High-temperature superconducting CORC® magnet cable and wire development and their application

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Outline

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2. Current status of CORC® cables
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7. Summary
CORC® magnet cables and wires

**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® 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 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
**“Current” (2015) CORC® cable performance**

**Winding CORC® cables**
- Accurate control of cable layout
- Long cable lengths possible
- $I_c$ retention after winding 95-100%
- 120 meters wound in 2016, of which 70 meter for commercial orders

**CORC® cable (measured 2015)**
- 50 tapes with 30 µm substrate
- 3 mm wide tape $I_c$ (77 K) = 108 A
- Lift factor $I_c(4.2K, 20T)/I_c(77K, s.f.) = 1.72$
- Bent to 100 mm diameter

Extrapolated $I_c$ (4.2 K, 20 T) = 6,354 A
Extrapolated $J_e$ (4.2 K, 20 T) = 309 A/mm²
Current CORC® cable performance (untested!)

Performance of commercial tapes
• Purchased 8,300 meters from SuperPower in 2016
• Tapes with 30 and 50 µm substrates

Record 2016 samples
• Lift factor $I_c(4.2\,K, 20T)/I_c(77K, \text{s.f.}) = 2.65$
• Typical lift factor (20 T) = 1.9
• $I_c (77\,K) = 167 \,A \,(4 \,mm, 50 \,\mu m)$
• $I_c (77\,K) = 82 \,A \,(2 \,mm, 30 \,\mu m)$
• Typical $I_c (4 \,mm) 150 \,A, (2 \,mm) 68 \,A$

CORC® cable Oct. 2015 $J_e(20\,T)$
• All estimates with $I_c$ retention of 70 %
• Typical $I_c$ and lift factor: $J_e(20\,T) = 375 \,A/mm^2$
• Highest $I_c$ and lift factor: $J_e(20\,T) = 560 \,A/mm^2$
• At 90 % $I_c$ retention: $J_e(20\,T) = 480-720 \,A/mm^2$
Common coil magnet from CORC® cables

Common coil SBIR Phase I program with Brookhaven National Laboratory

- CORC® cable common coil insert
- Combine with 10 T LTS common coil outsert

Common coil benefits

- Only large bending diameters required
- Allowing CORC® cables to be used
- Taking advantage of higher cost/performance ratio
High-$J_e$ CORC® wire layout

- 29 tapes, 2 mm wide, 30 µm substrate
- 3.6 mm diameter
- 5 turns on 60 mm diameter mandrel

- $I_c = 3,951$ A (4.2 K, 10 T, 1 µV/cm)
- Projected $J_e(20$ T) 250 A/mm²
Canted-Cosine-Theta magnets wound from CORC® wires

Canted-Cosine-Theta magnet program with Berkeley National Laboratory
• Conductor-friendly magnet design resulting in low stresses
• Delivers excellent geometric field quality in straight section and coil ends

CORC® CCT magnet program goals
• Reach 5 T in CORC® CCT insert with 10 T (15 T) LTS CCT outsert
• Develop the CORC® CCT magnet technology in several steps (C1, C2, C3)
Model coil C1-0: CORC® wire test for CCT-C1

CCT C1-0: CORC® wire with 16 tapes
- 2 Layers
- 3 Turns per layer
- Inner layer I.D. 70 mm
- Minimum bending diameter 50 mm

CCT C1-0 performance
- $I_c (77 \, \text{K}) = 646 \, \text{A} \, (\text{layer A})$ and $675 \, \text{A} \, (\text{layer B})$
- $I_c (4.2 \, \text{K}) = 6,700 \, \text{A} \, (\text{both layers})$
CCT C1 Magnet wound at LBNL

- 2 Layers
- 40 Turns per layer
- Total CORC® wire length about 40 m

Test at 4.2 K scheduled for September 2017
Model coil C2-0: CORC® wire test for CCT-C2

CCT C2-0: CORC® wire with 29 tapes
- 3-turn per layer
- Inner layer I.D. 85 mm
- Minimum bending diameter 60 mm

CCT C2-0 performance
- \( I_c (77 \text{ K}) = 1.092, 1,067 \text{ A (layer A, B)} \)
- \( I_c (4.2 \text{ K}) = 12,141, 11,078 \text{ A (layer A, B)} \)
- Dipole field 0.68 T (4.2 K)
- Peak \( J_e (4.2 \text{ K}) = 1,198 \text{ A/mm}^2 \)
- Expected field of CCT-C2 (40 turns) ~5 T

Coil B burned out at 12,400 A at 4.2 K due to unprotected quench
CORC® wire is being replaced to finalize testing
Full-size coil C2 expected to be wound in Q2 2018
**Final deliverable Phase II SBIR with ASC-NHMFL**

- 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
Racetrack coil from CORC® wire

Development of CORC® racetrack at CERN
• 8 meters of CORC® wire (29 tapes) delivered last week
• Racetrack with 2 layers and 8 turns per layer
• Coil performance of 0.38 T per kA
• Expected performance 4.5 kA at 10 T
45 kA (10 T) CORC®-CICC test in FRESCA (CERN)

45 kA (4.2 K, 10 T) 6-around-1 CORC®-CICC built at CERN
• 6 CORC® cables of 7.5 mm diameter
• 38 tapes per CORC® cable (commercial order 2014)

CORC®-CICC test results
• Power supply of FRESCA limited to 30 kA: no s.c. transition
• Test at 77 K in self-field: $I_c = 12.3\text{-}13$ kA as expected
80 kA (12 T) CORC®-CICC test in SULTAN

6-around-1 CORC®-CICC built at CERN
- Sample 1: fusion magnet CORC®-CICC forced flow cooling
- Sample 2: detector magnet CORC®-CICC conduction cooling
- Both rated at 80 kA at 4.2 K and 12 T

Test in SULTAN started last week and will continue September 18th.

See talk Tim Mulder later in this session
**Summary**

**CORC® cables and wires are maturing into magnet conductors**
- CORC® cable performance 10 kA and 300-500 A/mm² at 20 T
- CORC® wire performance 2-3 kA and 250-350 A/mm² at 20 T

**Magnet programs aimed at CORC® cables and wires**
- Common coil magnet (Brookhaven National Laboratory)
- Canted-Cosine-Theta magnets (Berkeley National Laboratory)
- Solenoid insert coil (National High Magnetic Field Laboratory)
- Racetrack coil (CERN)

**CORC®-CICC development**
- 80 kA CORC®-CICC currently being tested in Sultan
- Results expected middle of September 2017