Cryogenic Heat Sink for Helium Gas Cooled Superconducting Power Devices

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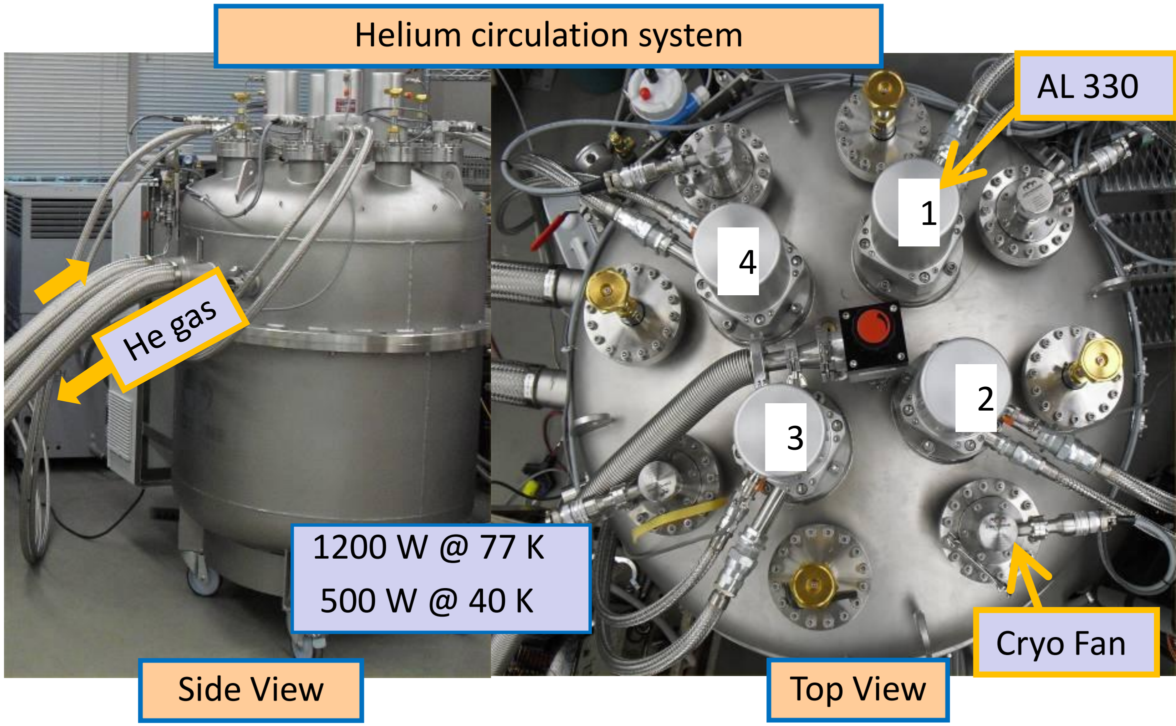
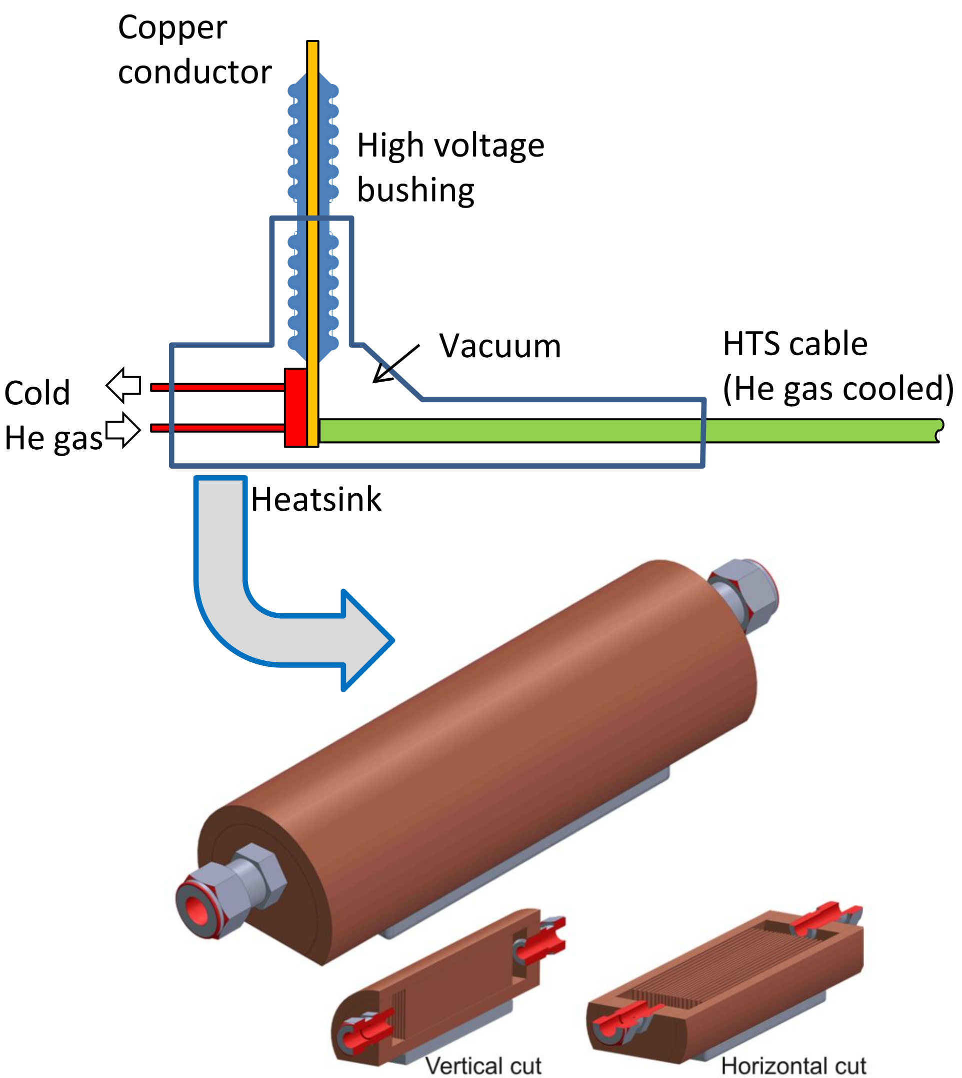
Superconducting Power Cables

- Superconducting cables for shipboard power system
  - Temperatures below LN2 → higher current density
  - Liquid cryogens not permitted (asphyxiation & explosion hazard)
  - Solution: Helium gas at 50...60 K and 1.8 MPa; flow rate up to 20 g/s

- gHe has lower heat capacity than LN2
  - Cooling more challenging, especially at terminations



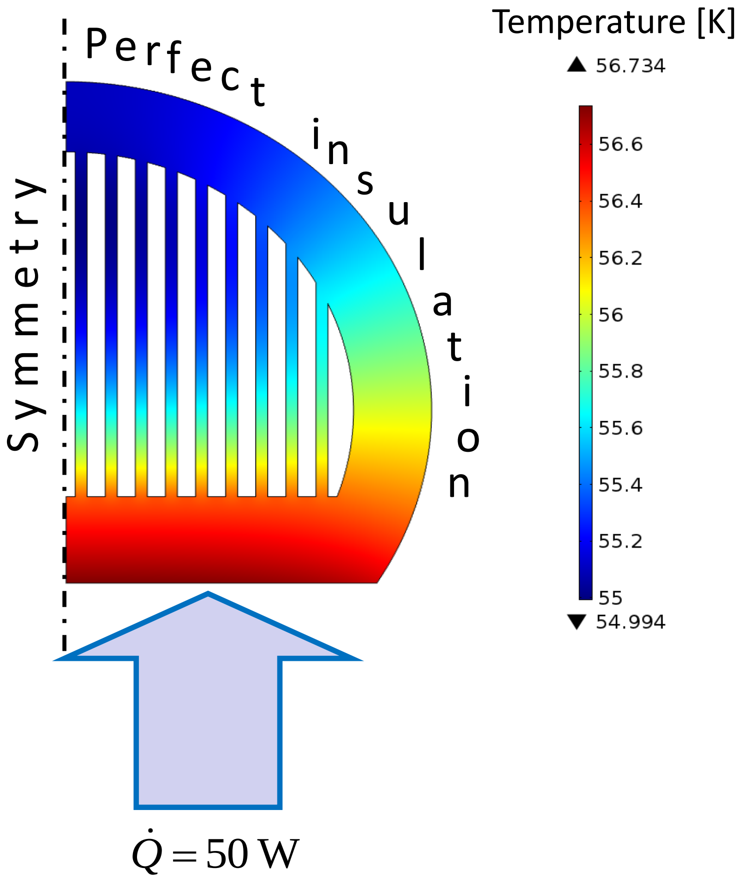
Model Heat Sink



- Problem:
  - Heat influx from ambient
  - Joule heating in bushing
- Solution:
  - Heat intercept attached to copper conductor
  - Cold He gas flow through heat sink
- Design:
  - Finned heat sink inside tube
  - Entirely made from copper
  - Design and dimensions need to be optimized by FEA
  - Small-scale model built for model validation

Finite Element Model: 2D Heat Transfer

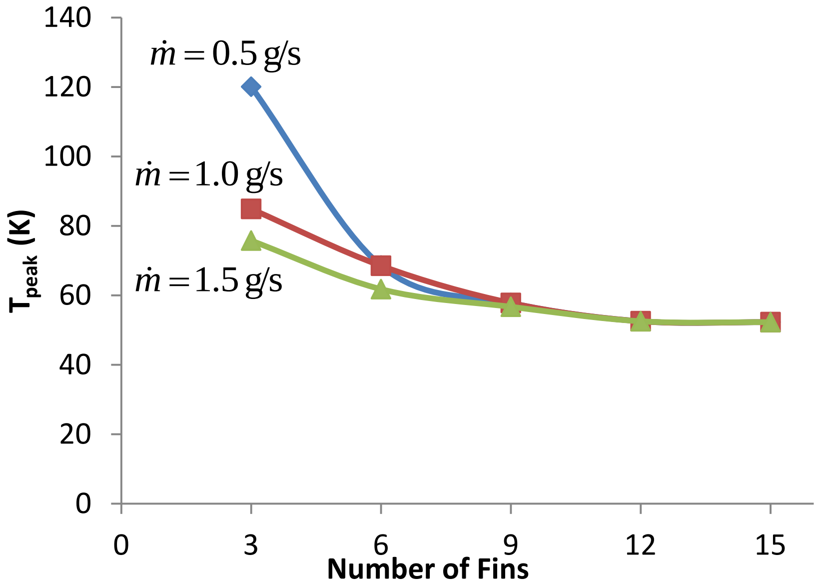
Goal: Determine optimal number of fins
Symmetry: All BC for ½ heat sink

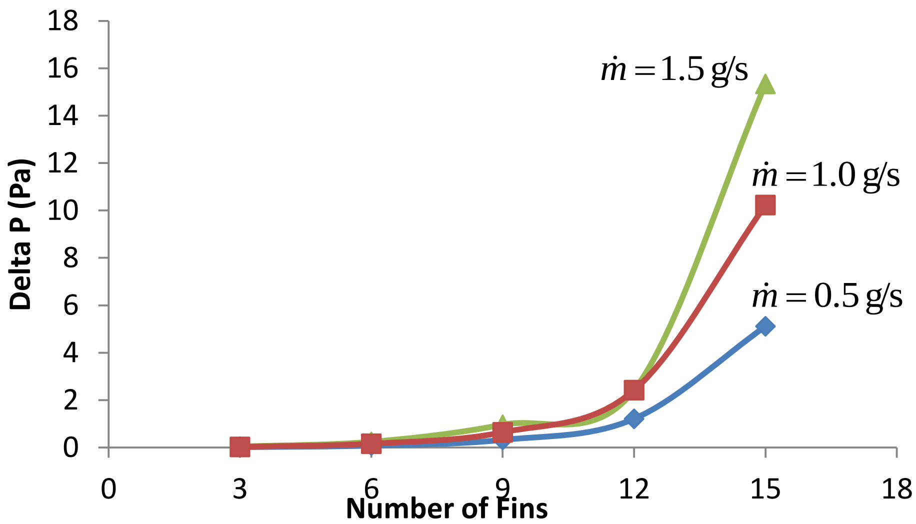


- Physics
  - *Heat Transfer in Solids*
  - No CFD, but
- Boundary conditions
  - Heat influx 50 W
  - Symmetry
  - Insulation (vacuum)
  - In channels: Convective cooling boundary condition (h = 90 W/m^{2}K for the 9-fin model, obtained by Dittus-Boelter correlation)
- Initial temperature: 50 K
- Material properties
  - Copper: k, c_p, ρ as a function of temperature
- Mesh size: normal (2986 elements for 9-fin model)
- Pressure drop calulated separately using Moody Diagram

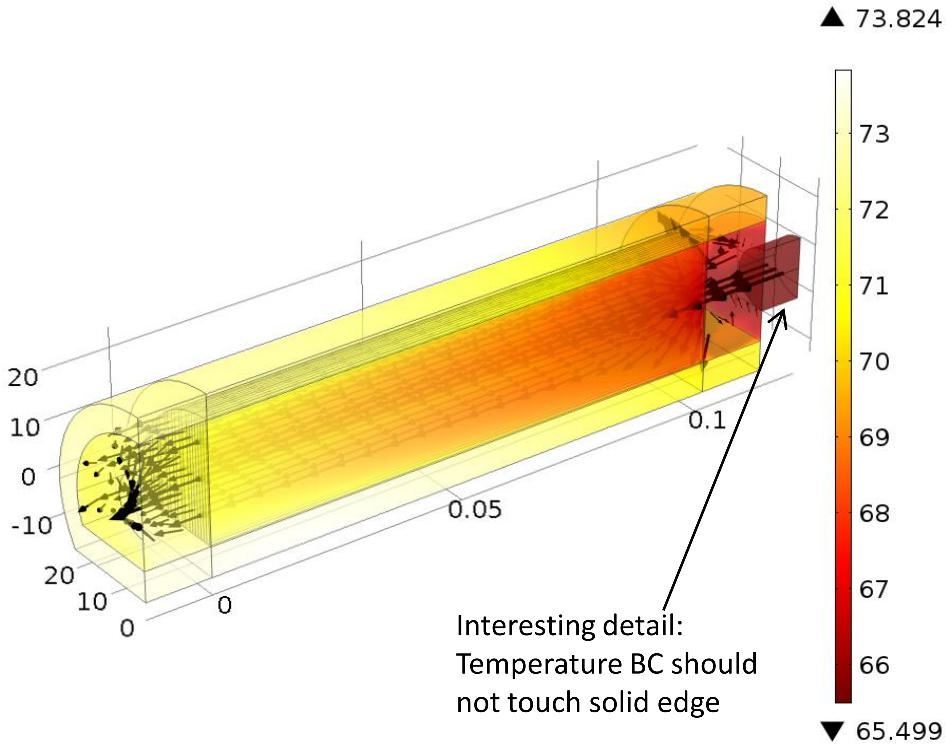
Results from 2D Model

- Maximum heat sink temperature and pressure drop as a function of number of fins for three different mass flow rates
- 9 Fins seem to be optimal
- Flow rates of below 1 g/s are sufficient (50 W input power)





Finite Element Model: 3D Fluid Flow



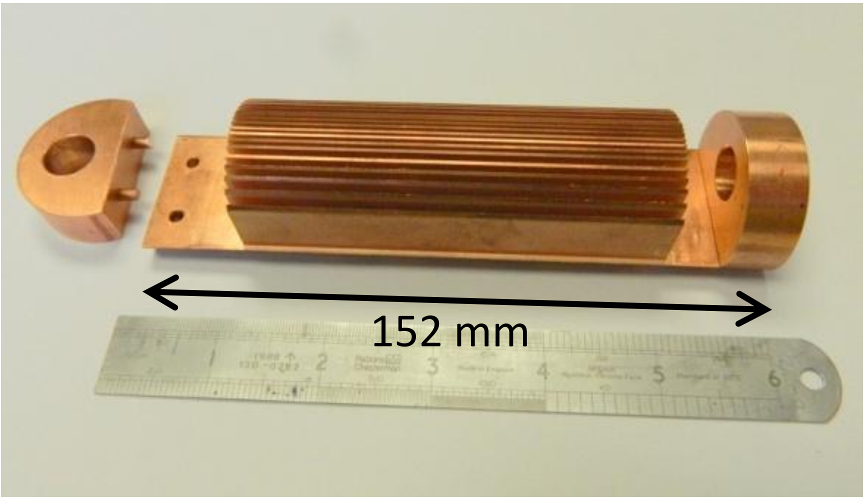
Temperature field for 100 W heat influx

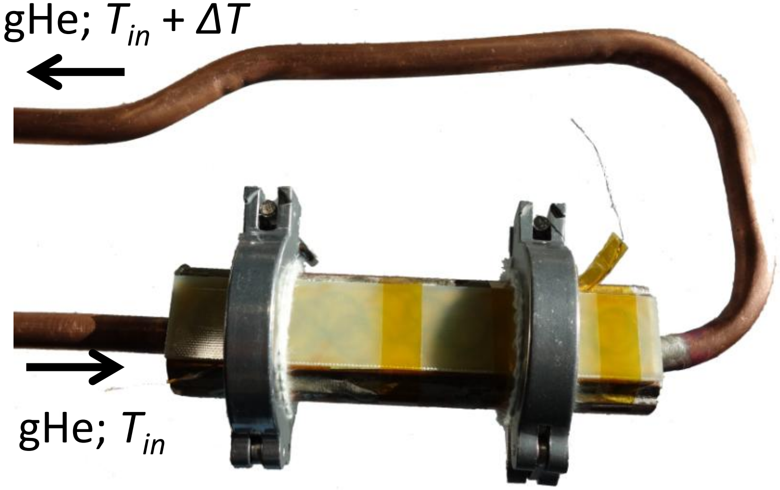
Simulation time: 156 min (on 2x Intel Xeon X5570)

- Physics
  - *Conjugate Heat Transfer*
  - Laminar flow
- Boundary conditions
  - Inlet: Helium, 50 K, volume flow rate
  - Outlet: Pressure
  - Heat influx: same as 2D model
- Helium properties
  - Density considered constant (at 58 K)
- Mesh
  - Fluid domain: normal
  - Solid domain: finer
  - Total 1.54 million elements
- Convergence
  - GMRES: 240 iterations
  - Non-lin: 45 iterations

Experiment for Model Validation

- Made from copper
  - Most parts mechanically machined
  - Fins were machined by EDM
  - Joined by silver braze (optimal heat transfer; leak free)
- Heater based on resistance wire
- Wrapped in aluminized Mylar
- Installed in vacuum chamber





Results of Validation

Parameter	50 W for full HS		100 W for full HS	
	Model	Experiment	Model	Experiment
Temperature inlet [K]	58.6	58.6	65.5	65.5
Temperature increase [K]	4.15	4.7	6.45	7.3
Temp. heat sink [K]	63.0	77.3	73.8	84.0
Pressure drop [Pa]	284	294	313	297

- Generally good agreement between simulation results and measurements
  - Except for heat sink temperature
  - Investigations under way to determine the reason for discrepancy (Model or measurement?)

Conclusion

- The chosen geometry is suitable
  - Low pressure drop
  - Excellent heat transfer
  - Higher flow rates for turbulent flow are under investigation
- The developed models are very useful tools for heat sink design and optimization
  - It will be used for a real application in near future
- Model will be extended to incorporate turbulent flow
- Optimization studies for geometrical parameters (non-uniform spacing of fins; thickness of fins)