Recent CORC® Progress

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CORC® magnet cables and wires

**CORC® wires (2.5-4.5 mm diameter)**
- Wound from 2-3 mm wide tapes with 30 µm substrate
- Typically no more than 30 tapes
- Highly flexible with bending down to < 50 mm diameter

**CORC® cable (5-8 mm diameter)**
- Wound from 3-4 mm wide tapes with 30-50 µm substrate
- Typically no more than 50 tapes
- Flexible with bending down to > 100 mm diameter

**CORC®-Cable In Conduit Conductor (CICC)**
- Performance as high as 100,000 A (4.2 K, 20 T)
- Combination of multiple CORC® cables or wires
- Bending diameter about 1 meter
$J_e$ in CORC® accelerator cables: current and future

CORC® cable $J_e$ on track to 600 A/mm² at 20 T
- .....  
- $J_e$ of 309 A/mm² at 20 T achieved in Oct. 2015

In-field CORC® cable testing @ 100 mm
- Large bore magnet at NHMFL (17 T)

![Graph showing $J_e$ growth over time]

Problems!
- NHMFL magnet decommissioned
Tests now need to be performed in-house!
In-house test facilities Univ. of Colorado

**In-field cable test setup**
- Several magnets: 12 T (80 mm cold bore), 14.5 T (56 mm bore)
- Currents exceeding 16 kA dc and fast ramping (> 1 MA/s)

**Mechanical testing setup**
- Transverse compression
- Axial tension
- Loads up to 10,000 lbs
- Including stress cycling >100,000 cycles
Record CORC® magnet wire performance

High-$J_e$ CORC® wire layout
- 50 tapes, 2-3 mm wide, 30 μm substrate
- 4.46 mm CORC® wire diameter
- 67 mm hairpin

- $I_c = 8,591$ A (4.2 K, 12 T, 1 μV/cm)
- Projected $J_e(20 \text{ T})$ between 379 and 429 A/mm²
- Projected $I_c(20 \text{ T}) = 6,500$ A
CORC® magnet cable and wire performance

CORC® cable tested at 100 mm diameter (2011 – 2015)

CORC® wire tested at 60 mm diameter (2016 – )

Design and picture
UNIVERSITY OF TWENTE.

Closing in on $J_e > 600 \text{ A/mm}^2$ goal
• $J_e$ (20 T) now exceeded 400 A/mm$^2$ in CORC® wire
• Combined with $I_{\text{gap}}$ (20 T) > 6,500 A
• Next step is thinner substrates 20 – 25 μm
• More details in Jeremy’s talk later today
**CORC® cable joint resistance 76 K**

**CORC® cable joint**
- 38 tapes, 10 layers
- 15 cm long joint, 100% In
- Different number of tapers

![Image of CORC® cable joint with V_tap](image)

- **Contact resistance lowest at full taper**
- **Joint R(76 K) = 96.8 nΩ**

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CORC® cable joint resistance 4.2 K

CORC® cable joint tested at 4.2 K
- Current up to 9,000 A
- Measured in self-field

- Contact resistance lowest at full taper
- Joint R(4.2 K) = 9.8 nΩ
- Factor of 10 lower than at 76 K
- CORC®-CICC (6 cables) suggest R=1.5 nΩ
- Further reduction possible
Common coil magnet from CORC® cables (SBIR Ph. I)

Magnet program with Brookhaven National Laboratory (Ramesh Gupta)
- Combine CORC® insert with 10 T LTS common coil outsert
- CORC® cable with expected $J_e(20 \, \text{T})$ 500 A/mm² delivered
- Operating current 10 kA connected in series with LTS outsert

Common coil benefits
- Only large bending diameters required
- Allowing CORC® cables to be used
- Allowing use of highest $J_e$ cables
The road to 21 T in CORC®-CCT magnets (SBIR Ph. 2)

Magnet program with Lawrence Berkeley Nat. Lab. (Xiaorong Wang)
- Develop a canted-cosine theta CORC® insert magnet
- Generate 5 T in a 16 T background field
- More details by Xiaorong Wang later today

Step 1: 2-Layer, 40-turns CCT magnet (C1)
- Generate 1 T in self-field
- CORC® wire $J_e(20 \text{T}) = 150-200 \text{ A/mm}^2$
- Learn to wind and protect CORC®-CCT magnets

Step 2: 4-Layer, 40-turns magnet (C2)
- Generate 3 T in self-field
- CORC® wire $J_e(20 \text{T}) = 200-300 \text{ A/mm}^2$
- CORC® wire bendable to 60 mm diameter

Step 3: 6-Layer, 40-turns CCT magnet (C3)
- Generate 5 T in self-field
- CORC® wire $J_e(20 \text{T}) = 300-400 \text{ A/mm}^2$
- CORC® wire bendable to 30 mm diameter
Baby coil C0a: CORC® wire test for CCT-C1

CCT C0a: CORC® wire with 16 tapes
- 2 Layers
- 3 Turns per layer
- Inner layer I.D. 70 mm
- Minimum bending diameter 50 mm

CCT C0a performance
- $I_c$ (77 K) = 646 A (layer A) and 675 A (layer B)
- $I_c$ (4.2 K) = 6,700 A (both layers)
CCT-C1 Magnet wound at LBNL
- 2 Layers, 40 turns per layer
- LBNL ordered 50 m of CORC® wire in 2016
- CORC® wire contains 16 tapes, $J_e$ (20 T) = ~150 A/mm²

CCT-C1 generated 1.2 T at 4,800 A (104% of expected performance)

$J_e = 640$ A/mm²

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BERKELEY LAB
Baby coil C0b: CORC® wire test for CCT-C2

CCT C0b: CORC® wire with 29 tapes
- 3-turn per layer
- Inner layer I.D. 85 mm
- CORC® wire $J_e$ (20 T) = $\sim$300 A/mm²

CCT C0b performance
- $I_c$ (77 K) = 1.092, 1,067 A (layer A, B)
- $I_c$ (4.2 K) = 12,141, 11,078 A (layer A,B)
- Dipole field 0.68 T (4.2 K)
- Peak $J_e$ (4.2 K) = 1,198 A/mm²
- Expected field of CCT-C2 (40 turns) $\sim$3-4 T

- Order for 75 m of high-$J_e$ CORC® wire received from LBNL
- Full-size coil C2 expected to be wound in Q2 2018
CORC® high-field insert solenoid (SBIR Ph. 2)

Magnet program with ASC-NHMFL (David Larbalestier, Dima Abraimov, Huub Weijers)
- Develop high-field insert solenoid wound from CORC® wires
- Test insert magnet at 14 T background field at ASC-NHMFL
- Aim for added field of at least 2-3 T, maybe 5 T depending on tape performance

![Diagram of CORC® high-field insert solenoid]

- Copper bus bars
- 14 T LTS outsert
- CORC® solenoid
**CORC® insert wire details**

**Coil 1 (Q2 2018)**
- Wound form ~17 meters of CORC® wire
- $I_{c_{pp}}$ (16 T) about 5,000 A
- $J_e$ (20 T) about 250 A/mm²
- Total of 48 turns in 4 layers
- Field generated 2.6 T in 14 T background

**Coil 2 (After coil 1)**
- Wound form 6-10 meters of CORC® wire
- Connected in series with Coil 1
- Goal is to generate 1.4-2.4T

<table>
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<tr>
<th>14 T</th>
<th>+ 2.6 T</th>
<th>58.8 mm</th>
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<td>80 mm</td>
<td>120 mm</td>
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<table>
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<tr>
<th>+ 1.4-2.4 T</th>
<th>= 18-19 T</th>
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<tr>
<td>58.8 mm</td>
<td></td>
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<tr>
<td>&lt; 55 mm</td>
<td>75 mm</td>
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Summary

Univ. of Colorado in-house cable test facility up and running
• Cable testing at up to 14.5 T and currents of 16 kA
• Mechanical testing up to 10,000 lbs, including cyclic loads

CORC® cables and wire performance
• In-house facility demonstrated $J_e(20 \text{ T}) = 400 \text{ A/mm}^2$ in 67 mm bending diameter
• $J_e(20 \text{ T}) = 600 \text{ A/mm}^2$ on the horizon
• CORC® cable joint resistance now < 100 nΩ at 76 K and < 10 nΩ at 4.2 K

CORC® cables and wires going into magnets
• Common Coil at Brookhaven Nat. Lab. (SIBR Phase I)
  • 500 A/mm² $J_e(20 \text{ T})$ CORC® cable delivered
• CCT 5 T (self-field) magnet at Lawrence Berkeley Nat. Lab (SIBR Phase II)
  • CCT-C1 (2x 18 meters CORC® wire): completed and tested at 1.2 T
  • CCT-C2 (4x 18 meters): CORC® wire in production
  • CCT-C3 first order design ready
• Insert solenoid magnet at the ASC-NHMFL (SIBR Phase II)
  • Coil 1 design complete: $I_{\text{opp}}(16 \text{ T}) = 5 \text{ kA}$
  • CORC® wire design complete and tested ($J_e(20 \text{ T}) = 250 \text{ A/mm}^2$)
  • Coil test anticipated Q2 2018 (magnet pit needs digging!)