Development of compact 2K GM cryocoolers

Mingyao Xu[1], Qian Bao[1], Akihiro Tsuchiya[1], Rui Li[2]

1: Technology Research Center, Sumitomo Heavy Industries, Ltd.
2: Precision Equipment Group, Sumitomo Heavy Industries, Ltd.

Introduction

For a superconducting electronic device, the requirement for a compact size is crucial because its size is large, comparing with a similar semiconductor device. A good example of superconducting electronic devices is a Superconducting Single Photon Detector (SSPD), which is now under developing at NICT, Japan by Miki et al. The size of an SSPD system is too large, which is the major obstacle to expand its application.

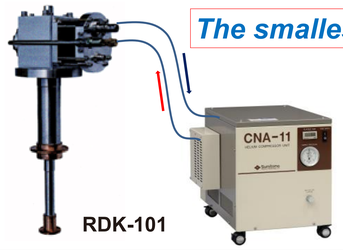
Acknowledgements

The research results have been achieved by "Development of a Compact Superconducting Single Photon Detector System for Photon-Quantum Information and Communication", the National Institute of Information and Communications Technology (NICT), JAPAN.

Conclusion

- A new, compact GM cryocooler, which can be used for cooling superconducting electronic devices, has been developed.
- The cylinder length is reduced by 85 mm compared with a commercial 0.1W 4K GM cryocooler.
- Under no-load condition, a low temperature of 2.1 K and a temperature oscillation of about ±20 mK has been achieved.
- A cooling capacity of 1 W at 44.4 K at the first stage and 20 mW at 2.23 K has also been achieved.
- In order to reach the expander height reduction target, the height of the valve housing assembly will be reduced in together with further cylinder length reduction.

Design Target of the new 2K GM cooler

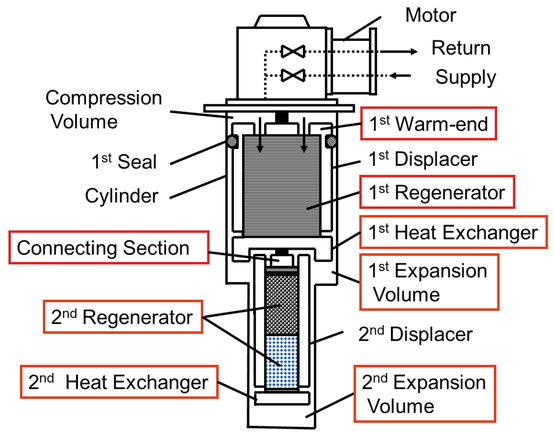


The smallest 4 K GM in the world

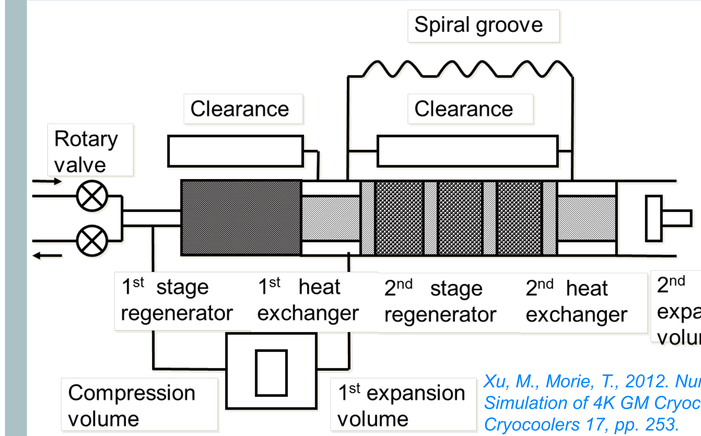
- To reach a no-load temperature of 2.2 K
- To further reduce the expander height to 67 %

Item	RDK-101D	Object
1st Cooling capacity at 60 K	3.0 W	1 W
2nd Cooling capacity at 2.3 K	Unreachable	20 mW
No-load 2nd stage temperature	>3 K	2.2 K
Expander height	442 mm	67 % of RDK-101D
2nd temperature oscillation displacement	> ±30 mK	±20 mK

Schematics of a two-stage GM cooler



Simulation Model & Results



Xu, M., Morie, T., 2012. Numerical Simulation of 4K GM Cryocooler, Cryocoolers 17, pp. 253.

Item	1st Stage at 45 K (W)	2nd Stage at 4.2 K (W)
P-V power	17.5	3.27
Cooling capacity after considering real gas effect	17.2	0.56
Regenerator loss	3.5	0.24
Shuttle loss	1.8	0.06
Pumping loss & thermal conduction loss	3.2	0.20
Radiation loss	1.5	0.0
Net cooling capacity	7.1	0.06

Performance Improvement

▪ Performance improvement with a new regenerator material

Regenerator Material	1st Stage Temperature (K)	2nd Stage Temperature (K)
Bismuth	45.7	2.46
New material	42.2	2.41

▪ Performance improvement with a $HoCu_2$/GOS hybrid regenerator

Magnetic Regenerator Material	1st Stage Temperature (K)	2nd Stage Temperature (K)
$HoCu_2$ only	50.7	2.32
$HoCu_2$/GOS hybrid	46.5	2.22

▪ Performance of the new 2K GM cooler

Item	Object	Measured Results
1st stage temperature with 1 W	60 K	44.4 K
2nd stage temperature with 20 mW	2.3 K	2.23 K
No-load 2nd stage temperature	2.2 K	2.09 K
Expander height	67 % of RDK-101D	81 % of RDK-101D
2nd temperature oscillation displacement	±20 mK	±20 mK

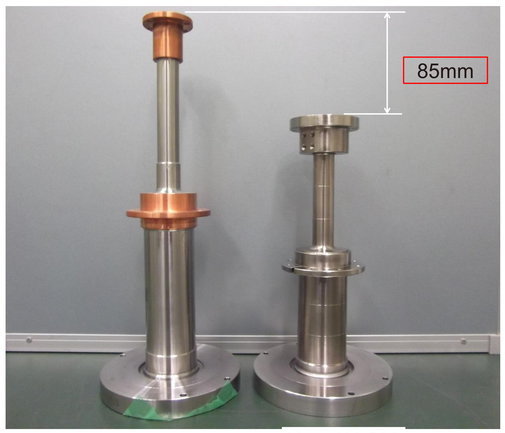
- Improved 3.5 K and 0.05 K with a new regenerator material at the warm-end of the 2nd stage regenerator
- Improved 3.2 K and 0.1 K with a $HoCu_2$/GOS hybrid regenerator

- Reached a no-load of 2.09 K
- Achieved a temperature oscillation displacement of about ±20 mK
- Achieved a cooling capacity of 20 mW at 2.23 K

Cylinder Length Reduction

Item	Length Reduction	Approach
1st Warm-end	5 mm	Design Optimization
Stroke	4 mm	Optimized by Simulation
1st Regenerator	28 mm	
1st Heat Exchanger	5 mm	
Connecting Section	21 mm	New Configuration
2nd Regenerator	10 mm	New Regenerator Material
2nd Heat Exchanger	12 mm	Optimized by Simulation
Total	85 mm	

- Reduced the cylinder length by 85 mm (19% reduction in total height) compared to RDK-101D



Existing 0.1W 4K GM New 2K GM

Sumitomo Heavy Industries, Ltd.