

Development of High-Temperature Superconducting CORC® Power Cable Systems

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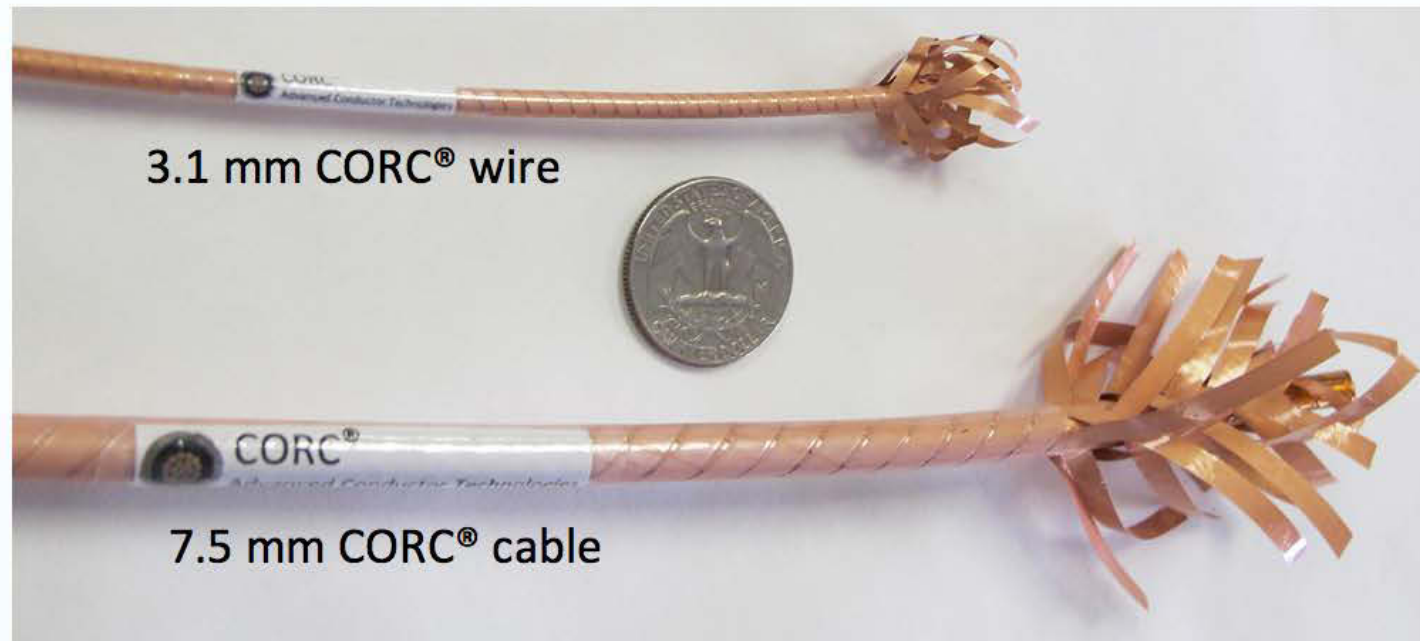
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Helium Gas Cooled CORC® Power Cables and Wires



Typical CORC® cable

- 7.5 mm diameter cable with 42 tapes
- I_c (77 K) = 4,500 A, J_e (77 K) = 100 A/mm²
- I_c (50 K) = 18,000 A, J_e (50 K) = 400 A/mm²

Typical CORC® wire

- 3.6 mm diameter wire with 29 tapes
- I_c (77 K) = 2,000 A, J_e (77 K) = 200 A/mm²
- I_c (50 K) = 8,000 A, J_e (50 K) = 800 A/mm²

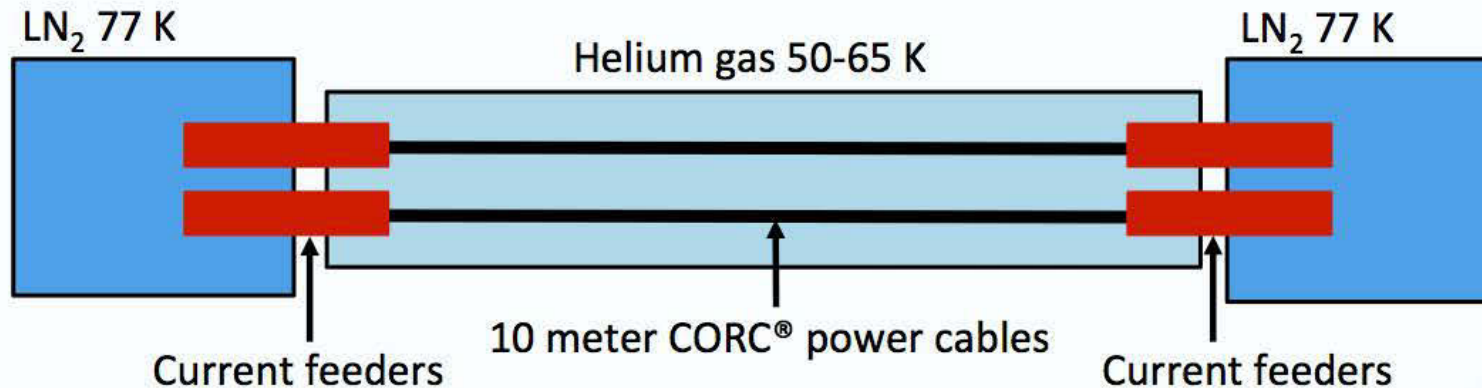


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CORC® Power Transmission Cable Systems



System specifications

- 2-Pole dc CORC® power cables rated 4 kA/pole
- Operating temperature 50 K in helium gas

Components

- 10-meter long, 2-pole dc CORC® power cable
- All cryogenic hardware
- Current feeders between LN₂ and GHe environment
- Connectors between feeder and power cables



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CORC[®] Power Cable and Terminations

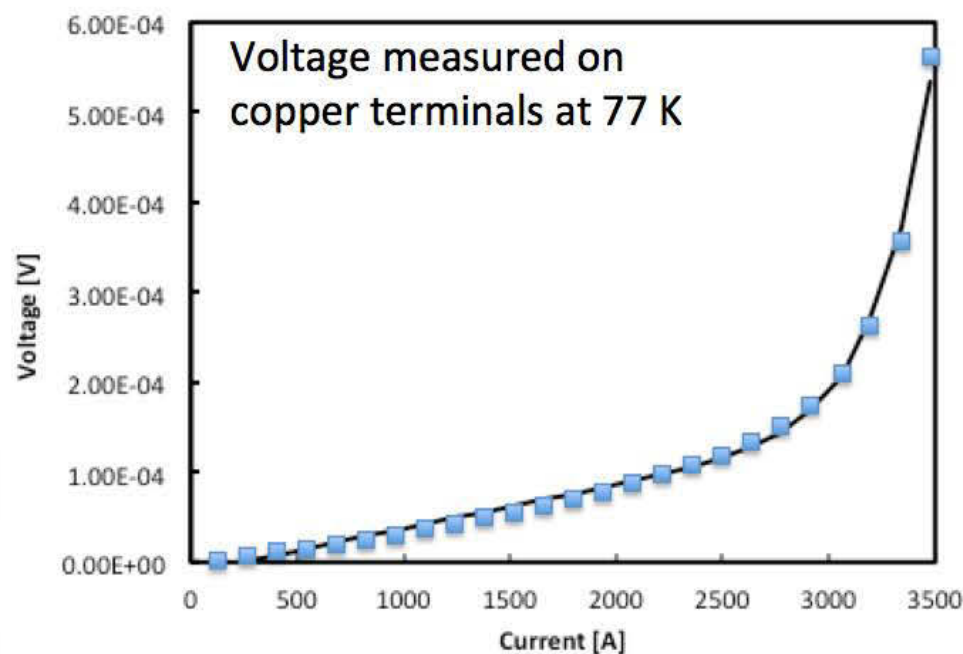
CORC[®] power transmission cable

- Designed with I_c to exceed 2,400 A at 77 K
- Expected I_c at 50 K > 10,000 A



CORC[®] cable terminations

- Capable of injecting large currents
- Low contact resistance < 25 nΩ



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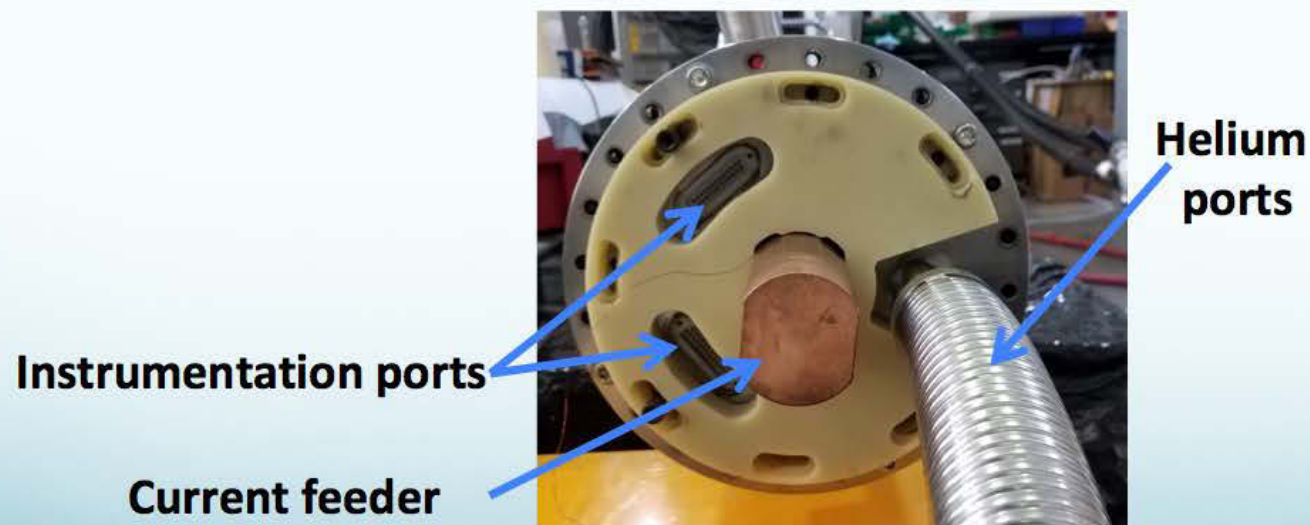
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CORC® Power Cable and Connector Test at 60 K

Short cable testing at CAPS

- 1.5 meter rigid cryostat
- 20 bar maximum helium gas pressure
- Maximum flow rate 8-10 g/s

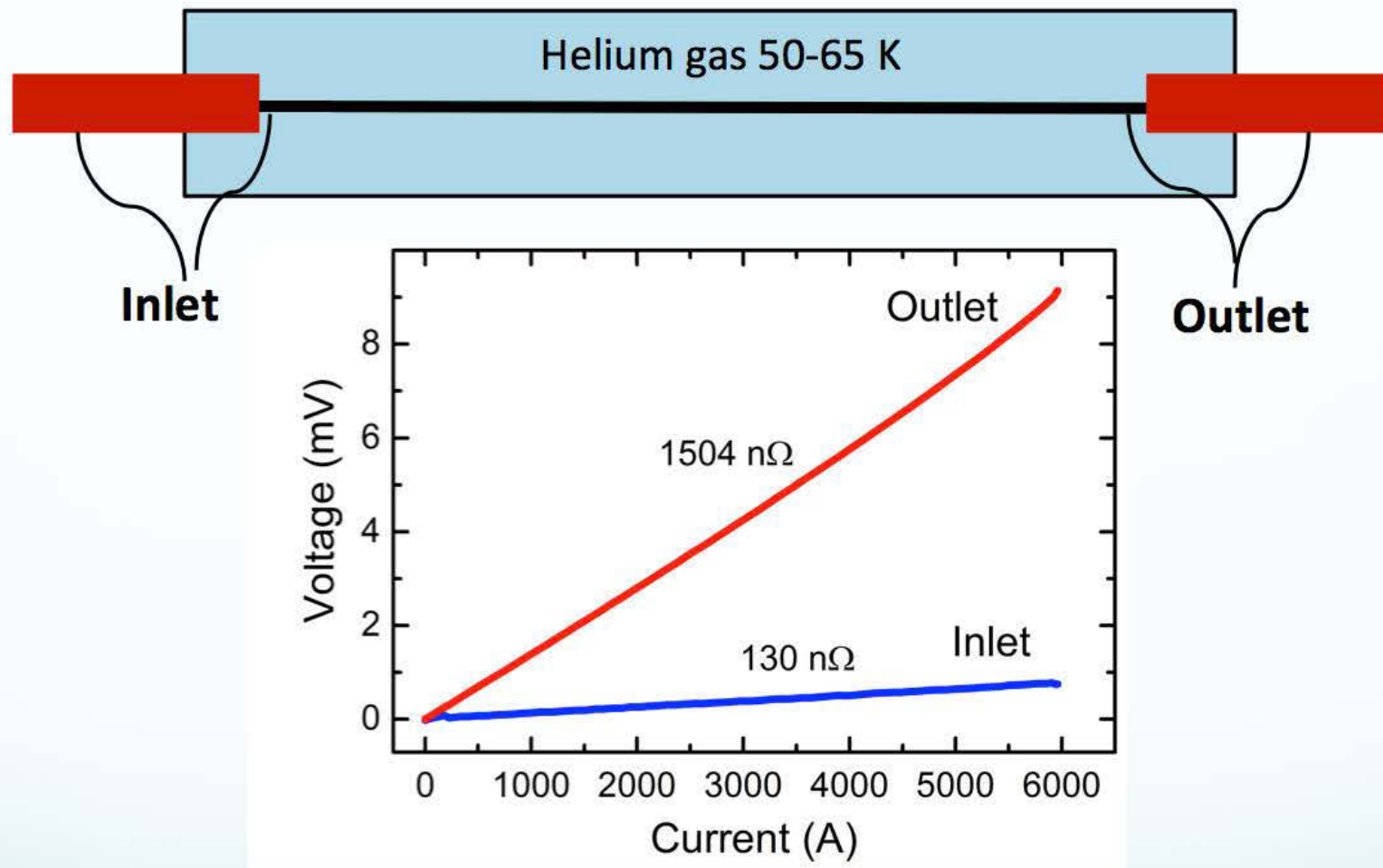


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CORC® Cable System Contact Resistances 60 K



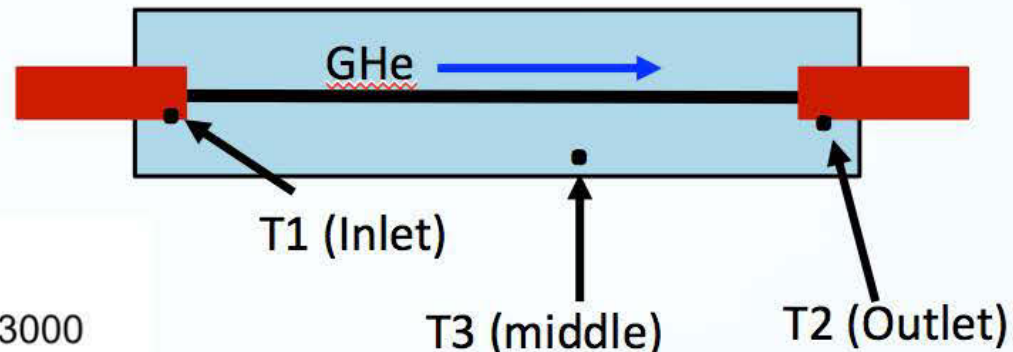
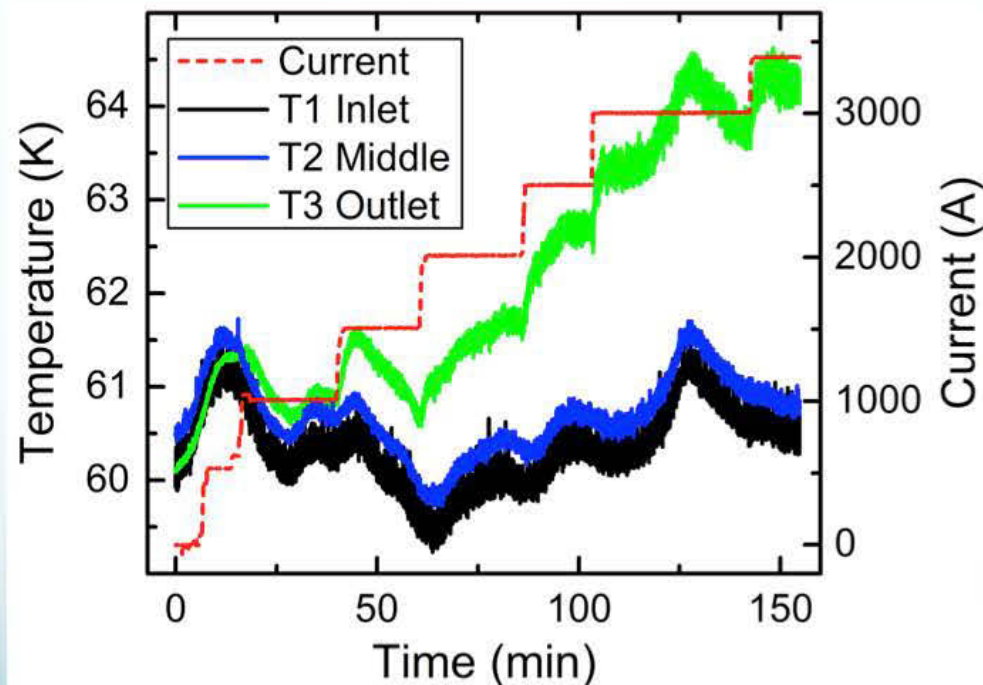
- **Contact resistance inlet side: 130 nΩ**
- **Contact resistance outlet side: 1,500 nΩ**
- **Dissipation at 6,000 A: 4.5 W**
- **Dissipation at 6,000 A: 52.5 W**
- **Due to connection between power cable and current lead**



CORC[®] System Temperature to 3,300 A

Helium gas inlet temperature 60 K

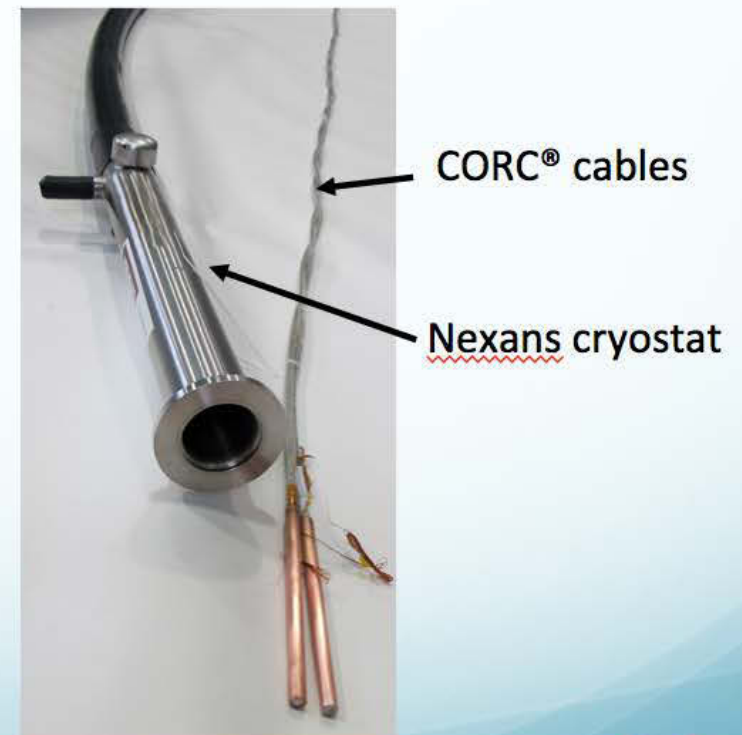
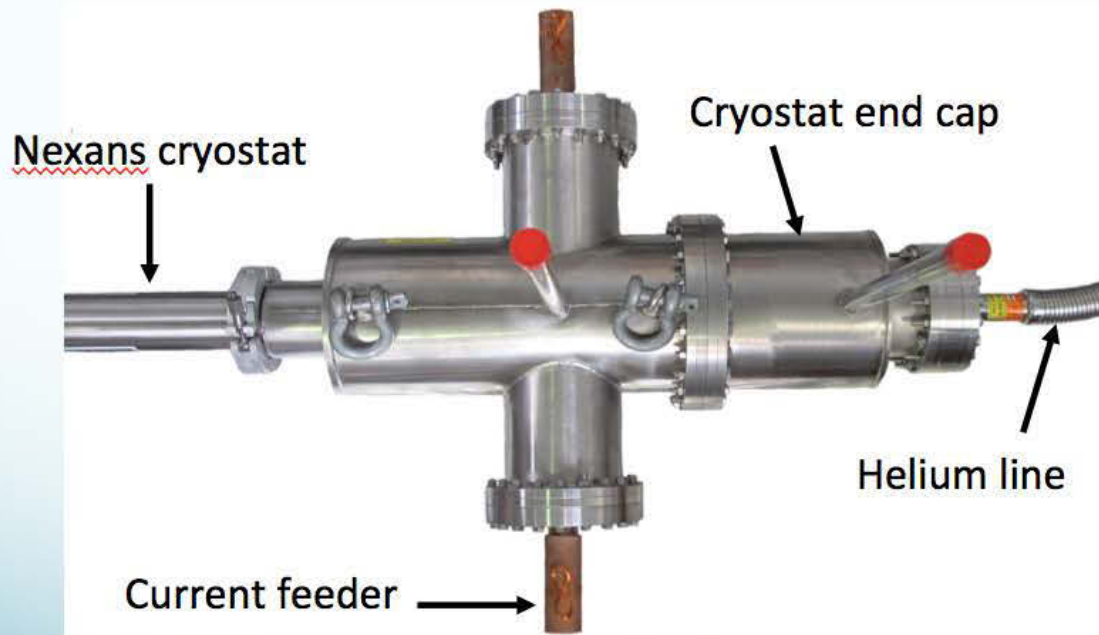
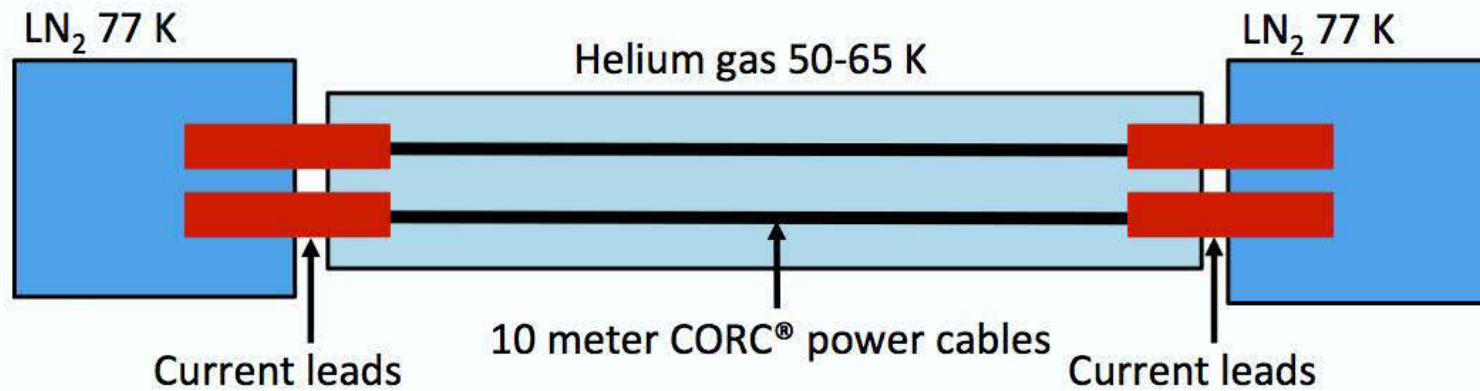
- Current ramped stepwise with 500 A every 20 minutes
- Maximum current of 3,300 A
- Total time at current 2.5 hours
- Helium flow is 5 g/s at 60 K



- **Temperature stable within 0.5 K**
- **Connector at outlet heats up at currents exceeding 1,000 A**
- **Connector will be closed better in final cryostat**
- **Current limited to 3,300 A due to copper cables to power supply**



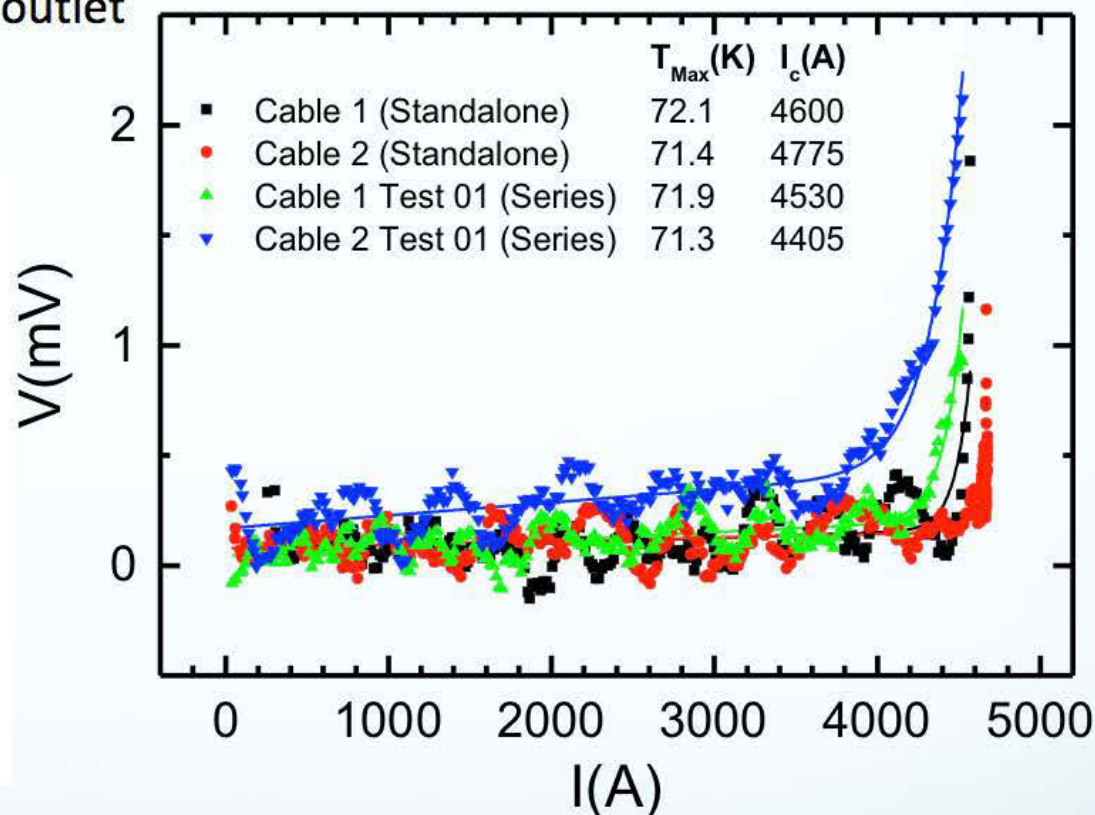
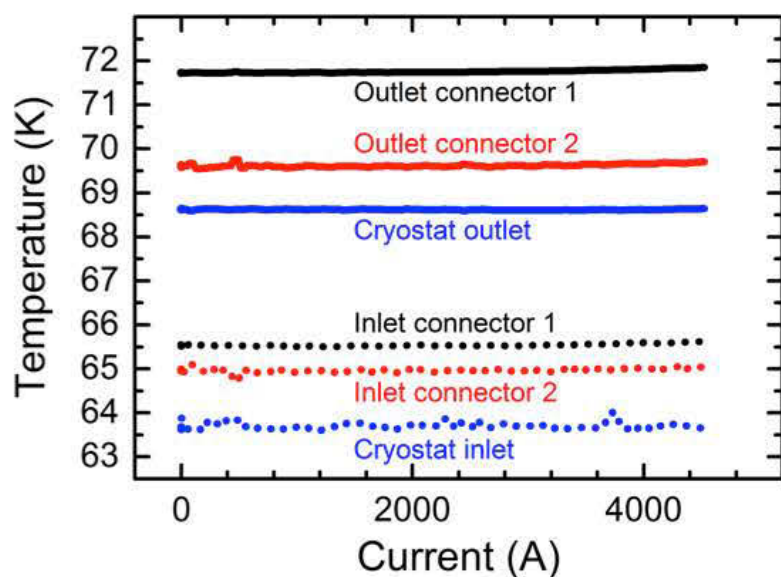
10-Meter 2-Pole CORC[®] DC Power System



10-Meter 2-Pole CORC[®] System Test

Test procedure

- Cool-down to 64 K inlet, and 72 K outlet
- Test each phase individually
- Test phases connected in series



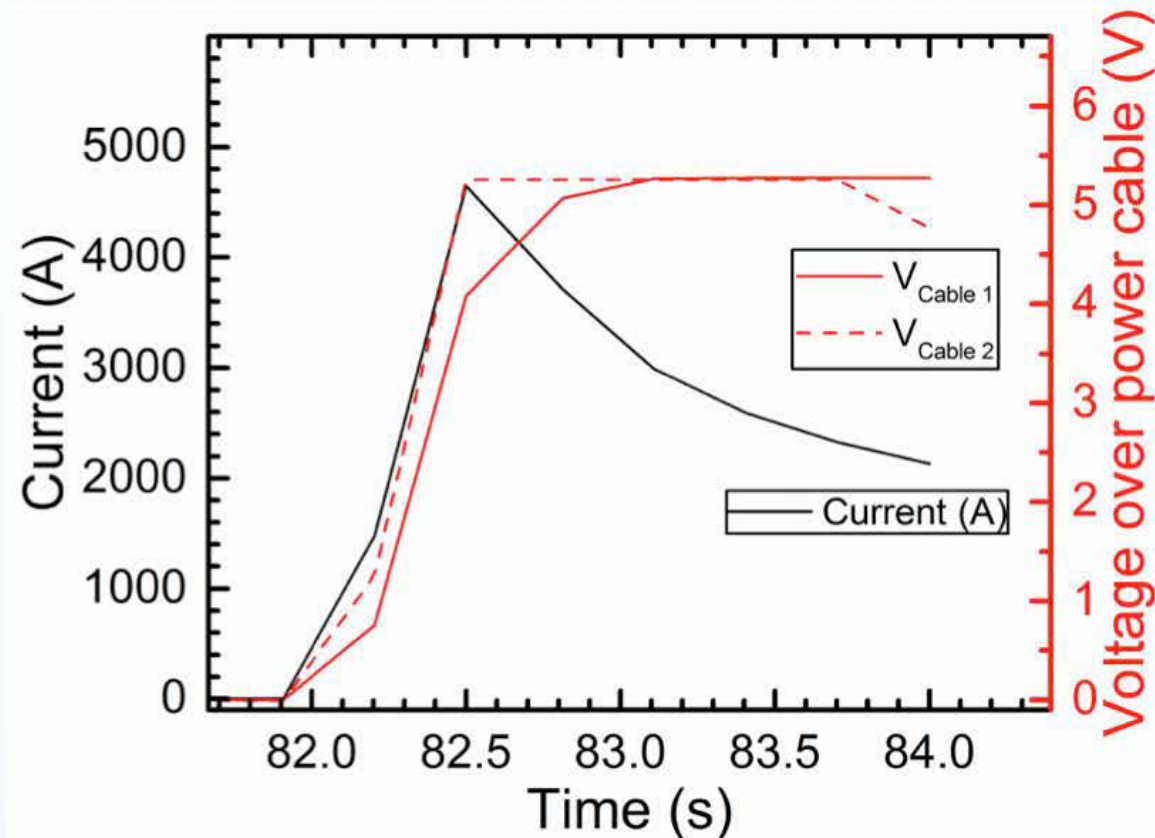
- Individual cable tests I_c (Cable 1) = 4,600 A, I_c (Cable 2) = 4,775 A
- Series connected cable tests I_c (Cable 1) = 4,530 A, I_c (Cable 2) = 4,405 A
- Results suggest that I_c at 50 K would be > 10,000 A



CORC[®] Power Cable Overcurrent Test

Fault Current Limiting Test

- Current to 6,000 A
- 10 V supply voltage



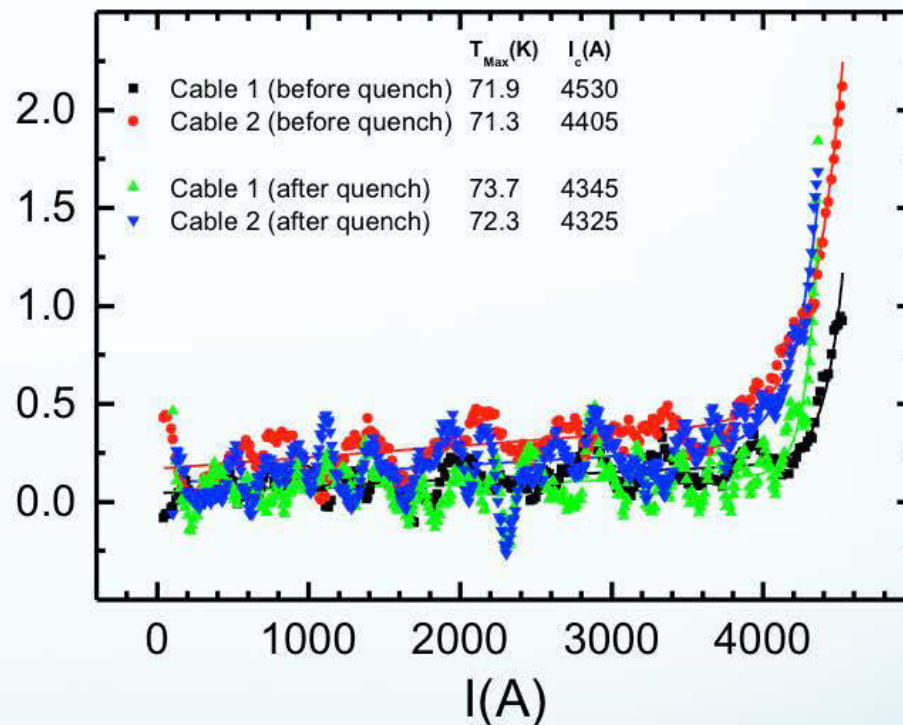
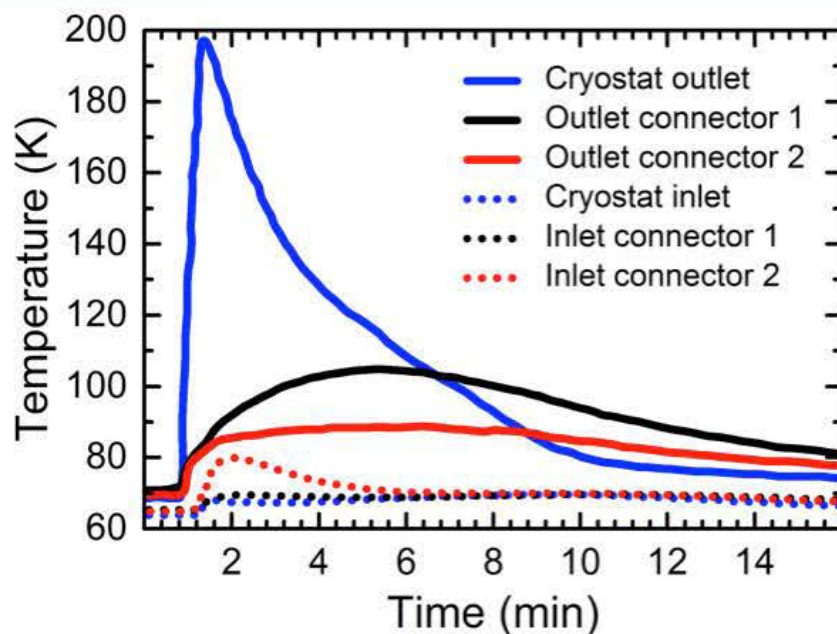
- **Current was limited to 2,000 A after 2 seconds**
- **Voltage over each pole was 5 V**
- **Maximum power dissipation: 43.4 kW**
- **Total energy dissipated: 53.7 kJ**



CORC® Power Cable Performance Verification

Recovery and performance verification

- Maximum helium temperature 200 K
- Recovery time > 20 minutes



- **CORC® power cable performance unchanged after FCL test**
- **Dissipation within helium gas needs to be limited during FCL event**
=> use of hybrid FCL cable with fast acting switch as solution



CORC® Power Cable System Shipped to the Navy



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Summary

Current rating of CORC® power transmission cables for operation in helium gas

- Demonstrated feasibility of CORC® cables and connectors at 4 kA at 60 K in helium gas
- Maximum dissipation at 6 kA of only 9 W in helium gas cryostat possible
- Current rating of 10 kA/phase at 50 K demonstrated in stranded CORC® cables

CORC® FCL operation in helium gas

- FCL test to 150 % of I_c successful
- Total energy dissipation of 53.7 kJ required > 20 minutes recovery time
- Dissipation in helium gas during FCL event needs to be limited to enable fast recovery

Next step: develop voltage rating of CORC® cables for operation in helium gas

- Voltage rating of 0.5 - 1 kV at 50 K in 2 MPa helium pressure not a problem
- Effort to increase voltage rating to 12 kV in the coming years using dielectrics sealed against helium gas penetration

