Characteristics of a 1.6 W Gifford-McMahon Cryocooler with a Double Pipe Regenerator

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1. Introduction & Purpose of this study

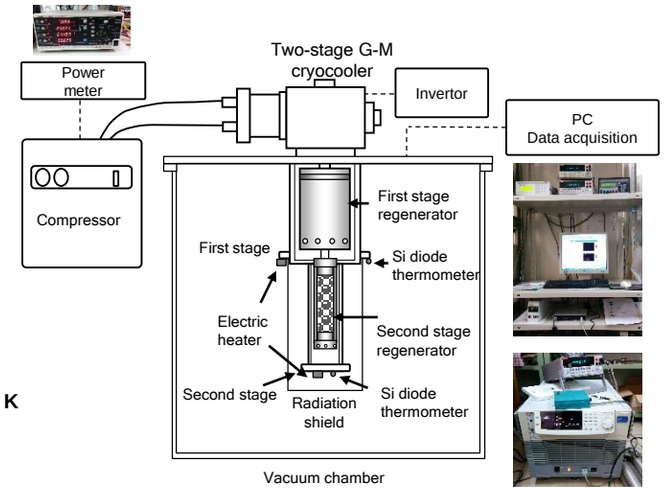
- Regenerative 4 K cryocoolers have been used for wide applications. However, the efficiency is not sufficient ! Much electrical input power is required to maintain the temperatures of 4 K level.
- In order to improve the efficiency at 4 K level, a "***double pipe regenerator***" is applied to the second stage regenerator of a Gifford-McMahon cryocooler.

2. Two-stage GM cryocooler

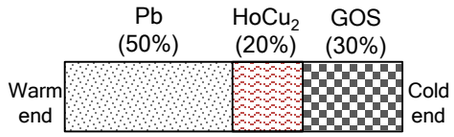
Compressor
C300G
(SUZUKISHOKAN)
7.3 kW at 60 Hz

Two-stage G-M cooler
RDK-408D2 (SHI)
Catalog spec: 1 W at 4.2 K

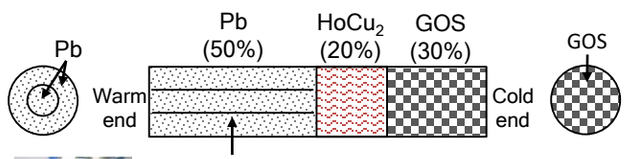
Initial charging pressure: 1.6 MPa
Operating frequency : 1.2 Hz



3. Double pipe regenerator



Three-layer



Three-layer pipe
(double pipe regenerator)

Image photograph

Schematics of the second stage regenerators

Second stage regenerator

	Inner diameter [mm]	Length [mm]
Second stage regenerator	30	140

Regenerator material

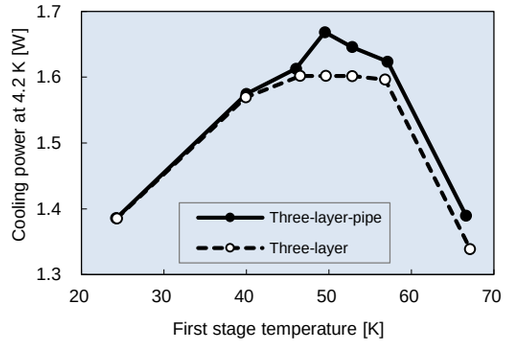
Material	Sphere diameter [mm]
Pb	0.212 – 0.3
$HoCu_2$	0.15 – 0.3
Gd_2O_2S (GOS)	0.25 – 0.3

Inserted stainless steel pipe

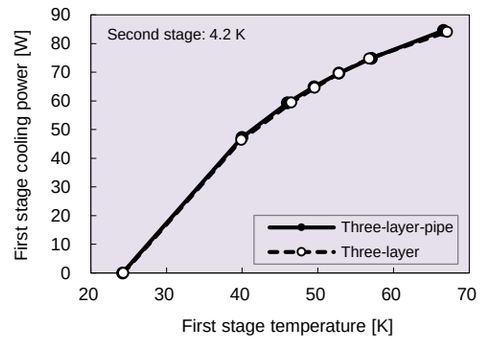
	Outer diameter [mm]	Length [mm]	Thickness [mm]	Thermal conduction loss* [mW]
Pipe	10	67	0.5	44

*Thermal conductivity of stainless steel form 60 K to 4.2 K was used.

4. Experimental results

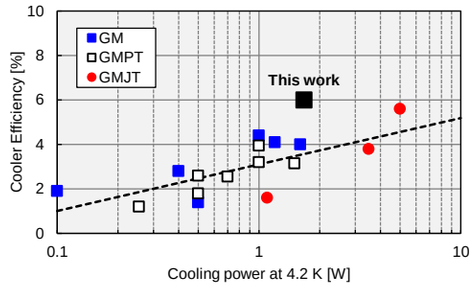


Cooling power at 4.2 K vs. first stage temp.



First stage power vs. first stage temp.

5. Efficiency



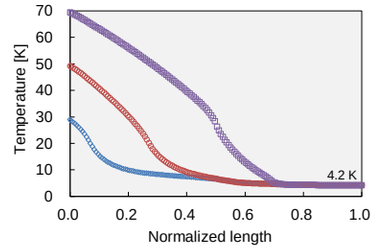
Green has presented the following equation to estimate the efficiency for two-stage cryocoolers. [1]

$$\eta = \frac{1}{P_{com}}\left(Q_1\frac{300-T_1}{T_1}+Q_2\frac{300-T_2}{T_2}\right)\times 100$$

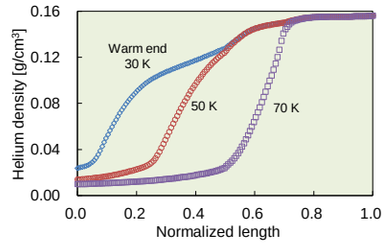
η : Cooler efficiency → 6.0%
Q_1: First stage cooling power at temperature T_1 → 64.9 W at 50 K
Q_2: Second stage cooling power at temperature T_2 → 1.67 W at 4.2 K
P_{com}: Electrical input power of the compressor → 7.37 kW

Ref: [1] Green M A 2015 *IOP Conf, Series.: Materials Science and Engineering* **101** 012001

6. Discussion



Simulated temperature distribution of the three-layer by REGEN3.3



Calculated helium density from the temperature distribution
(helium pressure: 1.5 MPa)

The increase in the mass flow rate from the warm end of 30 K to 50 K

$$\Delta\dot{m} = \alpha f_r V_r \int_0^1 (\rho_{30K} - \rho_{50K})dx$$

$= 0.87$ g/s

$\Delta\dot{m}$: Increased mass flow
α : Porosity
f_r: Operating frequency
V_r : Regenerator volume
ρ : Helium density
x : Normalized length

Calculated mass flow rate at the cold end by REGEN3.3 and measured cooling power at 4.2 K.

Regenerator type	Calculated mass flow rate at the cold end [g/s]			Measured cooling power at 4.2 K [W]	
	Warm end temp.		Increase in mass flow (30 K → 50 K)	Warm end temp.	
	30 K	50 K		30 K	50 K
Three-layer	5.70	6.25	0.55	1.45	1.60
Three-layer pipe (double pipe)	5.70	6.52	0.82	1.45	1.67

7. Summary

- The second stage cooling power of **1.67 W at 4.2 K** and the first stage cooling power of **64.9 W at 50 K** were achieved.
- The double pipe regenerator is able to improve the second stage cooling power at 4.2 K and restrain the non-uniform flow, then increase the mass flow rate at the cold end.

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