Development of high-temperature superconducting Conductor on Round Core magnet cables

Danko van der Laan
Advanced Conductor Technologies & University of Colorado
Boulder, Colorado, USA

Fraser Douglas
Advanced Conductor Technologies, USA

Xifeng Lu
University of Colorado, USA

Leslie Bromberg, Phil Michael & Joe Minervini
Massachusetts Institute of Technology, USA

Ulf Trociewitz, Patrick Noyes, George Miller & Huub Weijers
National High Magnetic Field Laboratory, USA
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Conductor on Round Core cables

**CORC cable principle:**
Winding many high-temperature superconducting YBCO coated conductors from SuperPower in a helical fashion with the YBCO under compression around a small former.

**Benefits:**
- Very flexible
- Very high currents and current densities
- Mechanically very strong
- Minimal degradation from cabling (< 10 %)
- Current sharing between tapes possible
CORC cable machine

Winding of long CORC cables:
- winding CORC cables layer-by-layer
- accurate control of:
  1. tape tension
  2. winding angle
  3. spacing between tapes

Long, high-quality CORC cables are now available!!!
Goals include:

- Cable operating current larger than 30 kA at 4.2 K and $B > 12$ T.
- Allowing for operation at high $\frac{dI}{dt} > 1000$ A/s
- Ensuring reliable operation under mechanical loads
- Develop reliable CORC cable terminations
Cables tested at the NHMFL in 19.8 T background field:
52 YBCO coated conductors, 17 layers, **cable O.D. 7.5 mm**:

\[ I_{\text{quench}} = 6000 \text{ A} @ 4.2 \text{ K}, 19 \text{ T} \]
\[ I_c = 5021 \text{ A} @ 4.2 \text{ K}, 19 \text{ T}, 1 \mu\text{V/cm} \]
\[ J_e = 114 \text{ A/mm}^2 @ 4.2 \text{ K}, 19.0 \text{ T} \]
High-current ramp rates at 19 T

Will current distribution become inhomogeneous in cables with many layers at high current ramp rates?

Cable: 52 CC in 17 layers.

Current ramp rates at 4.2 K, 19 T to 90 % of $I_{\text{quench}}$:
- 2017 A/s
- 9500 A/s

No effect of high current ramp rates!
High-current CORC cables for fusion magnets

CORC triplet rated at potentially $3 \times 5 \text{kA} = 15 \text{kA}$ at 4.2 K, 19 T.

CORC 6-around-1 rated at potentially $6 \times 5 \text{kA} = 30 \text{kA}$ at 4.2 K, 19 T.
Development of CORC cable terminations

Conical terminals: $R = 36 \text{ n}\Omega \ (76 \text{ K})$

Solder-filled terminals: $R = 225 \text{ n}\Omega \ (76 \text{ K})$

Both types show signs of current redistribution.
Slightly larger copper tube is placed over the cable, allowing for some expansion of the tapes:

Terminals are filled with solder to make electrical contact.

Tapering of layers in cable may reduce contact resistance.

Benefits include: ease of installation and small size.
Contact resistance increases with current when more layers are filled with current, but resistance is relatively low.

38-tape cable:

\[ I_c = 3913 \, \text{A}, \quad n=22 \]
\[ R = 209 \, \text{n}\Omega \, (76 \, \text{K}) \]

29-tape cable:

\[ I_c = 1959 \, \text{A}, \quad n=17 \]
\[ R = 304 \, \text{n}\Omega \, (76 \, \text{K}) \]
Terminating a CORC-CICC

Terminals for a 6-around-1 CORC-CICC:

Terminals could be the same diameter as that of the cable jacket.
CORC cables for accelerator magnets

Goals include:

- Improving the CORC cable flexibility to allow bending to 4 cm diameter
- Raising $J_e$ at 4.2 K and 20 T to exceed 600 A/mm$^2$
Improved CORC cable flexibility

Irreversible degradation of only 2.5 % due to bending to 40 mm diameter!
CORC $J_e > 100 \text{ A/mm}^2$ at 20 T and 6 cm diameter

Cable:
- 37 YBCO CC, 14 layers
- cable O.D. 6.4 mm

$I_c = 3989 \text{ A (10 cm)}$ 3967 A (6 cm)@ 4.2 K, 15 T ($J_e = 122 \text{ A/mm}^2$)
Expected $J_e = 103 \text{ A/mm}^2$ @ 4.2 K, 20 T

No degradation when bending from 10 cm to 6 cm: $J_e(20\text{T}) = 103 \text{ A/mm}^2$!
CORC cable $J_e$ projections relevant for accelerators

Improved $J_e$ at 20 T due to reduced substrate thickness:

Roughly 50% improvement of $J_e$ when using 30 microns substrate. CORC cable with 300 A/mm$^2$ is less than 5 mm in diameter!
Thinner substrates are coming!

“Advanced Conductor Technologies has been eagerly awaiting this new, thinner profile conductor for incorporation into our high current density Conductor on Round Core (CORC) cable,” said Dr. Danko van der Laan, founder and chief executive officer of the start-up company located in Boulder, Colorado…”

http://superpower-inc.com/content/superpower-adds-thinner-substrate-options-superconducting-wire-offerings
Summary

CORC cables are being developed for fusion magnets with aim:

1. Operating current of 60 kA at 20 T
2. Mechanical strength to minimize degradation during field/current cycling
3. Low-resistance terminations

CORC cable development for accelerator magnets aims at:

1. Improving the CORC cable flexibility to allow bending to 4 cm diameter
2. Raising $J_e$ at 4.2 K and 20 T to exceed 600 A/mm$^2$

High-quality CORC cables can now be delivered in long lengths!

danko@advancedconductor.com  +1-720-933-5674