Testing of a sub-scale HTS coil for wind turbine generator

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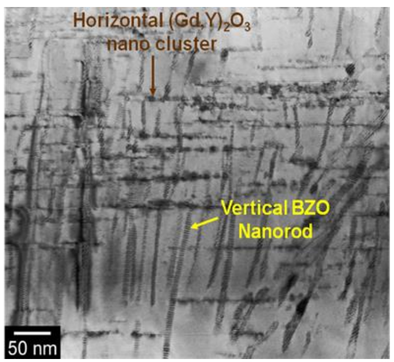
UNIVERSITY of HOUSTON TcSUH | SuperPower Inc. A Furukawa Company | Tai-Yang Research | TECO Westinghouse | NREL NATIONAL RENEWABLE ENERGY LABORATORY

ARPA-E funded program for High Performance Superconducting Wires and Coils

5X performance achieved at 30K, 3T

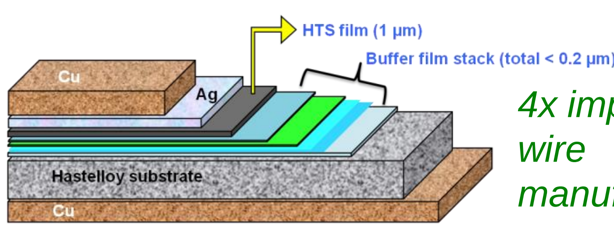
- ARPA-E funded program
- UH-led program with SuperPower, TECO-Westinghouse, Tai-Yang Research and NREL.



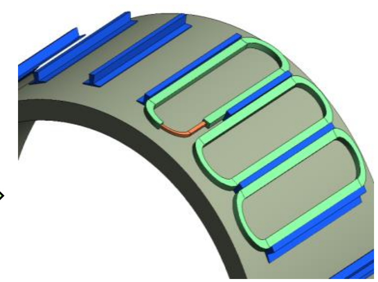
Technology Impact

Present-day superconducting wire constitutes more than 60% of the cost of a 10 MW superconducting wind generator. By quadrupling the superconducting wire performance at the generator operation temperature, the amount of wire needed would be reduced by four which will greatly enhance commercial viability and spur a tremendous growth in wind energy production in the U.S.

Engineered nanoscale defects



4x improved wire manufacturing



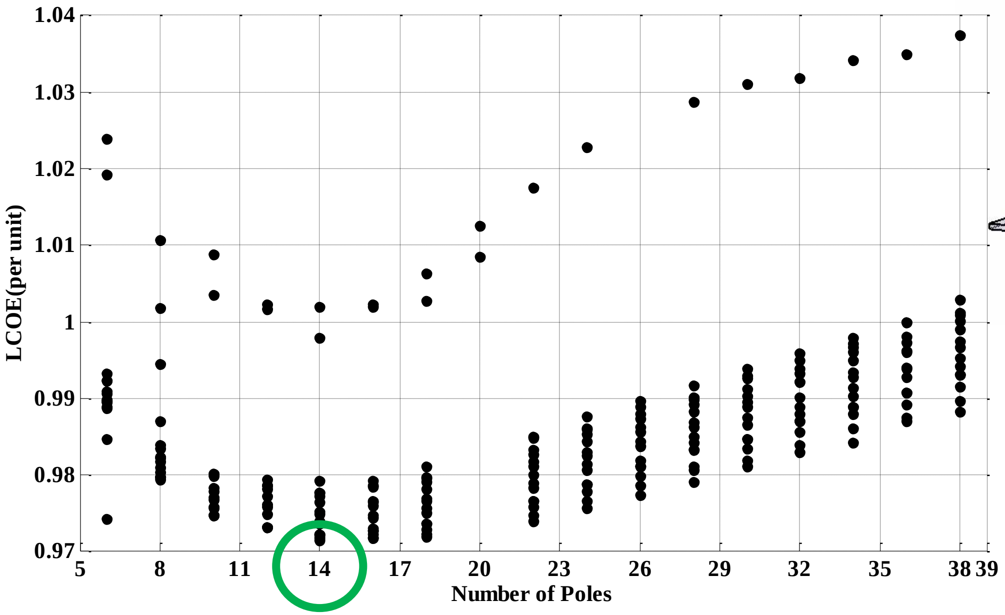
High-power, Efficient Wind Turbines

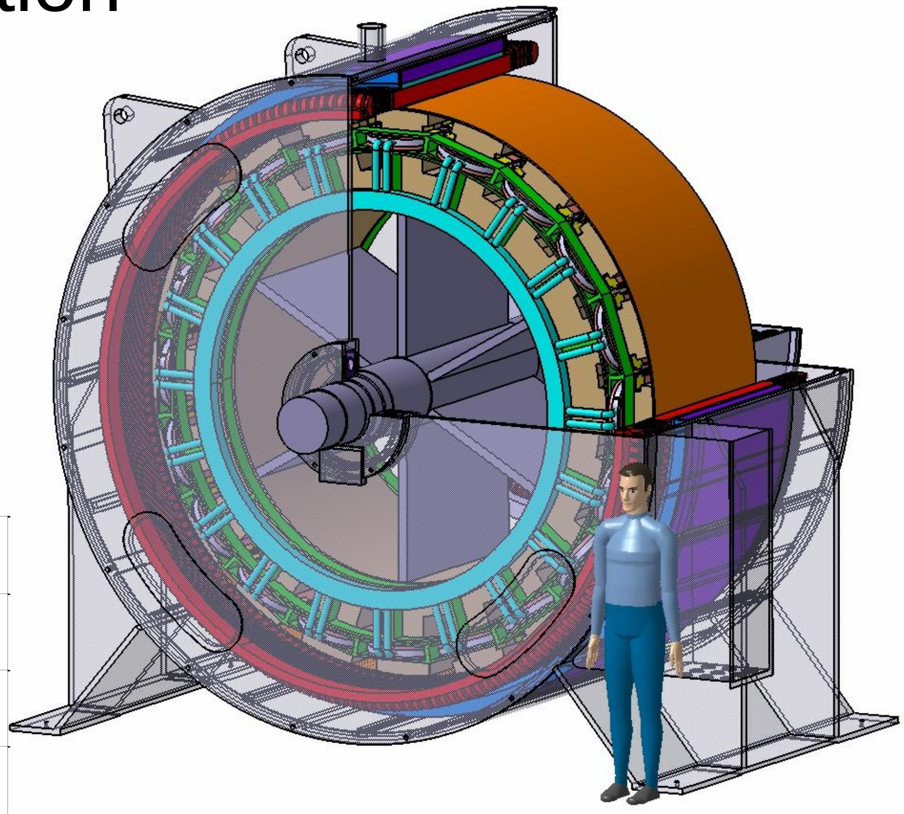
Lower cost Generator coils

Quadrupling Superconductor Wire Performance for Commercialization of 10 MW Wind Generators

HTS Generator Configuration

- 10 MW, 8 RPM
- Designed with respect to LCOE
- Based on 4X tapes developed at UH
- 30 K operation





Partially superconducting generator

- High number of poles
- “Ring” machine

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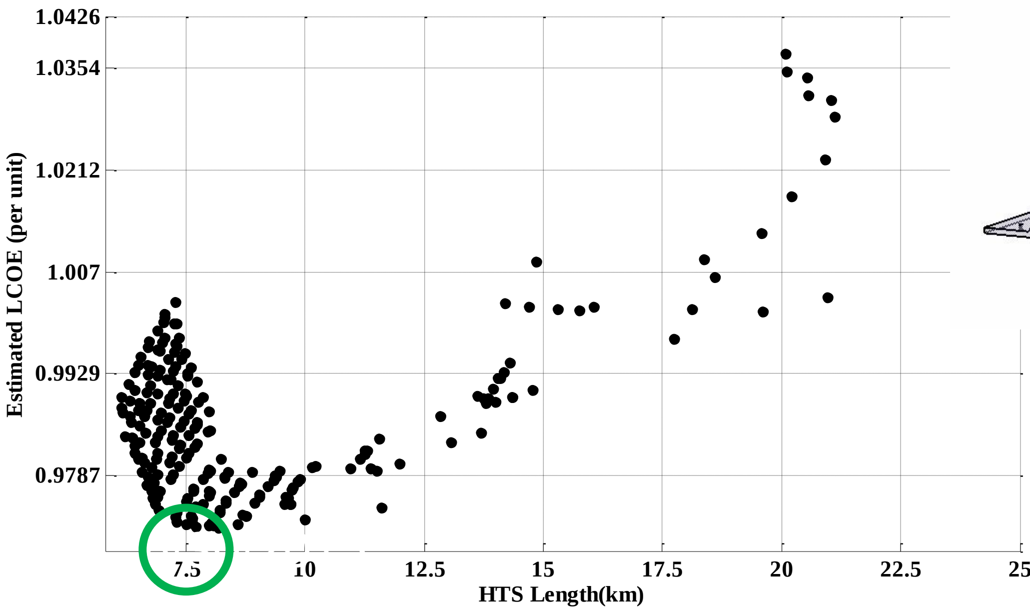

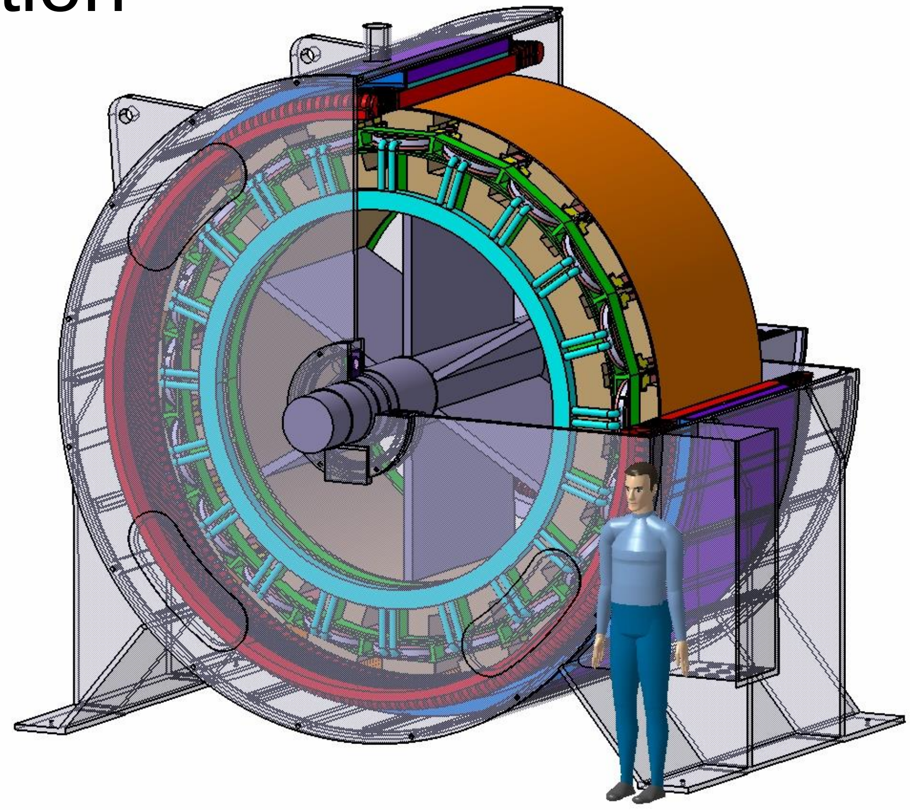

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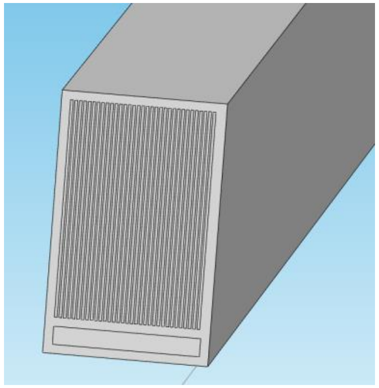
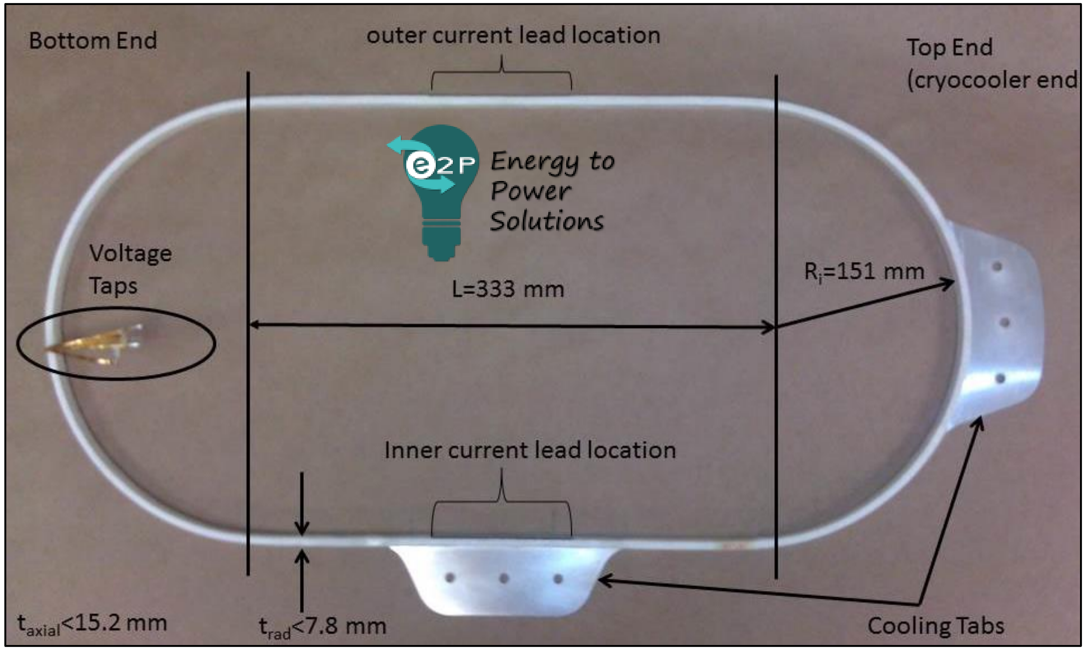
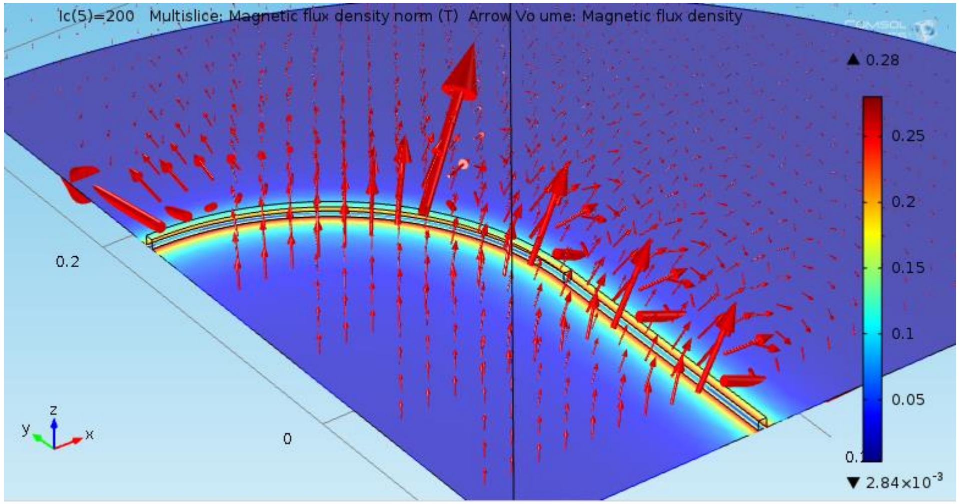
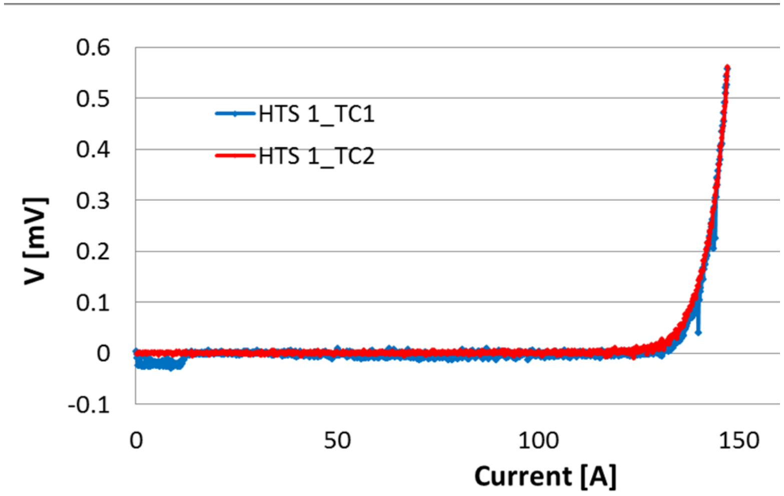
HTS Coil #1 – Superpower Conductor

- 12 mm YBCO tapes
- 33 turns
- Conduction cooled
- 159 A @ 77 K



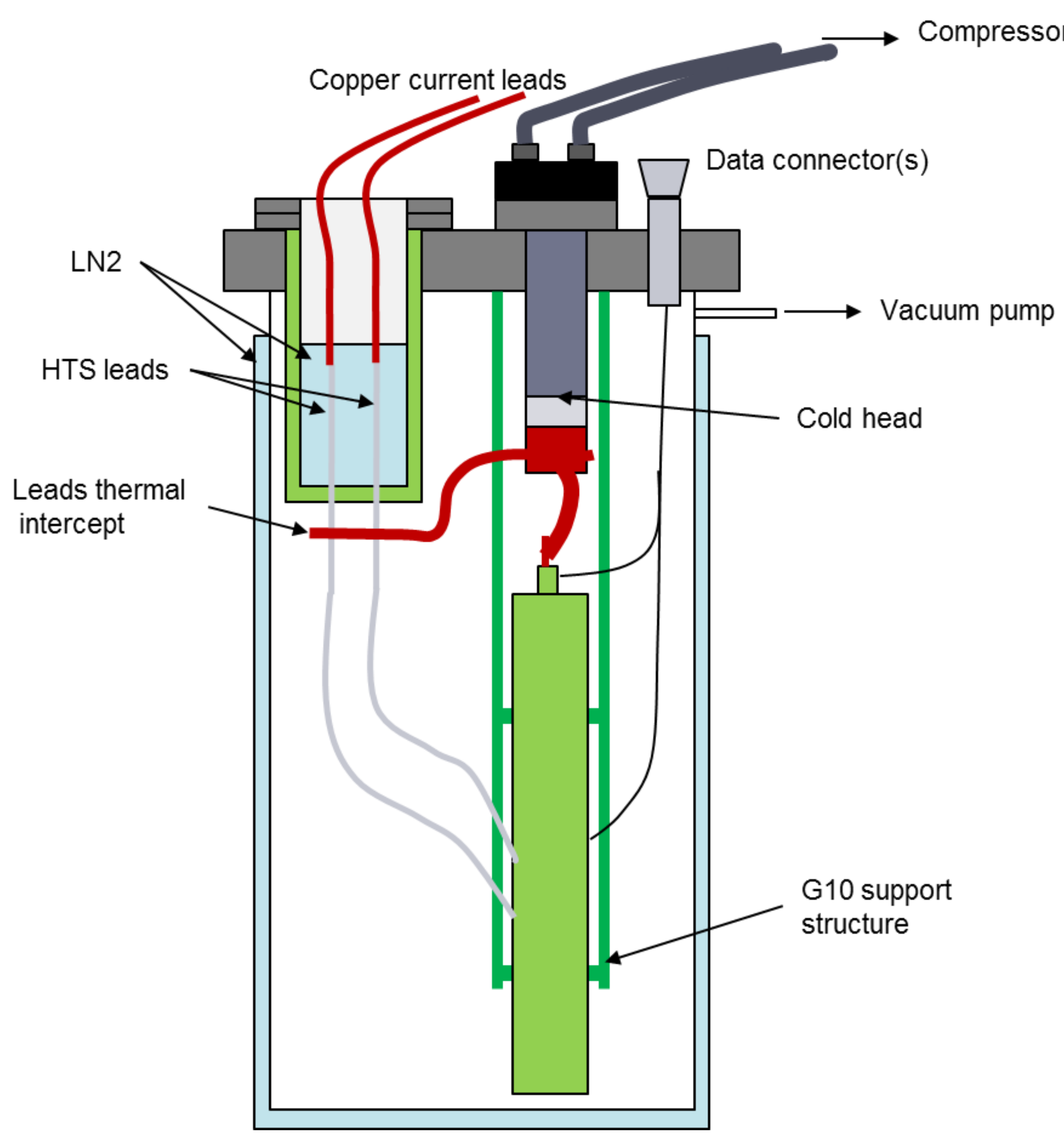






Test Facility

- Test facility Cryostat
    - Top plate
    - Vacuum pump*
  - Cryocooler AL325
    - Water chiller
  - 2000 A – 10 V DC power supplies
    - 400 V 3-phase transformer
  - Nano-voltmeter
  - Hall probes
  - Temperature control



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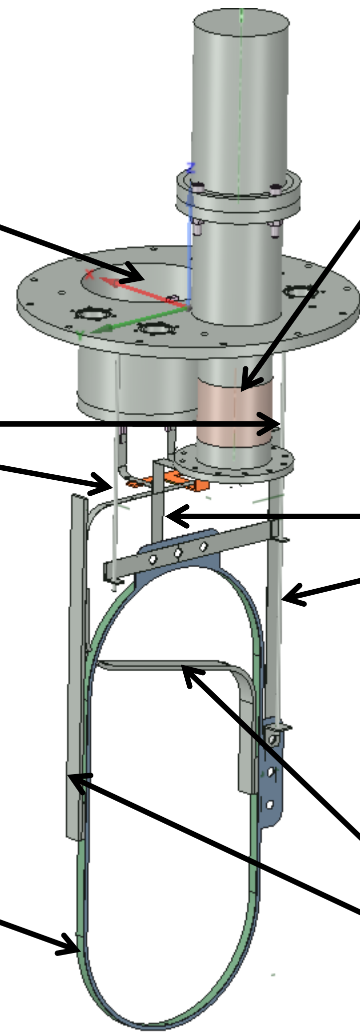
Experimental apparatus overview:



LN2 external tank (for copper current leads pre-cooling)

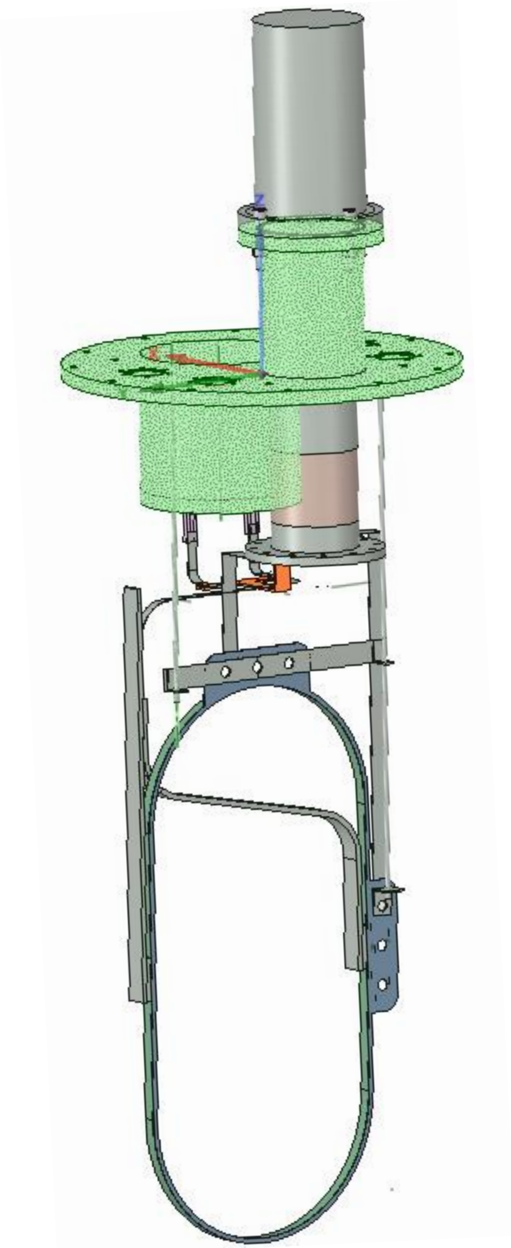
Cryocooler cold head

G10 threated rods (to hold the coil)

Copper braids (for coil conduction cooling)

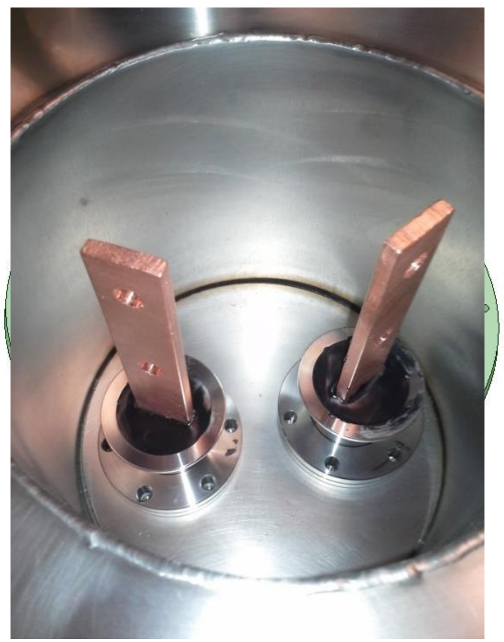
Superconducting racetrack coil

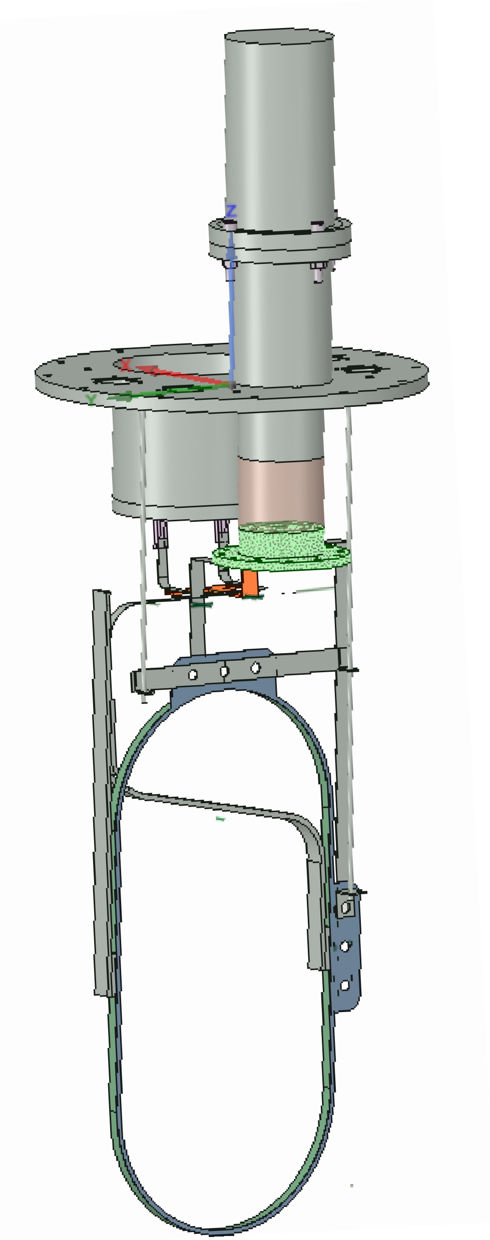
Copper bars (hold forces on superconducting current leads and help the conduction heat transfer)



Custom cryostat top plate (machining by Cryofab):

- 6 DN40CF vacuum flanges for electrical feedthrough
- LN2 tank for high current leads pre-cooling
- AL325 cold head support



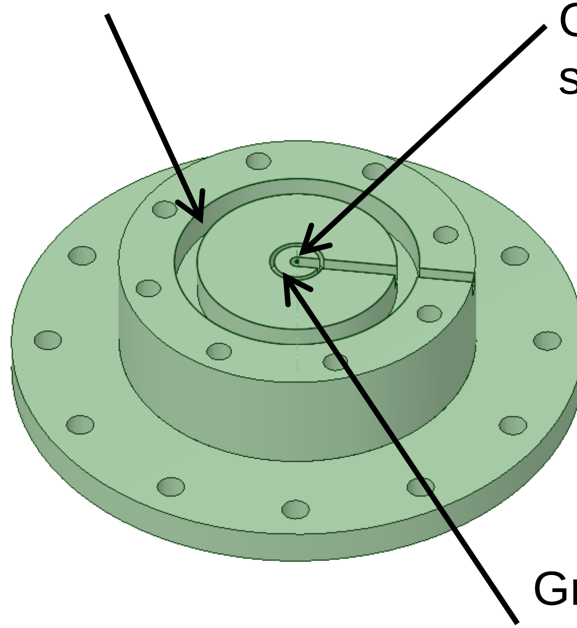


Cold Head temperature regulation:

- Copper part fastened on the cold head
- Resistive wire and Cernox temperature sensor encapsulated in epoxy resin

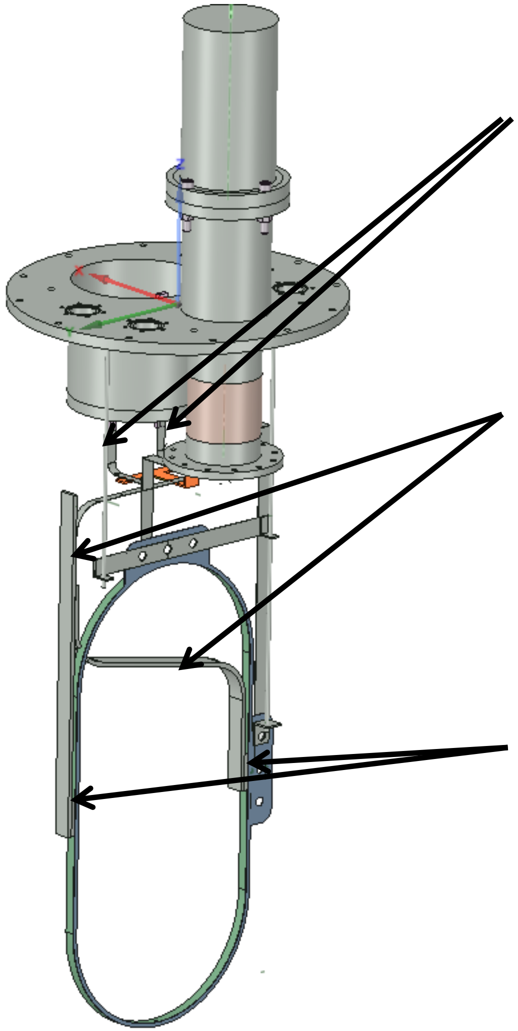
Groove for resistive wire

Groove for temperature sensor



Groove for temperature sensor wires thermalisation

Current leads:



Current leads, top part:

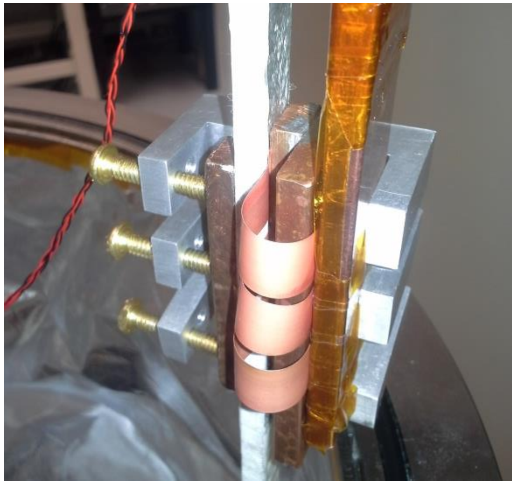
- 5 YBCO tape (12mm) in parallel and thermally connected to the cold head.

Current leads, bottom part:

- Made with 2 YBCO tapes (12 mm) in parallel.
- Mechanically attached to the copper supports bars.

Pressed electrical contacts:

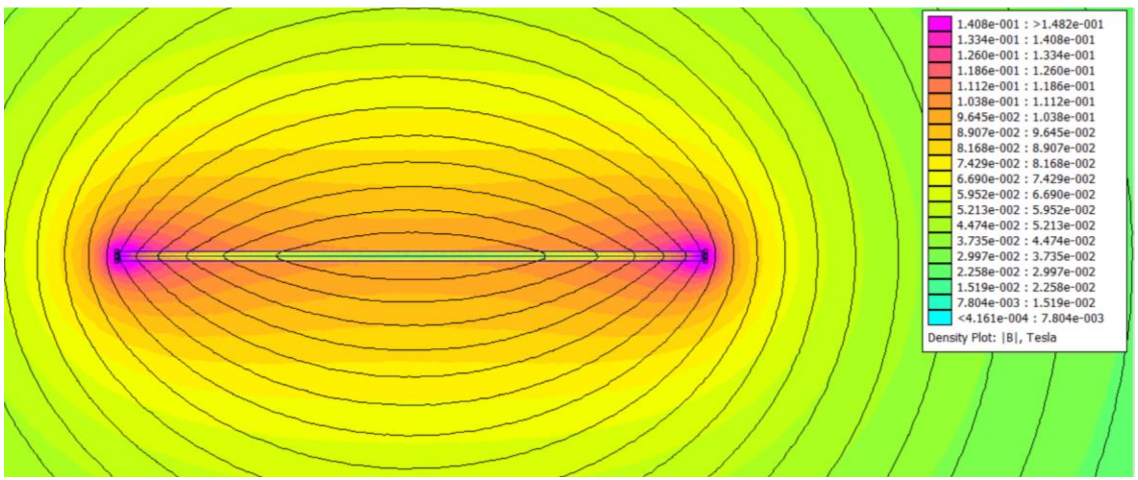
- A copper piece is place between the superconducting tapes and the coil.
- The copper piece is bypassed by 3 YBCO tapes in the second version of the experiment.



Superconducting current leads critical current calculation (bottom part):

- 2X12mm wide YBCCO tape from Superpower.
- Maximum self-field of two tapes: 0.148 T
- Ic>2,000A at 35K (maximum current leads temperature) and 1.7T // c-axis [1]
- Superconducting tape 4mm away from coil => |B|<1.45T (Comsol computation).

- Even if self-field and external field are collinear |B|<1.7T => Ic>2000 A

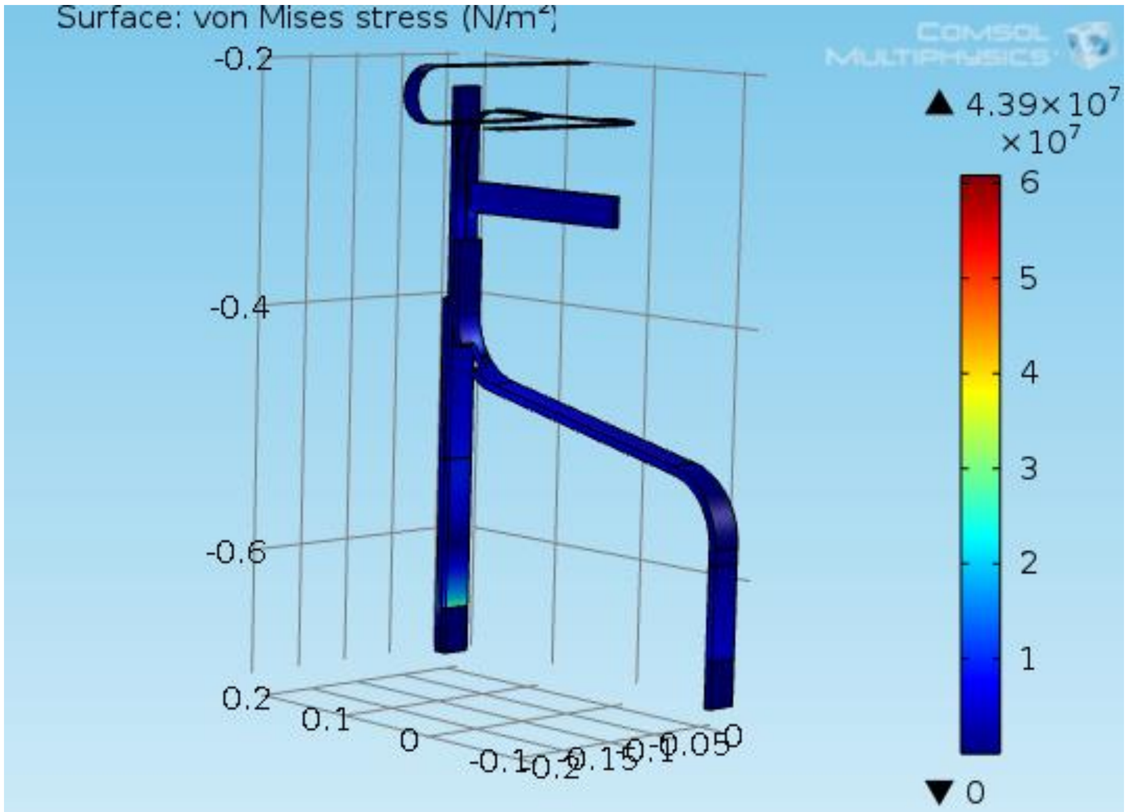


Self-field computation at 2,000 A

[1]: Value evaluated from superpower documentation (http://www.superpower-inc.com/system/files/SP_2G+Wire+Spec+Sheet_2014_web_v1.pdf).
Lifting factor evaluated at 5.5 by interpolation between data at 30K and 40K.

Mechanical stress calculation on copper bar supports

- Yield stress of annealed copper: 88-90 Mpa [1]
- Ultimate stress of annealed copper : 360-418 Mpa [1]

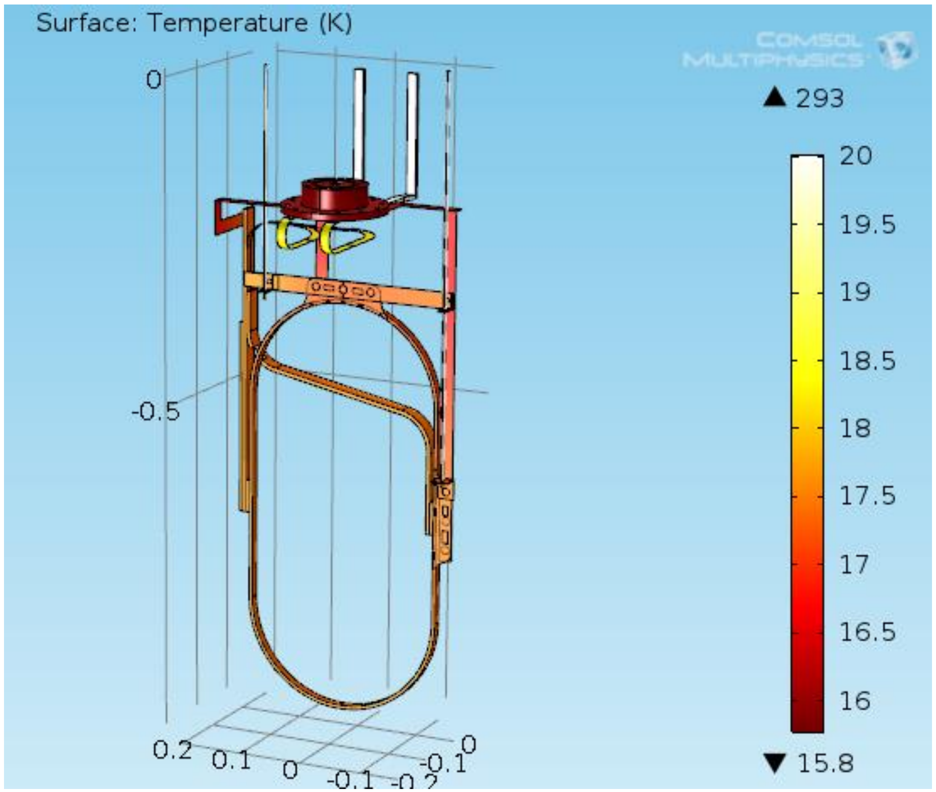


Picture correspond to the first version of the experiment

[1]: Helium Cryogenics, Steven W. Van Scive, Chapter 2: Low-Temperature Materials Properties

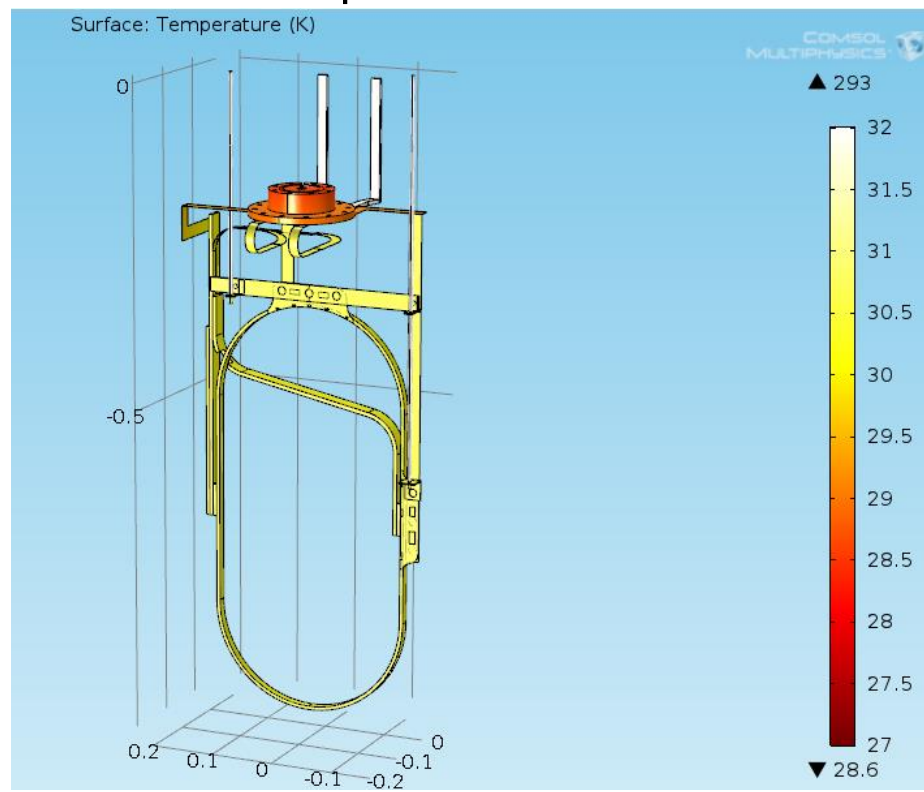
Coil cooling simulation using Comsol: Stationary study

Heater power = 0 W



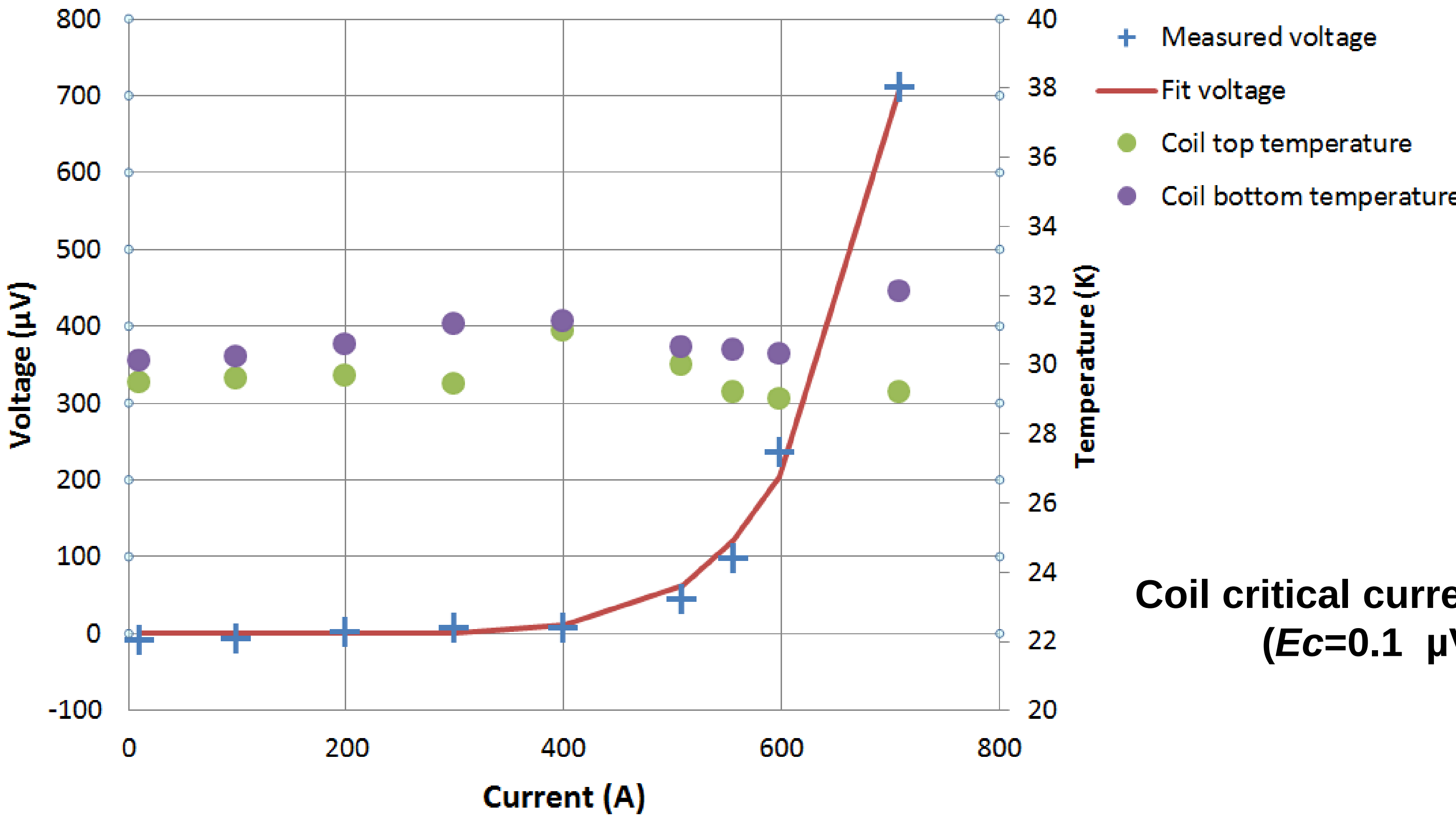
Average coil temperature = 17.26 K

Heater power = 107 W



Average coil temperature = 30.15 K
Maximum coil temperature = 30.25 K
Minimum coil temperature = 29.97 K

Measurements results



Coil critical current = 682.8 A
(*Ec*=0.1 µV/cm)

Summary

- A HTS coil test rig was developed
- Coils can be tested up to 2000 A at temperature in the range 20-77 K
- A 1.5 m cryostat is available for long coil testing
- A 2nd cryocooler is available if more cooling power is required

- Next step (ongoing work)
  - Test coils developed as part of the ARPA-e REACT project with advanced conductors (1.5X, 2X)
  - Integrate a quench detection/protection system (developed by E2P Solutions)