Cool-down acceleration of G-M cryocoolers with thermal oscillations passively damped by helium

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Outline

- Interest in thermal stability and rapid cool-down
- SHI’s helium thermal damper
- Cool-down with damper and calculations
- Modified damper gas management and results
- Additional thermal anchoring
Hypres and others have developed turn-key S.E. electronic systems:

- Josephson Junction Primary Voltage Standards
- Digital RF receivers
Niobium JJ Ideal Cryo-requirements

Stable temperature

- Critical currents of Junctions and bias points are temperature sensitive

Fast cool-down

- Quick temperature excursion through superconducting / normal transition
- Extraneous magnetic flux can lower the critical current of random junctions in a circuit, affecting performance – purge by heating to $T_c$
SHI RDK-101DP

Helium pot attached to 2nd stage
Capillary tube
Thermal link to 1st stage
RDK-101-DP coldhead

Room temperature gas buffer
Damper/No damper Cool-downs

- "Deflux" excursion cool-down much longer with damper
- Buffer pressure follows dropping He pot temperature
- Calculated cool-down agrees reasonably well with measurement
Dominance of heat from capillary flow

Heat removed from Helium per unit change in pot temperature (K)

- Capillary flow
- He in pot
Calculated cool-down

- Energy balance

\[ \dot{Q}_{ref} = m_p c \dot{T}_p + \Delta h m \]

- Mass in He pot known function of pressure, so defining temperature

\[ m_p = M - \frac{M_{He} V_b}{RT_{amb}} \left( P_p + \Delta P_i \right) \]
Low charge pressure cool-downs

- Lower charge pressure results in longer cool-down time
- Total mass flow through capillary is increased and peaks at lower temperature
- Rapidly changing density near critical point
Damping effectiveness vs charge pressure

- Thermal skin depth: \[ \delta = \sqrt{\frac{\alpha}{\pi f}} \approx 0.1\text{mm} \]
- Damping effectiveness/unit area: \[ \sigma = \delta c_p \rho \]
Modifications to He damper

- Modifications work passively
  - Spring-loaded non-return valves set to ~1/3 charge pressure (0.7 bar)
  - Additional thermal linkage at lower temperature
Cool-down with 0.7 MPa c.p. NRVs

- Measured cool-down is dramatically faster than without valves.... WHY??... Vapor-lock?......Thin film of liquid?

- *Calculated* time to 4 K is no different, in spite of 55% reduction in total capillary flow ---- heat load shifted to lower temperatures
Addition of 7K thermal intercept to capillary

- Even faster, approaching no-damper time
- Still faster than calculated
Conclusion

- Cool-down from 10K is retarded by warm He injected into He pot
- Reduction of charge pressure increases cool-down time
- In-line relief valves passively restrict buffer-pot mass flow, with dramatic reduction in cool-down time
- No reduction in damping
- Additional inter-stage thermal intercept reduces time to nearly twice un-damped system
## Sumitomo SRDK-101D-A11

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
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<tbody>
<tr>
<td>Heat Load (Manufacturer Spec)</td>
<td>0.1 W at 4.2 K and 5 W at 60K</td>
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<tr>
<td>Heat Load (Measured)</td>
<td>0.2 W at 4.2 K and 6 W at 53K</td>
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<tr>
<td>Input Power</td>
<td>1.3 kW, 100±10 V (60 Hz)</td>
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<tr>
<td>Compressor Size</td>
<td>0.45 × 0.385 × 0.40 m³</td>
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<tr>
<td>Cold Head Dimension</td>
<td>0.13 × 0.226 × 0.442 m³</td>
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<tr>
<td>Compressor Weight</td>
<td>42 kg</td>
</tr>
<tr>
<td>Cold Head Weight</td>
<td>7.2 kg</td>
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</tbody>
</table>
Temperature Oscillations of Sumitomo Cooler

250 mK