# Development of High-Capacity Single-Stage GM Cryocooler

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## ABSTRACT

Markets for single-stage Gifford-McMahon (GM) cryocoolers are pushing towards higher-capacity systems with higher efficiencies. Sumitomo (SHI) Cryogenics of America, Inc. has developed a high-performance, low-noise single-stage cryocooler for LN2 generators, HTS applications, and circulating cooling system applications. This cooler provides higher liquefaction rates, faster cool down times, and better efficiencies. The development of this high-capacity single-stage GM cryocooler, which has a capacity of more than 600W at 77K at 60Hz, is described in this paper. The presented research includes trade-off studies during development, such as the cryocooler's performance at different speeds and regenerator designs.

## INTRODUCTION

Sumitomo (SHI) cryogenics has been working on developing a high-capacity single-stage cryocooler which has high cooling power at liquid nitrogen temperature (77K) to address the demand from our customers to build compact, cost effective, and higher efficiency systems for LN2 generators, HTS, and circulating cooling system applications. During the ICC19 conference in 2016, the development status and prototype results were provided. In this paper we present the released product design and lessons learned throughout development.

The first prototype was built with our traditional scotch-yoke driven GM type cryocooler design with typical cooling capacity of 650W at 80K with ~14kW input power. Work continued over the past several years, where we combined our CH series pneumatic drive technology with other novel technologies resulting in the release of the CH-160D2. It has a specified cooling capacity of 525/630W at 50/60Hz respectively, with an input power of 15-18kW.

## CRYOCOOLER DESIGN

The CH-160D2 Cold Head consists of a cylinder, a displacer, a drive mechanism, and a drive motor. The motor drives a rotary valve which controls the timing of the helium gas intake and exhaust, synchronized with the reciprocating motion of the displacer assembly. Unlike our original prototype GM cryocooler driven by a scotch-yoke, the displacer in the CH-160D2 is connected to a driving stem, which is driven by the gas pressure difference.

The displacer assembly, containing the regenerator, slides within the cylinder, and the helium gas, passing through the regenerator, cools the materials within the regenerator. Gas exiting the

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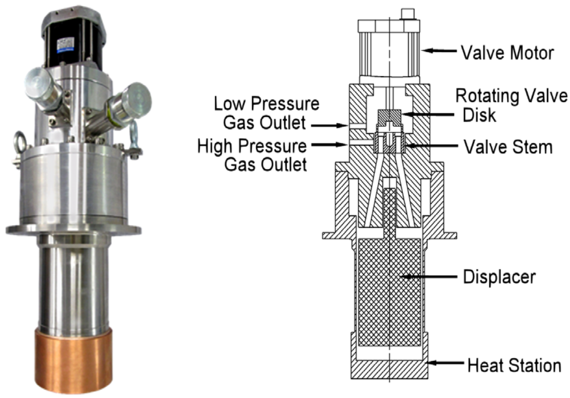


**Figure 1.** High-Capacity Single-Stage GM Cryocooler: (left) Picture; (right) Outline.

regenerator can be cooled to around 20-30 K depending on the material properties of the regenerator material. Shown in Figure 1, the main features of the CH-160D2 are:

- Pneumatic drive technology to limit the number of wear parts in the cryocooler.
- New gas-balanced valve design to reduce the torque, which in turn reduces the size of the motor required and the wear of the valve disc.
- Stem drive design which functions based on the gas pressure difference and improves overall efficiency
- Gas-energized seals on the displacer assembly which: reduces the wear, stabilizes the stroke, and increases product reliability.
- Novel heat exchanger designed with high surface area and an increased efficiency in transferring cooling from the expansion volume to the heat station
- Fixed orifice for low cost & performance stability.

## SYSTEM DESCRIPTION

The typical, complete operating system consists of a helium compressor, interconnecting gas lines, cryocooler cable, and the cryocooler. Electricity to power the cryocooler's drive motor is supplied from the compressor by the cryocooler cable. Figure 2 shows a typical system configuration with two F-70 compressors, while Figure 3 shows a typical configuration with one F-100 compressor.

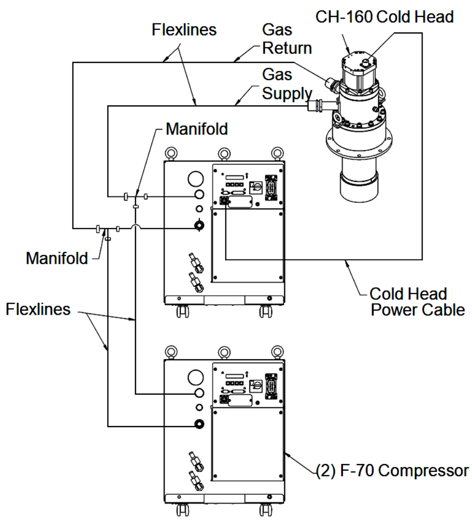


**Figure 2.** System with two F-70 Compressors.

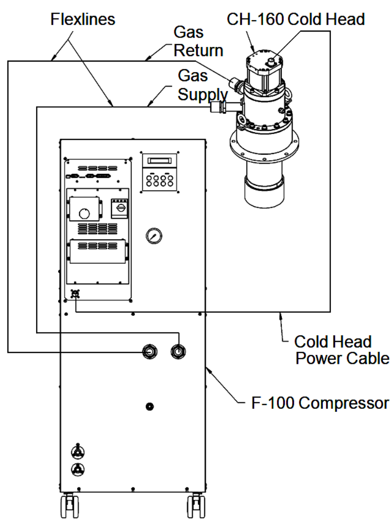


**Figure 3.** System with one F-100 Compressor.

**Table 1.** Performance Specification of CH-160D2 with (2) F-70 Compressors.

| Power Supply | 50 Hz | 60 Hz |
|---|---|---|
| Specified Cooling Capacity with (2) F-70's | 525W@77K | 630W@77K |
| Input Power | 15 kW | 18 kW |
| Minimum Temperature | <35K | |
| Cool Down Time to 77K | <20 minutes | |
| Equalization Pressures | 215-225 psig | |
| Typical Operating Pressures | Supply: 290-330psig<br>Return: 80-110psig | |
| Maintenance Interval | 8000hrs | |

**Table 2.** Performance Specification of CH-160D2 with (1) F-100 Compressor.

| Power Supply | 50 Hz | 60 Hz |
|---|---|---|
| Specified Cooling Capacity with F-100 | 455W@77K | 545W@77K |
| Input Power | 11.5kW | 14.5kW |
| Minimum Temperature | <35K | |
| Cool Down Time to 77K | <20 minutes | |
| Equalization Pressures | 227-237 psig | |
| Typical Operating Pressures | Supply: 275-315psig<br>Return: 100-125psig | |
| Maintenance Interval | 8000hrs | |

Table 1 shows the performance specification of the CH-160D2 with two F-70 compressors. The specified cooling capacities are: 525W at 77 K and 50 Hz, and 630W at 77 K and 60 Hz. The minimum system temperature is <35 K. The input power is 15-18 kW. Table 2 shows the performance specification of the CH-160D2 with one F-100 compressor. The minimum system temperature is <35K. The input power is 11.5-14.5 kW. The performance has been validated on multiple engineering prototypes and production-built cryocoolers. The cryocooler has an 8000 hr maintenance interval. Currently, work is in progress to increase this to a service interval of 13,000 hrs.

## TEST RESULTS AND ANALYSIS

### Regenerator and Orifice Optimization

Based on the finalized cryocooler design, engineering prototypes were manufactured to optimize the regenerator and orifice. The system configuration with two F-70 compressors was used to perform the optimization tests. Several regenerator diameters were tested to optimize the performance near 77 K. Figure 4 shows temperature data with a constant heat load of 650W at the cold end with both different regenerator diameters and cryocooler motor frequencies. Regenerator A is 5 mm smaller than regenerator B; regenerator C is 3 mm larger than regenerator B. The larger regenerator shows improved performance, but there is an optimized regenerator B for specific flow and stroke length

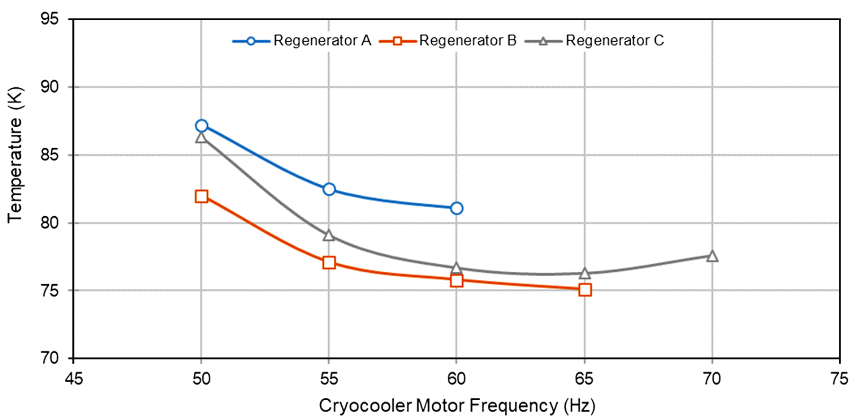


**Figure 4.** CH-160D2 Regenerator Optimization-Temperature at 650 W.

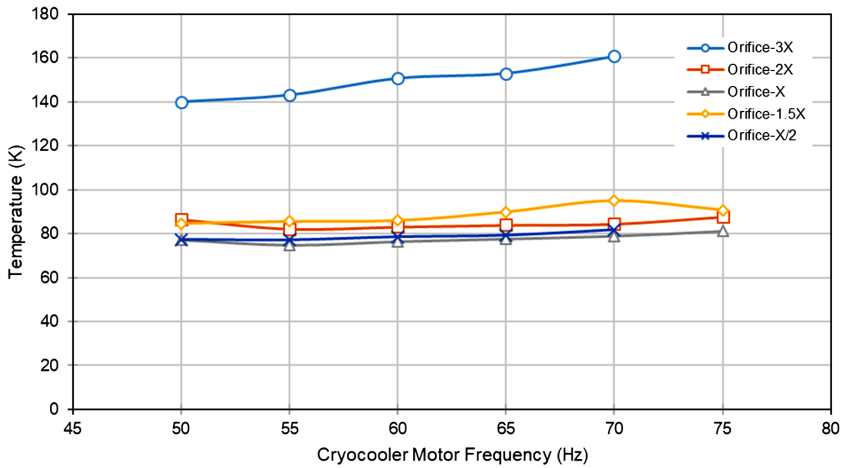


**Figure 5.** CH-160D2 Orifice Optimization-Temperature at 600 W.

which has lower pressure drop and uses the regenerator area more efficiently for heat exchange when compared to regenerator C.

Figure 5 shows temperature data with a constant heat load of 600W at the cold end with different orifices and cryocooler motor frequencies. Smaller orifices, such as X and X/2, provide better performance, as the flow difference at the stem drives the displacer more efficiently. This creates a more ideal stroke and more work is produced at the expansion space of the cold end. Bigger orifices like 3X tend to experience greater regenerator losses.

## Cooling Capacity and Cool Down Curve

Cooling capacity tests were conducted on multiple engineering and production CH-160D2 cryocoolers with the two F-70 compressor system configuration (Figure 2) and with the one F-100 compressor system configuration (Figure 3). Performance was measured at the cold end of the heat exchanger from 0-700W. Typical capacity maps are shown in Figure 6.

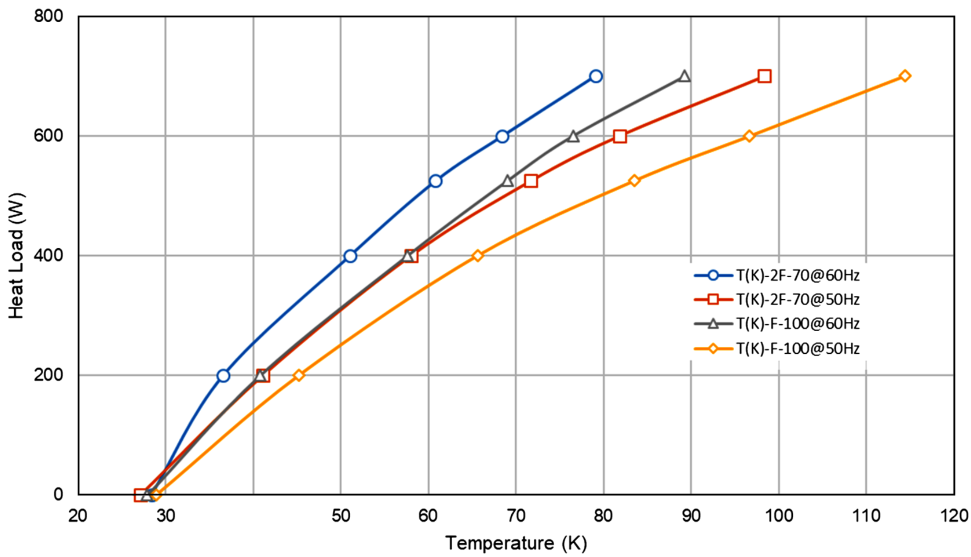


**Figure 6.** Typical Capacity Maps of CH-160D2 with (2) F-70 and F-100.

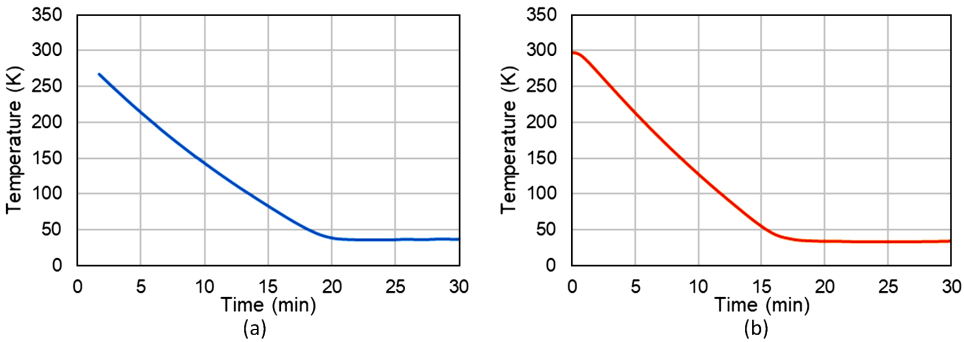


**Figure 7.** Typical Cool Down Curve of CH-160D2 with (1) F-100 at (a) 50Hz and (b) 60 Hz.

The measured cooling capacities of the CH-160D2 cryocooler with two F-70 compressors are: 560W at 77K and 580W at 80K at 50Hz; 670W at 77K and 700W at 80K at 60Hz. This provides good margin against our performance specifications shown earlier in Table 1.

The measured cooling capacities of the CH-160D2 cryocooler with one F-100 compressor are: 480W at 77 K and 500W at 80 K at 50 Hz; 590W at 77 K and 615W at 80 K at 60 Hz. This provides good margin against our performance specifications shown earlier in Table 2.

Example cool down curves are shown in Figure 7. With no heat load it takes <13 minutes to reach 77 K, <20minutes to reach <35 K, and about <40 minutes to reach minimum temperature at 50/60 Hz. Typical minimum temperature is <30 K.

## Sound Level

The CH-160D2 cryocooler system has a rated sound level of ≤72 dBA at 1 m at 60 Hz and rated sound level of ≤71 dBA at 1 m at 50 Hz in a reflective environment as seen in Table 3. The sound level measure includes both compressor and cryocooler. We expect the cryocooler sound level by itself will be <70 dBA if isolated tests are conducted.

## CONCLUSIONS

Sumitomo (SHI) Cryogenics of America, Inc. developed a high-capacity single-stage cryocooler, the CH-160D2, available in the market for liquid nitrogen temperature applications. Typical cooling capacities with the two F-70 compressor configuration are: 560W at 77 K and 580W at 80 K at 50 Hz; 670W at 77 K and 700W at 80 K at 60 Hz. Typical cooling capacities with the one F-100 compressor configuration are: 480W at 77 K and 500W at 80 K at 50 Hz; 590W at 77 K and 615W at 80 K at 60 Hz. Typical cool down time to 77 K is <13 minutes and to minimum temperature is <40 minutes at 50/60 Hz with both configurations.

The CH-160D2 system has a rated sound level of ~71-72 dBA at 1.0 m at 50/60 Hz. Future work is under progress to develop a low temperature version of the CH-160D2 to target performance in the range of ~30 K.

**Table 3**. Sound Levels of CH-160D2 with (1) F-100 Compressor at 50 and 60Hz.

| Sound Level at 50Hz | | Sound Level at 60Hz | |
|---|---|---|---|
| | Simpson Sound Meter at 1m (dBA) | | Simpson Sound Meter at 1m (dBA) |
| Cool Down | 71 | Cool Down | 72.1 |
| Minimum Temperature | 69.7 | Minimum Temperature | 70.2 |
| At 525W | 70.4 | At 630W | 71.5 |
| At 600W | 10 | | |

## REFERENCES


1. K. Yamada, "Development of a large cooling capacity single stage GM cryocooler," *Cryogenics,* vol. 63, (2014), pp. 110-113.
2. Q. Bao, M. Xu and K. Yamada. "Development Status of a High Cooling Capacity Single Stage GM Cryocooler," *Cryocoolers 19*, ICC Press, Boulder, CO (2016), pp. 291-299.