C3Po1B-02 [14]

Improved Utilization of Cryocooling Power in Superconducting Undulators at the Advanced Photon Source

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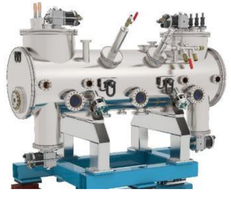
Introduction

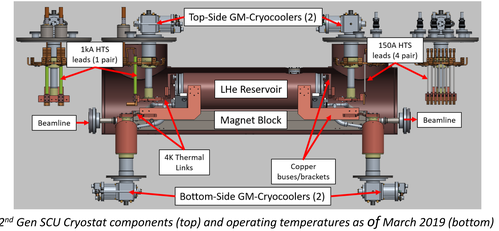
- A new (2nd Generation) cryostat for superconducting undulators (SCU's) was installed at APS in 2018
  - Cooling of SCU's is provided by natural circulation of liquid helium (LHe)
  - Helium recondensation via conductive cooling of the LHe reservoir wall (zero boil-off operation)
- The thermal resistance of the cooling circuits limits cryocooling capacity
  - Cryocooler 2nd stages operating at 3.1K-3.5K
  - Steady-state cooling power / cryocooler of 0.3W-0.6W (vs. 1.5W @4.2K)
  - Limits ability to absorb a magnet quench
- Current project seeks to:
  1) Quantify major thermal resistances analytically/experimentally
  2) Propose redesigns to improve system's thermal conductance/cooling capacity

Background: the 2nd Generation SCU Cryostat at APS

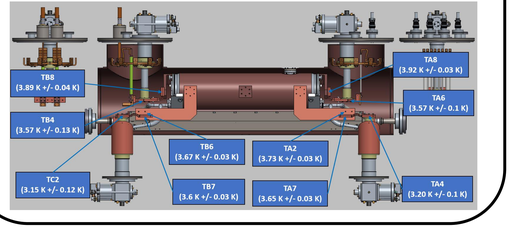


CAD model of the 2nd Gen SCU cryostat

- Supports planar, helically-wound (HSCU) and arbitrary-polarizing (SCAPE) undulators
- LHe-cooled magnets; zero boil-off
- 4K coldmass cooling system:
  - 4 Sumitomo RDK 415D cryocoolers
    - 2-stage GM; 1.5W@ 4.2K
  - Conductive cooling circuits
    - OFHC thermal buses bolted / soldered to LHe tank wall
    - Braided copper thermal links with Ag-plated end fittings

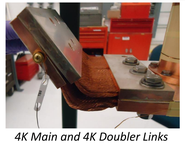


2nd Gen SCU Cryostat components (top) and operating temperatures as of March 2019 (bottom)

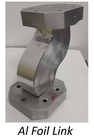


Characterization of Cooling Circuit Thermal Resistances

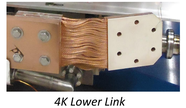
Thermal Links



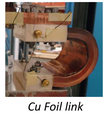
4K Main and 4K Doubler Links



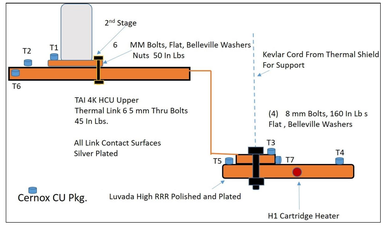
Al Foil Link



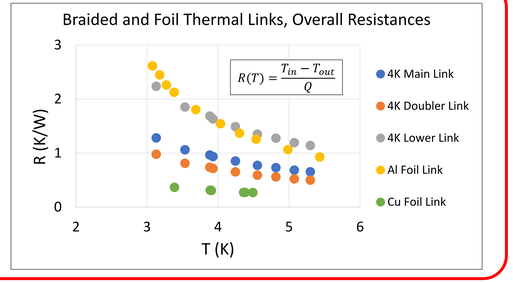
4K Lower Link



Cu Foil link



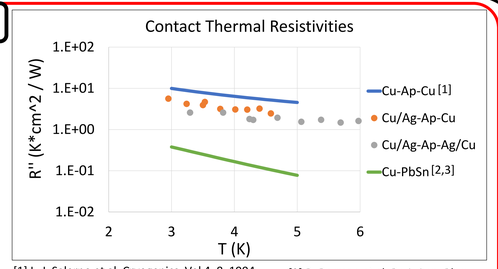
4K Main copper braid thermal conductance measurement setup



Contact Resistances

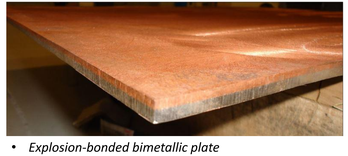
Four types of contacts:

1) Copper-Stainless Steel (LHe tank wall)
2) Copper-PbSn solder (L-bracket/wall joint)
3) Silver-plated copper with Apiezon-N interposer (all thermal link connections)
4) Silver-plated copper to bare copper, with Apiezon-N interposer (coldhead connections)

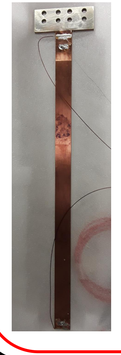


[1] L. J. Salerno et al, Cryogenics, Vol 4, 8, 1994
[2] L.J. Barnes and J.R. Dillinger, Phys. Rev. Let. Vol 10, 7, 1963
[3] R. Berman et al, Br. J. App. Phys., Vol 6, 181, 1955

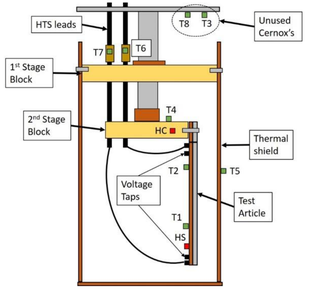
LHe Tank Wall



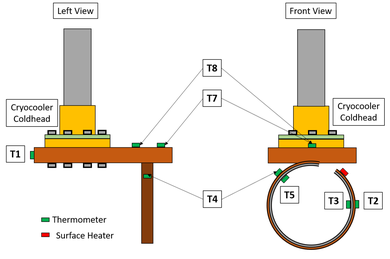
- *Explosion-bonded bimetallic plate*
  - *1/8"-thick copper on 3/16" AISI 316 steel substrate*
  - *Post-bonding heat treatment (1100F for 1-2 hours)*
  - *Rolled to form cylinder of LHe tank*
- *Could the bonding/rolling processes have reduced the copper's thermal conductivity?*



Beam (left) and ring (below) specimens of the bimetallic material

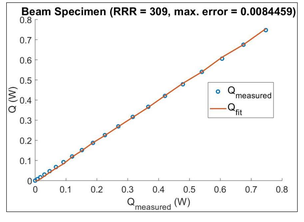


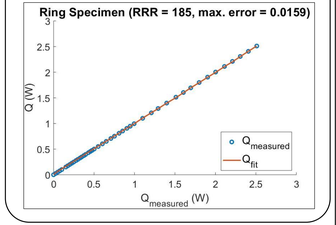
Beam (above) and Ring (below) specimen thermal conductance measurement setups



Thermal Test Results: Integrated Conductivity Curve-Fitting [4]

$$Q_{fit}(RRR) = \frac{A_{c,Cu}}{L_{12}} \int_{T_2(Q_{meas})}^{T_1(Q_{meas})} [k_{NIST}(T, RRR)]\, dT$$





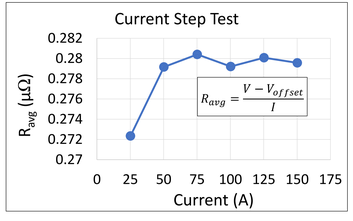
	Copper layer RRR*	Copper Thermal Conductivity @ 4K
Beam Specimen	300 +/-15% (250-350)	1900 W/m*K
Ring Specimen	185 +/-15% (157-213)	1170 W/m*K

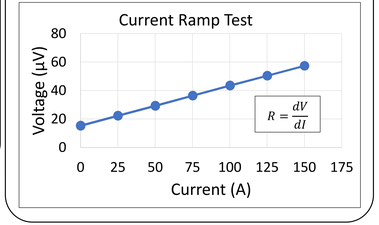
*+/-15% margin of error on NIST correlation

Electrical Resistivity Test Results (Beam Specimen only)

$$\rho_{4K} = R\frac{A_{c,Cu}}{L_{taps}} = 0.052\ n\Omega m$$

$$RRR = \frac{\rho_{273K}}{\rho_{4K}} = \begin{cases} 298 & (using\ NIST\ \rho_{273K} = 15.5\ n\Omega m) \\ 248 & (using\ measured\ \rho_{273K} = 13\ n\Omega m) \end{cases}$$

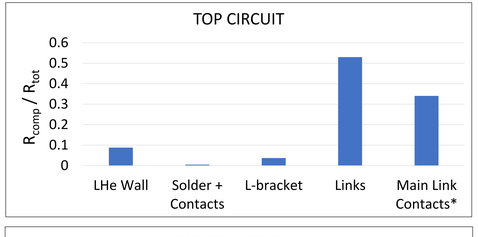


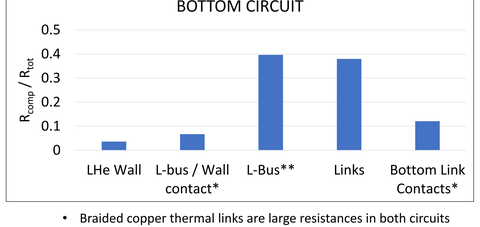


[4] N.J. Simon et al, NIST Monograph 177, 1992, p. 7-16

Analysis and Conclusions

	Total ΔT	Total Resistance	Estimated Cooling Power (Steady State)
Top Circuit	0.70 K	1.125 K/W	0.62 W
Bottom Circuit	0.99 K	2.75 K/W	0.36 W





- Braided copper thermal links are large resistances in both circuits
  - Replacement with copper foil links may be advisable
- Copper L-bus in bottom circuit should be redesigned/replaced
  - Higher RRR copper or reduced length
- Thermal contacts between links should be inspected