A Compact Cold Helium Circulation System with GM Cryocooler

C. Wang, E. Brown and A. Friebel

Cryomech, Inc.,
Syracuse, NY 13211, USA

ABSTRACT

A new cold helium circulation system with a GM cryocooler, model CHCS110, has been developed to replace an existing cold helium circulation system model at Cryomech, Inc. A set of check valves connects to the cold head expansion chamber to convert a small portion of AC oscillating flow in the cold head to DC gas flow for circulating cold helium in the remote loop. The GM cryocooler, model AL200 (nominal 200 W at 77 K), is used to build the cold helium circulation. The orifice for controlling the circulation flow and regenerator geometry are optimized for capacity at 77 K. Cold helium circulates through a 5 m long flexible transfer line to a co-axial cold finger. The cold finger can provide 109 W at 77 K with a total power input of 7.7 kW. The new cold helium circulation system features a compact size, lower vibration, and lower cost than the existing cold helium circulation system.

INTRODUCTION

Cold helium circulation with a GM cryocooler is a cooling solution for a remote location, such as cooling sapphire laser amplifiers[1], IR detectors, and HTS superconducting devices[2], etc. The benefits of the remote cold finger are very low vibration, smaller size, and easy integration. However, these cold helium circulation systems (CHCS) employ a counter flow heat exchanger and independent circulation loop. These components make the system bulky and expensive to manufacture.

A continuous flow integrated circulator has been developed for a pulse tube cryocooler by Maddocks, et al[3]. It is a rectifier that converts the oscillating flow (AC flow) of a regenerative cryocooler into a circulating flow (DC flow) of cold gas that can be distributed for remote cooling.

We employed a similar concept to develop a GM cryocooler with cold helium circulation[4]. Two check valves and orifices are used for the rectifier at the bottom of the cold head to control the circulation flow. Different configurations of orifice size and location in the circulation loop had been investigated for obtaining the optimum performance. Using a model AL125 cryocooler (nominal 125 W at 77 K), the cold finger provided 50 W at 81 K for a power input of 4.1 kW.

A production model, CHCS110, has been developed at Cryomech, Inc. with this new technology. The design and performance optimization are presented in this paper.

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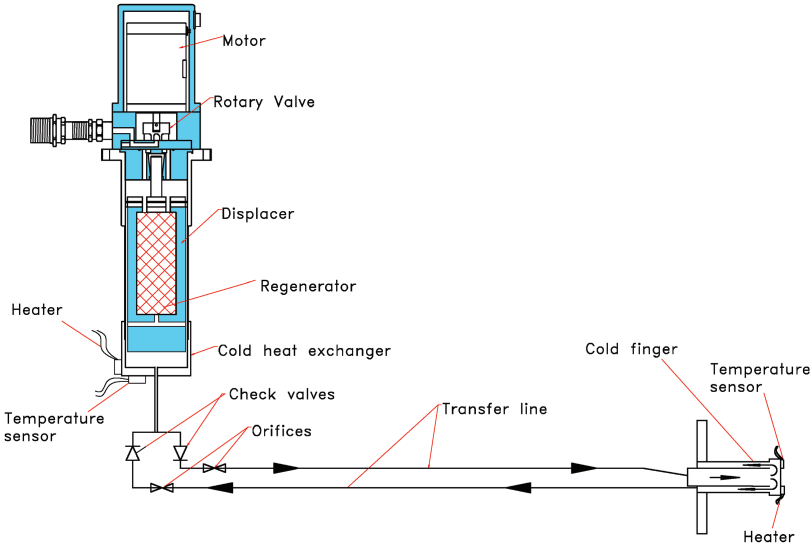

Figure 1. Schematic of the new CHCS with a GM cryocooler.

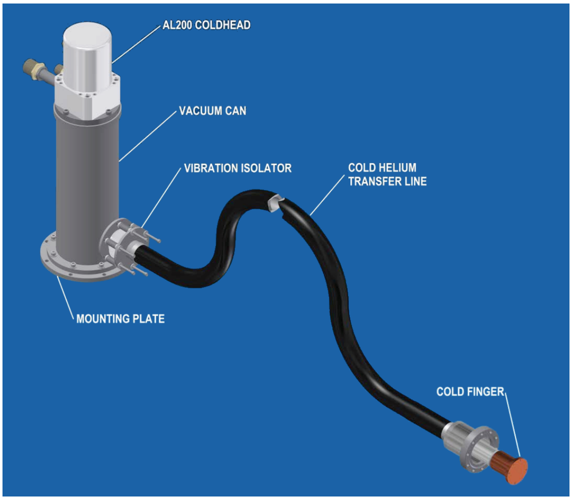

Figure 2. Design of the new CHCS, CHCS110.

SYSTEM DESIGN

Fig. 1 shows the schematic of the GM cryocooler with cold helium circulation. The location of orifices is chosen based on the results of the comparison test in reference [4] for the best cooling performance and lowest vibration. The vibration measurements of the cold finger with parallel flow pattern in reference [4] indicate higher displacement of ~±2 μm in the horizontal direction at the cold finger. In the production model, a coaxial cold finger is designed to reduce the horizontal vibrations.

Fig. 2 shows the design of the new CHCS, model CHCS110. The cold helium transfer line is 5 m long and vacuum insulated. The GM cryocooler is the model AL200 which has a nominal cooling capacity of 200 W at 77 K. A bellows assembly is added between the cold head vacuum chamber and the cold helium transfer line to damp the vibration from the cold head assembly to the cold finger.

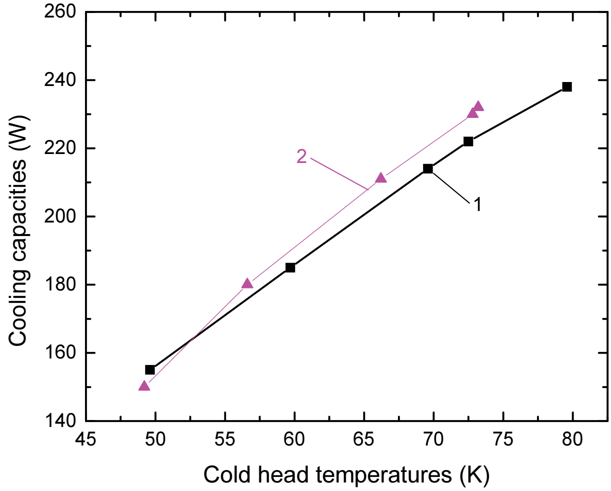

Figure 3. Cooling capacities of the AL200 cold heads. 1. AL200 cold head A for the new CHCS; 2. AL200 Cold head B for the existing CHCS

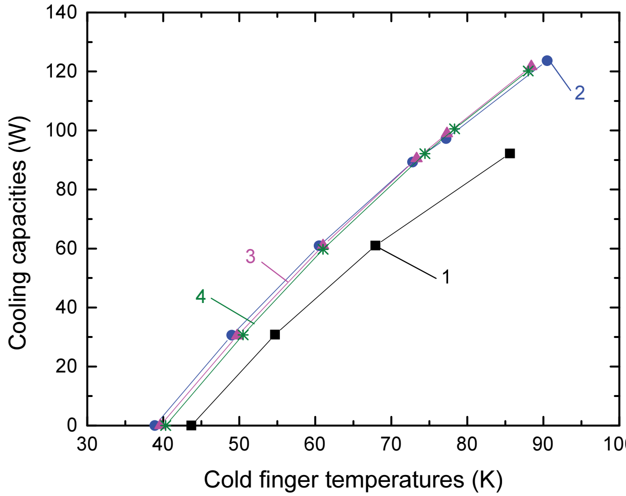

Figure 4. Cooling capacities of the cold finger with the different orifice diameters. 1. 0.84 mm; 2. 0.94 mm; 3. 1.02 mm; 4. 1.09 mm.

EXPERIMENTAL RESULTS AND ANALYSIS

Before assembling the cold helium circulation components, the standard AL200 cold head with a CP289C compressor was tested. Fig. 3 shows the performance of the AL200 cold heads. Cold head A was used for the new CHCS. Cold head B was used for the existing CHCS. Cooling performances of both CHCSs have been compared later on. Both cold heads are running with the same CP289C compressor. Cold head B has a higher cooling capacity than that of cold head A by ~10 W at 73 K.

Cold head A was installed in the new design of the cold helium circulation system. The orifices on both the inlet and outlet of the transfer lines were optimized for the best performance. The two orifices had the same diameter for each test. Fig. 4 shows the cooling capacity with different diameters of the orifices. The three orifice diameters of 0.94 mm, 1.02 mm and 1.09 mm give similar cooling capacities in the measured temperatures. The following results are obtained with the orifice diameter of 1.02 mm.

Table 1. Mass flow through the cold finger

T_{in} (K)	T_{out} (K)	T_{cf} (K)	Q (W)	P_l (kPa)	P_h (kPa)	P_{ave} (kPa)	$\dot{m}$
58.9	76.3	76.6	101	655	2425	1540	1.1 g/s
61.6	81.2	81.3	110				1.1 g/s

T_{in} is inlet temperature of the cold finger; T_{out} is outlet temperature of the cold finger; T_{cf} is temperature of the cold finger; Q is cooling capacity on the cold finger; P_l is suction pressure of the compressor; P_h is discharge pressure of the compressor; P_{ave} is average pressure in the transfer line; $\dot{m}$ is calculated mass flow rate.

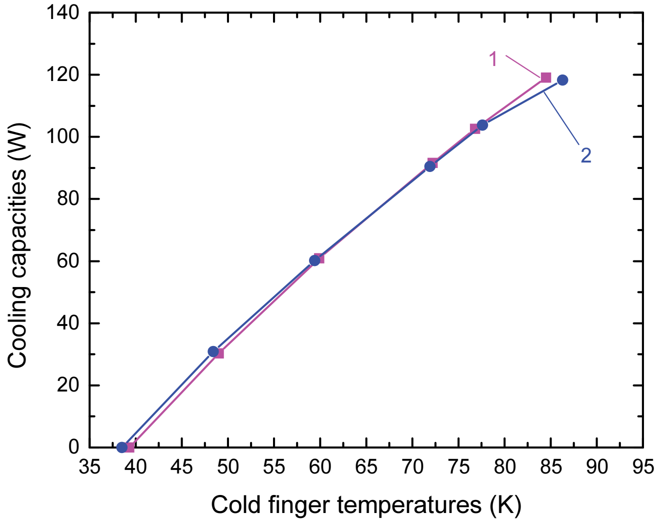

Figure 5. Cooling capacities of the cold finger with different strokes of the cold head displacer. 1. 32 mm stroke; 2. 29 mm stroke.

The mass flow rate passing through the cold finger is calculated by using Eq. (1). The measured three temperatures, cooling capacity, and high/low pressures are given in Table 1. The calculated mass flow rate for the cold helium circulation through the cold finger is 1.1 g/s. The CP289C compressor provides a mass flow rate of ~6.2 g/s in the operating pressures in Table 1. The cold helium circulation loop takes ~18% of the total mass flow rate from the compressor.

$$Q = \dot{m}\, C_p\, \Delta T \tag{1}$$

The cooling capacities of the cold finger with two different stroke lengths of the cold head displacer are given in Fig. 5. Modifying the stroke of the displacer barely changes the cooling capacity near 77 K. However, it tends to provide higher cooling capacities at higher temperatures, and lower cooling capacities at lower temperatures.

The cooling capacities of the cold finger with different regenerator sizes are given in Fig. 6. Considering the larger amount of mass flow through the cold head regenerator, the regenerator size is increased to improve the regenerator efficiency. Curve 1 in Fig. 6 represents the increased diameter of 50.8 mm for the regenerator. The larger diameter regenerator improved cooling capacities at all temperatures. The cooling capacity was increased by ~6 W at 77 K. The standard 47.6 mm regenerator was tested with an increased length and showed a decrease in performance.

The cooling capacities of the new and existing CHCS are compared in Fig. 7 along with the input power to the system. The new CHCS had a cooling capacity of 109 W @ 77 K with a power input of 7.8 kW. The existing CHCS had a cooling capacity of 128 W @ 77 K for the same power input. The new CHCS has a little less cooling capacity than the existing one. The

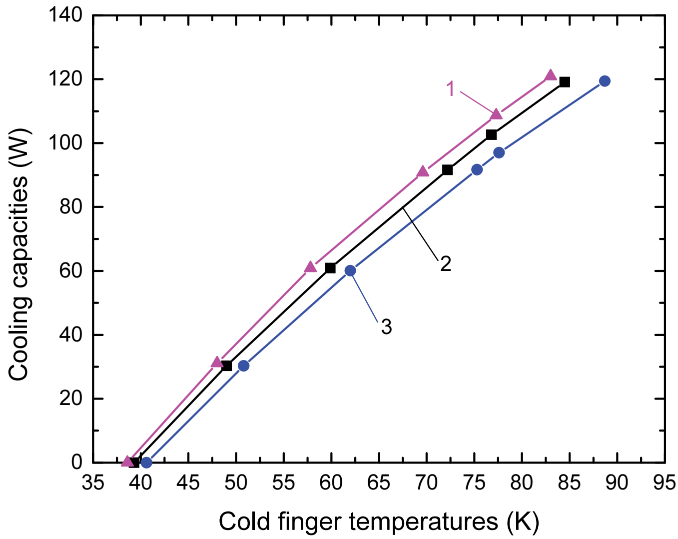

Figure 6. Cooling capacities of the cold finger with different regenerators. 1. Increased regenerator diameter of 50.8 mm; 2. Standard regenerator with a diameter of 47.6 mm; 3. Increased length of the standard regenerator by 19 mm.

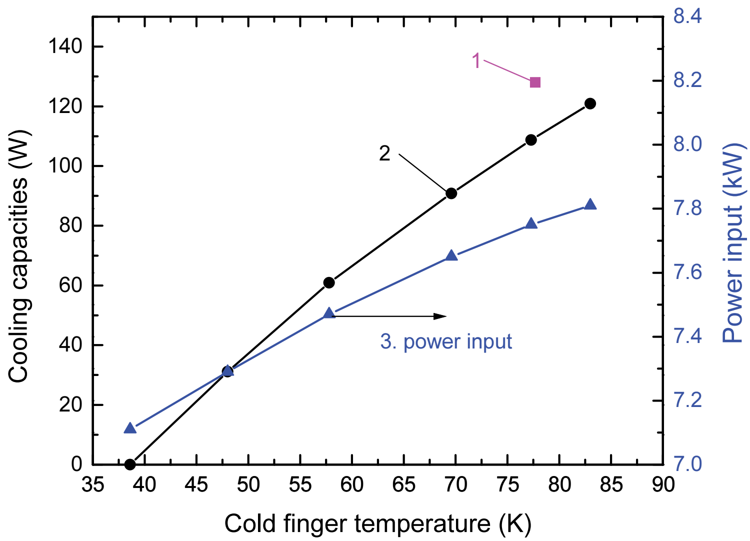

Figure 7. Performance comparison of the new CHCS with the existing CHCS. 1. Cooling capacity of the existing CHCS; 2. Cooling capacity of the new CHCS; 3. Power input of the CHCS.

cold head used with the existing CHCS has ~10 W higher capacity at 73 K than the cold head used with the new CHCS. The differences in cooling capacity are partly due to the differences of cooling capacity of the individual cold heads used.

Future works of the new CHCS will include using better check valves and improving the efficiency of the transfer line.

CONCLUSION

A compact and low cost cold helium circulation system, model CHCS110, has been developed at Cryomech to replace the existing cold helium circulation system. It can provide 109 W at 77 K with 7.8 kW power input. The new system will soon be used for cooling laser amplifiers and some other applications.

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