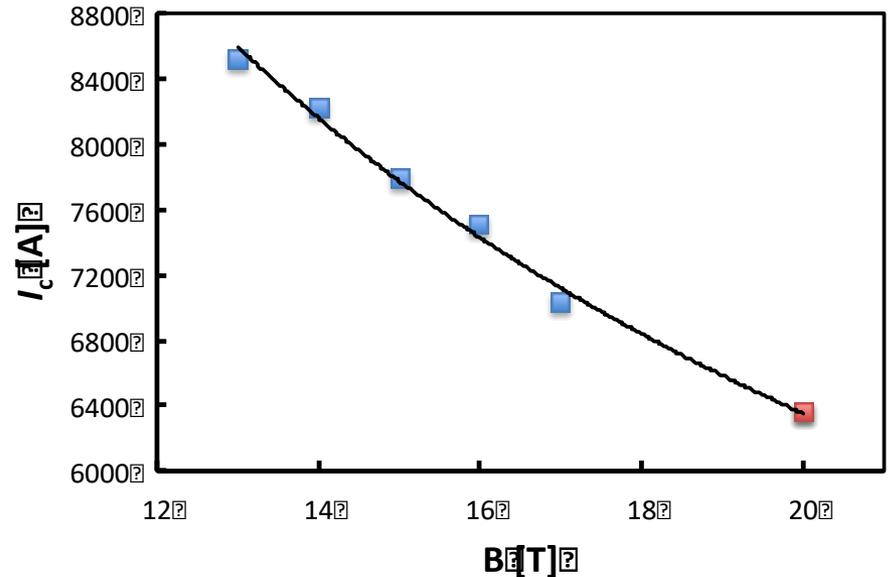
- 3 mm wide tape I_c (77 K) = 99 A
- cable outer **diameter 5.1 mm**



I_c (4.2 K, 17 T) = 7,030 A

J_e (4.2 K, 17 T) = 341 A/mm²

Still 30 % degradation due to lack of support



Extrapolated I_c (4.2 K, 20 T) = 6,354 A

Extrapolated J_e (4.2 K, 20 T) = 309 A/mm²

New record!

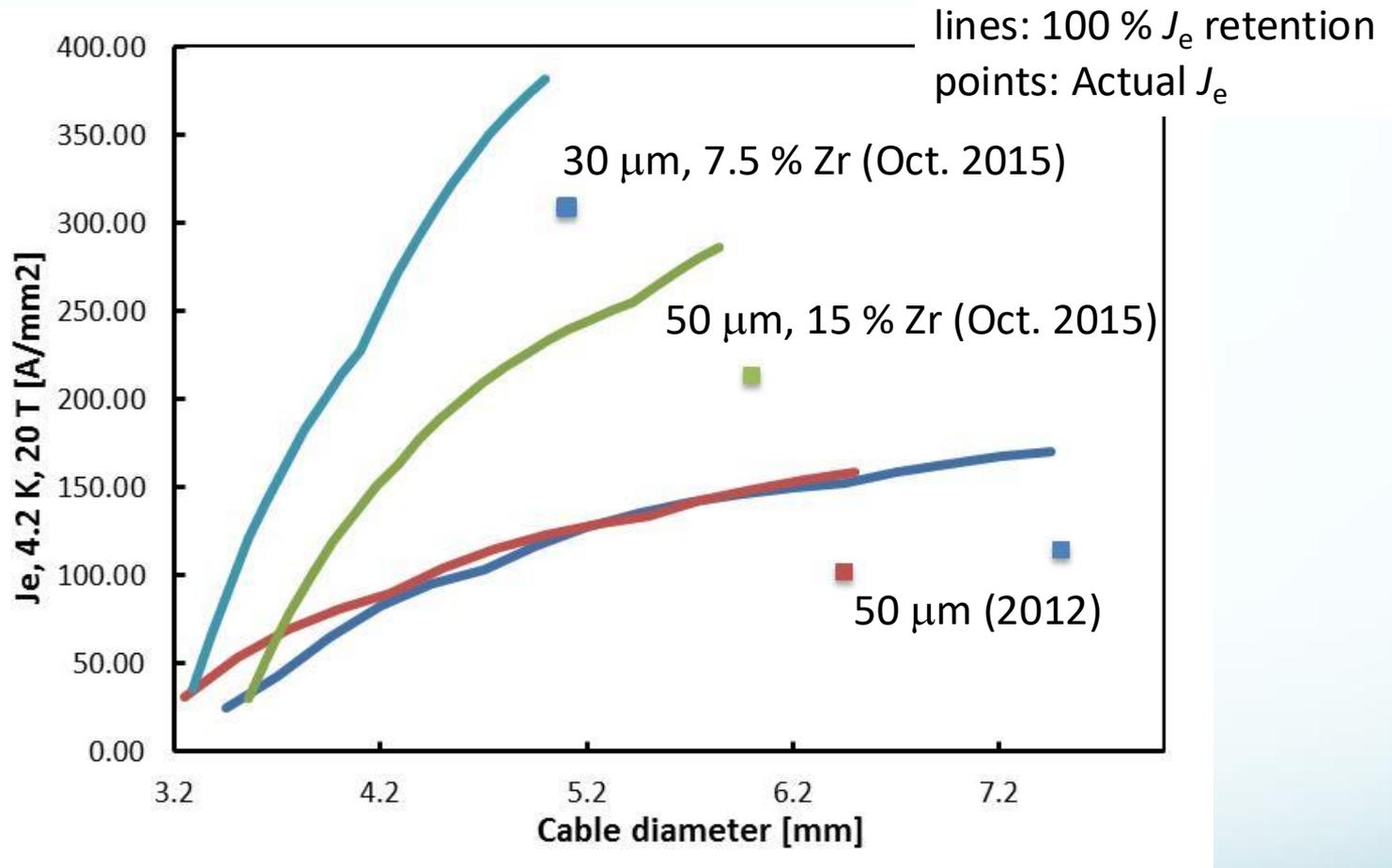


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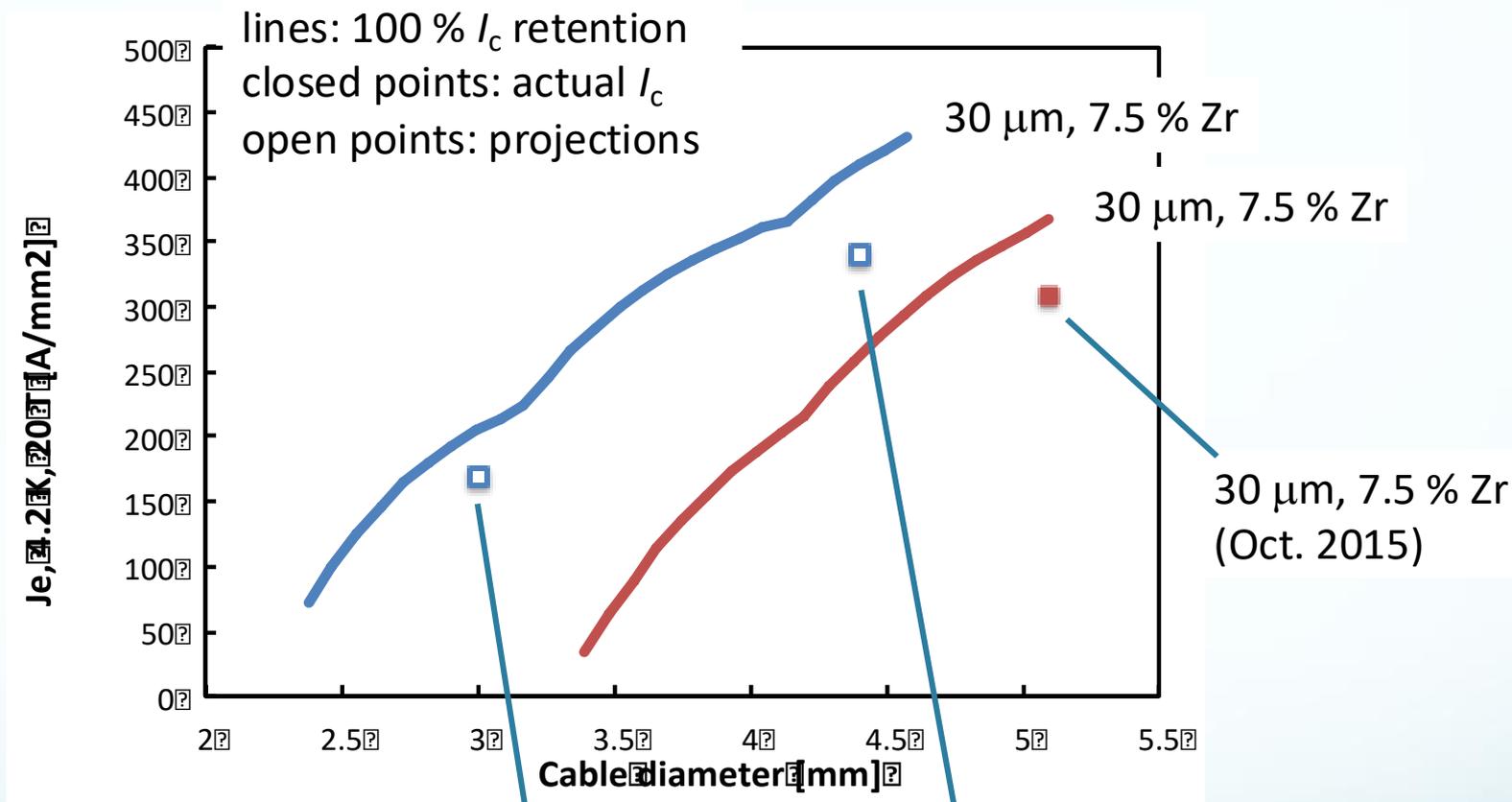
DOE-High Energy Physics
Awards DE-SC0009545, DE-SC0013723



CORC[®] cable $J_e(20\text{ T})$ current status



Development of CORC[®] wires needed for flexibility



Projections based on tapes
that we have in-hand

4.4 mm CORC[®] wire: $J_e(20\text{T}) = 350\text{ A/mm}^2$

3.0 mm CORC[®] wire: $J_e(20\text{T}) = 170\text{ A/mm}^2$



Development of CORC[®] magnet wires



CORC[®] cables

- tapes with 50 μm substrate
- O.D.: 5 – 10 mm
- tapes of 3 mm and 4 mm width

CORC[®] wires

- tapes with 30 μm substrate
- O.D.: 2.5 – 5 mm
- tapes of 2 mm and 3 mm width

First round, isotropic YBCO wire!

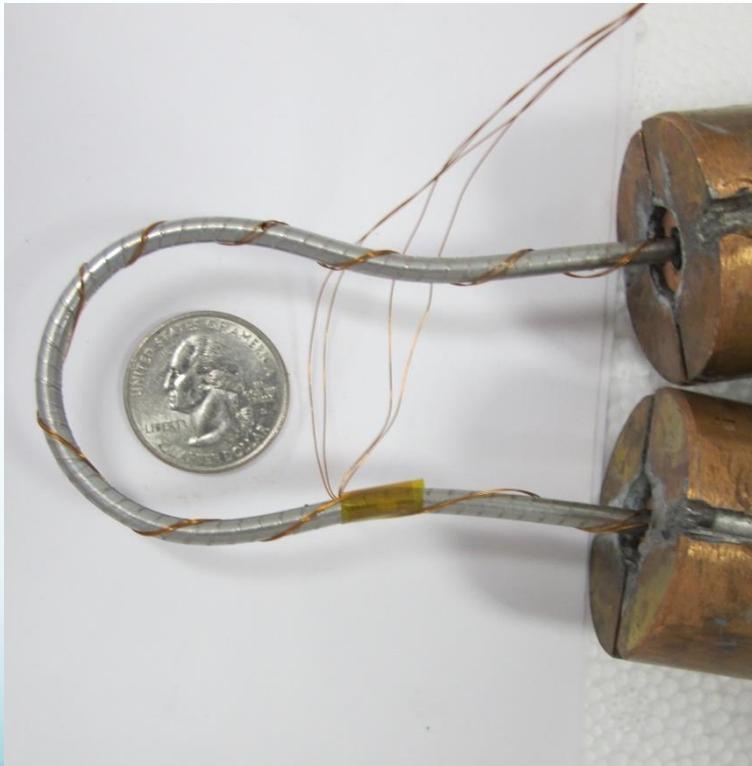


Testing the CORC[®] wire flexibility

CORC[®] wire layout

- A. 12 tapes of 2 mm width (3 mm O.D.)
- B. 24 tapes of 3 mm width (4.7 mm O.D.)

Bending wire followed by I_c measurement

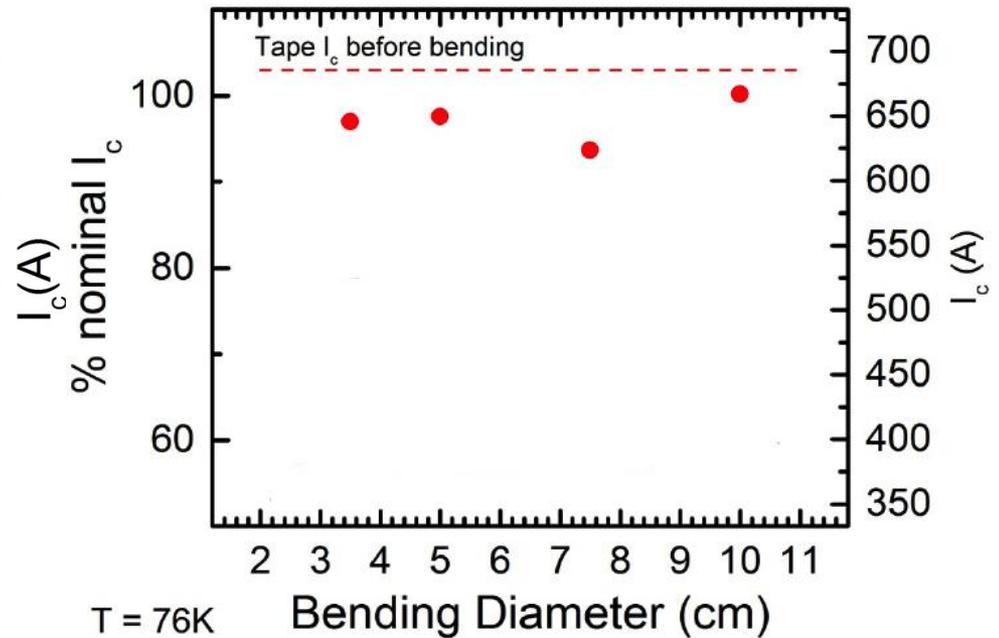
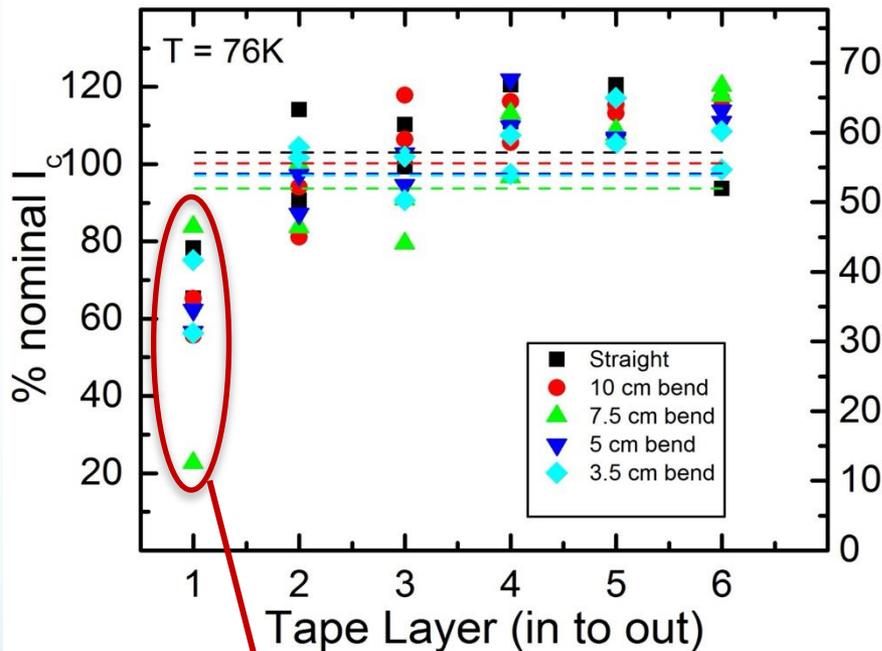


Bending wire sections followed by extracted tape I_c measurements



3 mm CORC[®] wire bending results

Bending wire sections followed by 2 mm wide tape I_c measurements

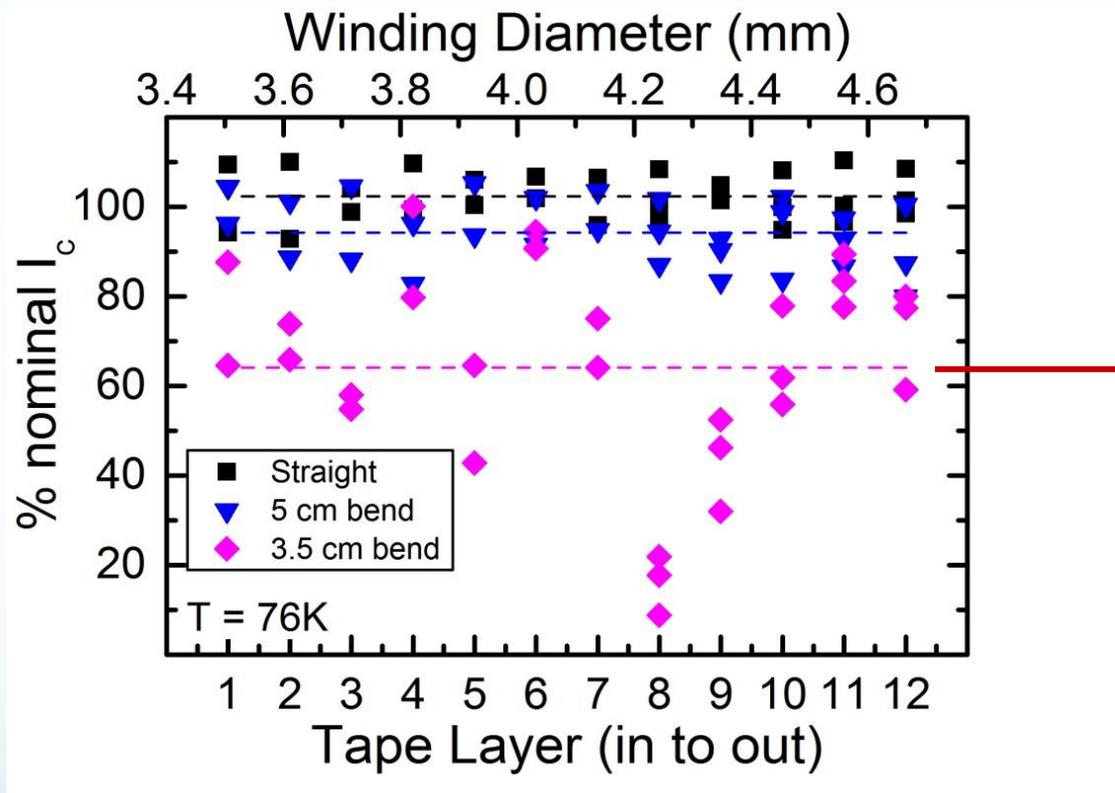


Degradation in inner layer due to surface roughness

> 93 % I_c retention even at 35 mm bending diameter

4.7 mm CORC[®] wire bending results

Bending wire sections followed by 3 mm wide tape I_c measurements



Degradation at 50 mm diameter due to closing of gaps between tapes

> 90 % I_c retention even at 50 mm bending diameter



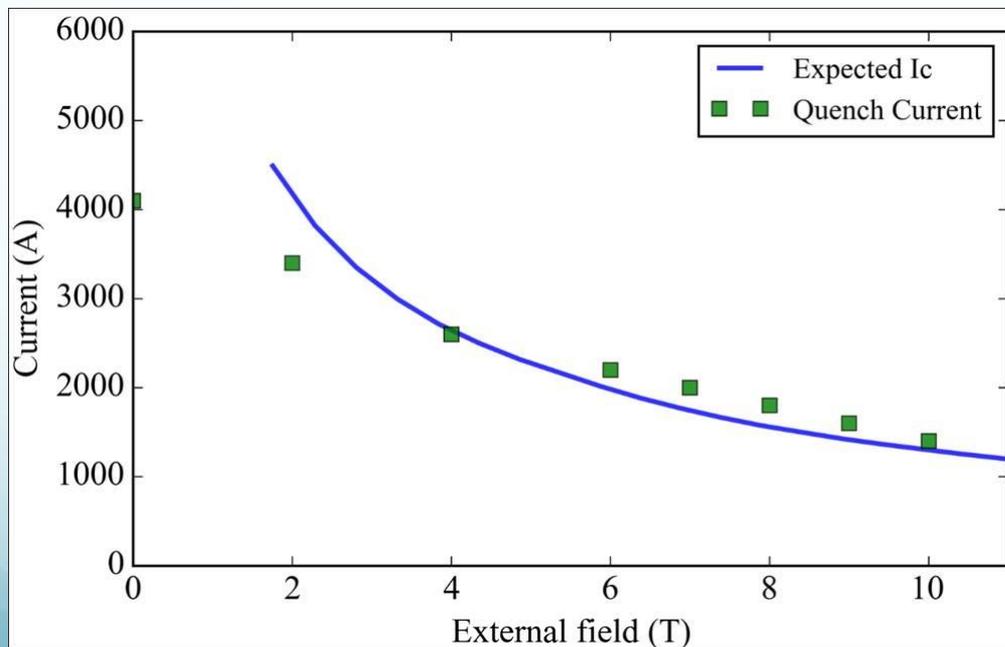
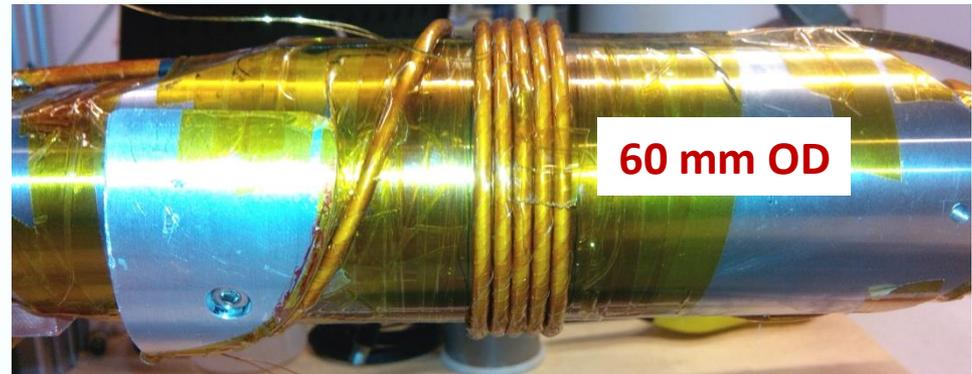
First in-field performance of CORC[®] wires

CORC[®] wire layout

- 16 tapes of 2 mm width
- 3 mm diameter

Test layout

- 5 turns at 60 mm diameter
- Stycast reinforcement



Results

- I_c 1,695 A (4.2 K 10 T)
- Projected J_e 145 A/mm² (20 T)

No significant degradation observed

2nd CORC[®] wire layout

- 24 tapes of 3 mm width
- 4.4 mm diameter
- test in coming weeks

UNIVERSITY OF TWENTE.



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DOE-High Energy Physics
Award DE-SC0009545

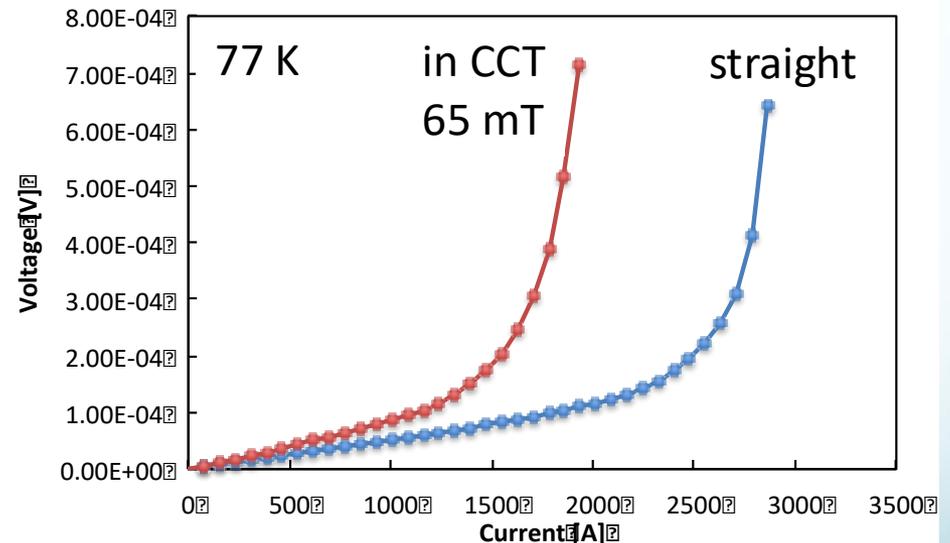
CORC[®]-based Canted-cosine theta magnet

CORC[®] wire layout

- 26 tapes of 3 mm width
- 4.5 mm diameter

CCT magnet layout

- 80 mm O.D.
- 60 degree angle
- 46 mm diameter bend



I_c (76 K) = 2,800 A (straight)

I_c (76 K) = 1,774 A (in CCT, 65 mT on wire)

J_e (20 T) expected at 280 A/mm²

DOE-High Energy Physics Award DE-SC0009545



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Summary

CORC[®] cable J_e on track to 600 A/mm² at 20 T

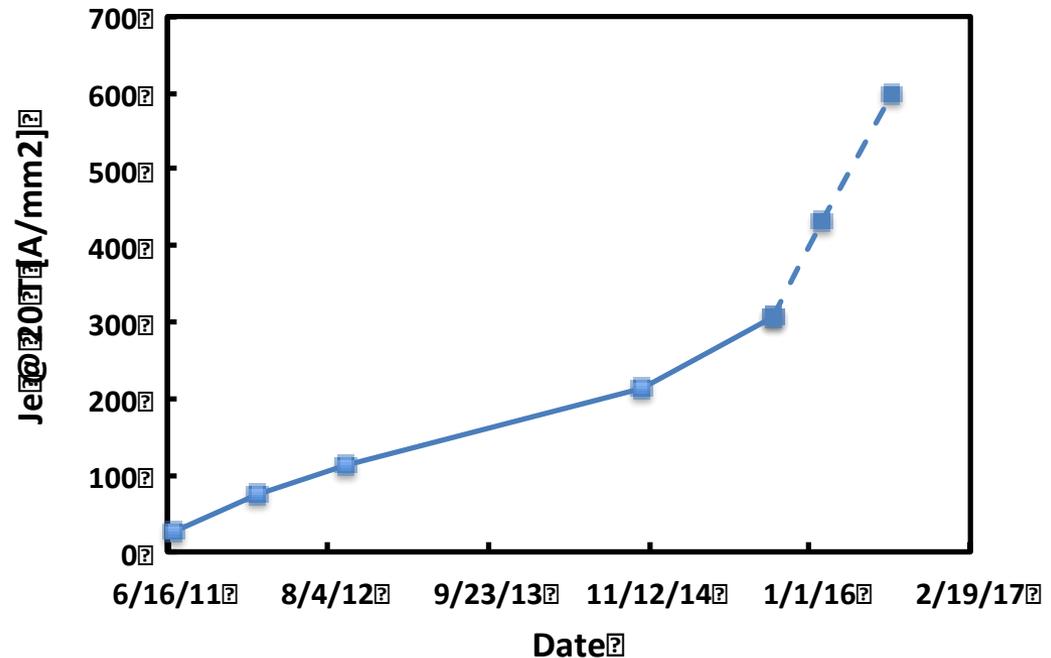
- J_e of 309 A/mm² at 20 T achieved
- J_e could have been 400 A/mm² when cable was supported properly
- Transition from 7.5 % Zr to 15 % Zr will result in $J_e(20\text{ T})$ 600 A/mm²

CORC[®] wires are now available

- Diameters of 2.5-5 mm
- Bendable to 30-50 mm diameter
- $J_e(20\text{ T}) > 300\text{ A/mm}^2$ in CORC[®] wires possible today

CORC[®] wires are practical!

- No reaction needed
- No handling of single tapes
- CORC[®] wires are ready for use in accelerator magnets



Many thanks to SuperPower for making the transition to 30 μm substrates!