25 K performance of conduction-cooled solenoids wound from exfoliated filament YBCO cables

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Outline

- Introduction to ExoCable technology
- Mini coil test results: 77 K and 25 K
- Flux dynamics at 25 K and effect of temperature gradients
- Conclusion and future work
Motivation: **we need** defect tolerant cable

Across-tape defects

- Deposition malfunction

Some defects emerge during coil operation

Along-tape defects

Epitaxy failure

✓ Avoiding defects in YBCO layers is difficult
✓ Some defects are hidden, get revealed only after coil tests

Courtesy of Anatolii Polyanskii
NHMFL

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Solution: electrically coupled cable

We are solving the following problems:

- Single-filament magnets proven difficult to protect against burnout
- Substrate prevents efficient current sharing
- Multifilamentary cable is far more expensive than a single tape
- Not compatible with epoxy impregnation

2G wire stack

BTG exfoliated filament stack
Multi-filamentary cable architecture

 Nichrome cladding

 Copper stabilizer

 Solder

 YBCO

 ✓ Electrically connected filaments are the key element
Test coil manufacturing process

- **Dry wound**
- **Vacuum impregnation, Stycast 1266**
- **Cooling collar attached**

**Upper current lead**

**Voltage taps**

**Voltage taps**

**12 coils, over 100 meters of cable tested**
77 K performance after re-flow and impregnation

- No Ic and n-value degradation after multiple rapid cool-downs to 77 K
- Solder re-flow significantly reduces the winding noise, but reduces Ic by 8%
Winding magnetization: flux penetration model into a coupled cable, highly anisotropic filament

- Cross-filament loop (coupling currents)
- Cross-filament dipole
- Persisting current loop (in-plane currents)
- In-plane dipole (same as in pancakes)
- Axial field, $H_a$
- Radial field, $H_r$
- In-plane dipole
- Shields $H_r$, subtracts from $H_s$
- Solenoidal field $H_s$
- Cross-filament dipole
- Shields $H_a$, adds to $H_s$ in the bore
Central field hysteresis at 77 and 25 K

At 22 K field dynamics is defined by relaxation at high currents
Flux dynamics at 77 and 25 K

Completely different field settling profile at 77 and 25 K.
Heat migration from the current leads and effect on the field quality

- Winding temperature gradient are responsible for the field decay

![Image](image_url)
Proposed cryocooled rectifier

Traditional approach

AC power  Transformer  Rectifier  Magnet coil

Vacuum vessel  Cryogenic environment

Proposed Cryo-cooled rectifier

High voltage, low current leads  Low voltage, high current leads
Mechanical design of the current management system

![Diagram](image.png)
System cooldown, cryogenic current drive

Lighter high-voltage input introduces very little conduction loss
Powering a double-pancake coil with a cryogenic current drive

✓ Significantly reduced hysteresis
Conclusion and future challenges

Conclusion:
- Demonstrated operation of epoxy-impregnated multi-filamentary cable in conduction cooled mode
- Winding magnetization at 25 K is strongly affected by thermal gradients, due to heat leakage trough current leads
- Cryogenic current drive reduced hysteresis

Future challenges
- Scale-up of the filament handling
- Continuous splicing
- Designing interleaved multi-module current drive