Experimental investigation of compact 2K GM cryocoolers

Qian Bao, Akihiro Tsuchiya, Mingyao Xu, Rui Li

Technology Research Center
Sumitomo Heavy Industries, Ltd.
Background
Background

Cryogenic applications

- http://en.wikipedia.org/wiki/Magnetic_resonance_imaging

Cryocoolers

Background

Rapid growth of superconducting electronic devices

Development of 2K GM cryocooler

Short supply of high reliability cryocoolers with bottom temperature under 3K

<table>
<thead>
<tr>
<th>Item</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>1\textsuperscript{st} Temperature with 1 W</td>
<td>60 K</td>
</tr>
<tr>
<td>2\textsuperscript{nd} Temperature with 20 mW</td>
<td>2.3 K</td>
</tr>
<tr>
<td>Height reduction of expander comparing to the existing 0.1W 4K GM cryocooler</td>
<td>33.3%</td>
</tr>
<tr>
<td>Temperature oscillation displacement</td>
<td>$\leq 20$ mK</td>
</tr>
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</table>

(Development target)
Background

Progress of prototype unit

The world’s smallest 4K GM cryocooler: RDK-101D

Performance Specifications

<table>
<thead>
<tr>
<th></th>
<th>50</th>
<th>60</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Supply Hz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2nd Stage Capacity Watts @ 4.2 K</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>1st Stage Capacity Watts @ 60 K</td>
<td>3.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Cooldown Time to 4.2 K Minutes</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>Weight kg (lbs.)</td>
<td>7.2</td>
<td>(15.9)*</td>
</tr>
<tr>
<td>Maintenance Hours</td>
<td>10,000</td>
<td></td>
</tr>
</tbody>
</table>

*Cold head only. Drive unit weighs 1.0 kg (2.2 lbs.).

Standard Scope of Supply

- RDK-101D Cold Head
- CNA-11B/C Compressor
- 3 m (10 ft.) Helium Gas Lines
Background

Progress of prototype unit

85 mm reduced in length

Lower reached temperature

Lower temperature oscillation

RDK 101D

Prototype

85 mm

Length 240 mm
Background

Approaches to achieve higher cooling capacity

Second stage regenerator material (Gd$_2$O$_2$S)

Optimization of cylinder wall thickness

\[ q = A \cdot \delta \cdot \nabla T \]

- \( q \) – Heat flux
- \( A \) – Cross section area
- \( \delta \) – Thermal conductivity
Experiment setup
1. Stabilized temperature under no-load condition.

2. Stabilized temperature under 0W-4W (for first stage), 0W-20mW (for second stage) thermal load.

3. Temperature oscillation under no-load condition.

4. Temperature oscillation under certain thermal load.
Experiment apparatus

CNA-11B Air-cooled Compressor

- Electrical Supply: 100V/50Hz
- Power Consumption: 1.1-1.2kW @ 50Hz

Motor

1st cylinder

2nd cylinder

2nd stage heat flange

Radiation shield

Vacuum vessel
Temperature measurement

- Radiation shield
- 2\textsuperscript{nd} stage heater
- Cernox temperature sensor
- PtCo temperature sensor
- 1\textsuperscript{st} stage heater
Experiment results
Cool-down curve

Typical cool-down process

- 1st Stage Temperature
- 2nd Stage Temperature

Temperature (K) vs. Time (min)
Cool-down curve

Typical cool-down process

![Graph showing temperature (K) vs. time (min) for two stages of cooling process. The first stage has a blue line, and the second stage has a green line.](image-url)
Considerable capability under 3K
Load-map (Prototype)

Considerable capability under 3K

No-load condition:
Temperature reached: 39.2K/2.09K

Specification:
1\textsuperscript{st} stage 1.0W/
2\textsuperscript{nd} stage 20mW
Temperature reached: 44.4K/2.23K
Temperature oscillation

A theoretical analysis

Ph

Pl

<table>
<thead>
<tr>
<th>Temperature (K)</th>
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<tbody>
<tr>
<td>1.5</td>
</tr>
<tr>
<td>1.7</td>
</tr>
<tr>
<td>1.9</td>
</tr>
<tr>
<td>2.1</td>
</tr>
<tr>
<td>2.3</td>
</tr>
<tr>
<td>2.5</td>
</tr>
<tr>
<td>2.7</td>
</tr>
<tr>
<td>2.9</td>
</tr>
<tr>
<td>3.1</td>
</tr>
<tr>
<td>3.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Entropy (J/kgK)</th>
</tr>
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<tbody>
<tr>
<td>1000</td>
</tr>
<tr>
<td>1200</td>
</tr>
<tr>
<td>1400</td>
</tr>
<tr>
<td>1600</td>
</tr>
<tr>
<td>1800</td>
</tr>
<tr>
<td>2000</td>
</tr>
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- P = 2.2 Mpa
- P = 0.8 Mpa
Temperature oscillation

Temperature oscillation suppressed.

Temperature oscillation less than $\pm 20\text{mK}$ has been achieved.
Conclusion
1. A new, compact 2K GM cryocooler has been developed and the cooling capacity of prototype unit was tested in this study.

2. The prototype unit showed sufficient cooling capability and can meet a wide range of thermal-load:

   No-load condition: 39.2K / 2.09K
   1W/20mW: 44.4K / 2.23K

3. Temperature oscillation displacement under no-load condition was less than ±20mK.

4. Future work: A completely new designed cooling system including cryostat, cryocooler, compressor for small scale applications.
Acknowledgement

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Thank you!