A 4 K Pulse Tube Cryocooler with Large Cooling Capacity

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ABSTRACT

We are developing a large cooling capacity pulse tube cryocooler to be used for applications such as cryogen-free dry dilution refrigerators and large superconducting magnets, etc. The pulse tube cryocooler with standard design, model PT420S, is driven by a compressor, Cryomech model CP1114, with an input power of ~11.5 kW. After optimizing the PT420S design, it provides, simultaneously, a cooling capacity of 2.01 W at 4.2 K on the 2nd stage and 52.6 W at 45 K on the 1st stage. By modifying the first stage regenerator and flow controls, a large cooling capacity of 83 W at 45 K and 1.85 W at 4.2K could be provided. A low vibration design with a remote motor, Model PT420RM, can provide 1.76 W at 4.2K and 53W at 45 K.

INTRODUCTION

4 K pulse tube cryocoolers have opened many challenging applications which require low vibration, high reliability and long mean time between maintenance. For example, they cool superconducting magnets and SQUIDs; pre-cool dilution refrigerators, He3 adsorption coolers and adiabatic de-magnetization refrigerators for sub-Kelvin cooling[1,2]. Some 4 K pulse tube cryocoolers have been used for laboratory scale helium liquefiers and reliquefiers to re-liquefy the boil off from open liquid helium cryostats[3]. Many Cryomech 4 K pulse tube cryocoolers have operated continuously for more than 50,000 hours in the field without cold head maintenance.

Currently, the largest 4 K pulse tube cryocooler can provide 1.5 W at 4.2 K. Some large superconducting magnets have to use multiple 4 K pulse cryocoolers[4]. Furthermore, some applications of dry dilution refrigerator demand a large 4 K pulse tube cryocooler to increase cooling capacity at a temperature of ~10 mK. Some laboratories also require helium liquefiers with higher liquefaction rate.

In response to these market demands, Cryomech is developing a larger 4 K pulse tube cryocooler to provide a cooling capacity of ~2 W at 4.2 K. This paper presents some results of the development.

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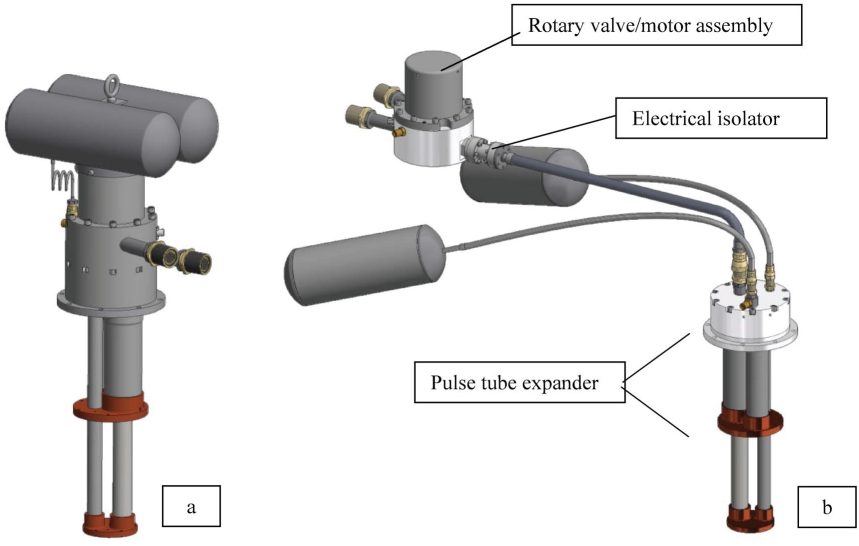

Figure 1. Large 4 K pulse tube cryocoolers. (a) standard design, model PT420S; (b) remote motor design, model PT420RM.

SYSTEM DESIGN

We are developing the 4 K pulse tube cryocooler with two types of rotary valve integration. 1. Standard design with the rotary valve/motor assembly integrated on the warm end of the pulse tube expander, See figure 1 (a), Model PT420S; 2. Remote motor design with the rotary valve/motor assembly separated from the pulse tube expander, see figure 1 (b), Model PT420RM. The standard design of the 4 K pulse tube cryocooler had been described in reference [1].

In the remote motor design, the rotary valve/motor assembly is connected to the pulse tube expander through a 61 cm long stainless steel flexible line. An electrical isolator is installed on the flexible line to isolate electrical noise generated by the compressor and cold head motor. Two reservoir volumes are connected to the pulse tube expander through one meter long stainless steel flexible lines. The remote motor model can be used for extremely vibration-sensitive applications.

Both the PT420S and PT420RM are driven by the same compressor, Cryomech model CP1114, with an input power of ~11.5 kW.

PERFORMANCE AND DISCUSSION

Performance Optimization

The development of the larger 4 K pulse tube cryocooler was started with the standard cold head model PT420S by modifying an existing 4 K pulse tube cryocooler, model PT415, which provides 1.5 W at 4.2 K. The new system is driven by a larger compressor model, CP1114.

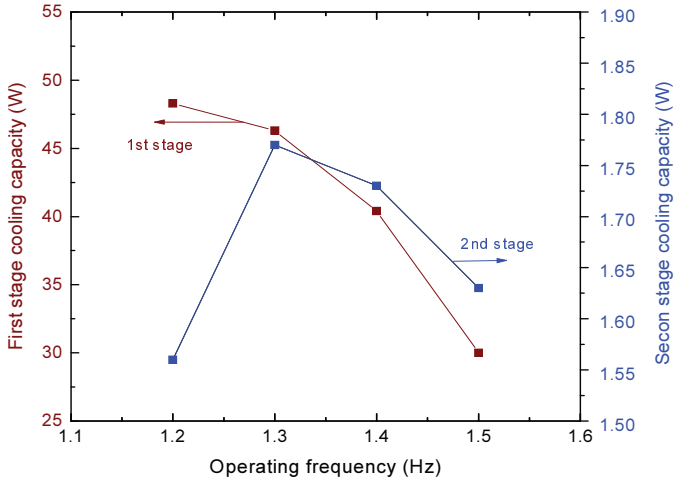

Figure 2. Performance optimization at different operating frequencies

The performance of the 1st stage at 45 K and 2nd stage at 4.2 K has been tested at several operating frequencies. The results are given in Figure 2. The 2nd stage provides the best performance of 1.77 W at 4.2 K with a frequency of 1.3 Hz. It also can also provide 1.73 W at 4.2 K with a 1.4 Hz operating frequency. All existing 4 K pulse tube cryocoolers at Cryomech operate at 1.4 Hz. Considering production compatibility, an operating frequency of 1.4 Hz was chosen for the PT420. The following improvements are all obtained at the frequency of 1.4 Hz.

Table 1 lists the performance improvements seen with a few modifications. Using new heat exchangers for the 1st and 2nd stage, the performance of the PT420S was improved to have 1.88 W on the 2nd stage and 41.4 W on the 1st stage. The highest 2nd stage capacity of 2.01 W at 4.2 K was achieved by increasing the sizes of both 1st and 2nd stage pulse tube volumes. Modifying the 1st stage regenerator gives the best 1st stage performance of 83W at 45 K. We obtained two results for the best 1st stage performance or the best 2nd stage performance with the No.3 design or No. 4 design.

Figure 3 shows the cooling capacity map for the best 2nd stage performance implementing the No. 3 design. It achieves bottom temperatures of 31.5 K on the 1st stage and 2.83 K on the 2nd stage. It can simultaneously provide 52.6 W at 45 K and 2.01 W at 4.2 K with an input power of 11.42 kW.

Table 1. Performance improvements of various designs

Cooling performance	No.1 design	No. 2 design	No. 3 design	No. 4 design
1st stage at 45 K	40.6 W	41.4 W	52.6 W	83.0 W
2nd stage at 4.2 K	1.73 W	1.88 W	2.01 W	1.85 W

No. 1, original PT415; No. 2, New 1st and 2nd stage heat exchanger; No. 3, increase both 1st and 2nd stage pulse tube volume; No. 4, new 1st stage regenerator.

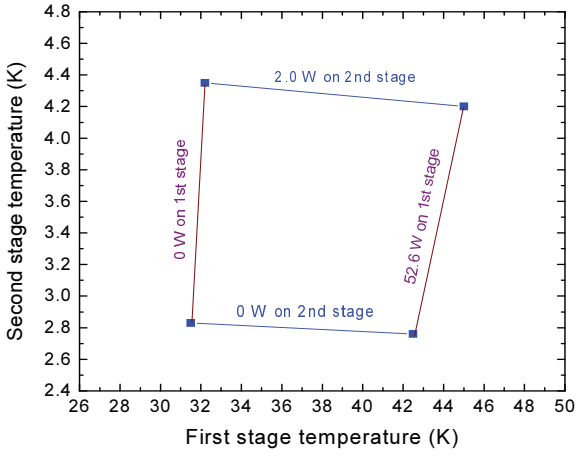

Figure 3. Cooling capacity map for the best 2nd stage cooling capacity

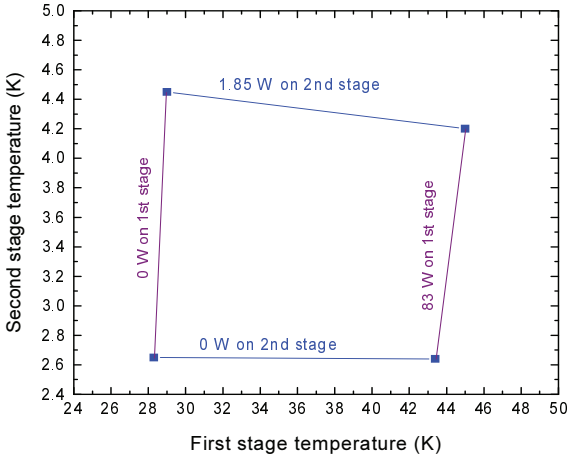

Figure 4. Cooling capacity map with a new regenerator

Figure 4 shows the cooling capacity map for the best 1st stage performance with No. 4 design. It has a lower bottom temperature of 28.3 K for the 1st stage and 2.65 K for the 2nd stage. The No. 4 design achieved lower temperatures on both stages than the No.3 design. The cryocooler can simultaneously provide 83 W at 45 K and 1.85 W with an input power of 11.47 kW.

Figure 5 shows a cool-down time of the PT420S with the No.4 design. The cool-down speed is measured with a 60 W heat load on the 1st stage and a 1.8 W load on the 2nd stage. It takes 133 min for the 1st stage to reach a bottom temperature of 38.7 K and 105 min for the 2nd stage to reach a bottom temperature of 4.15 K.

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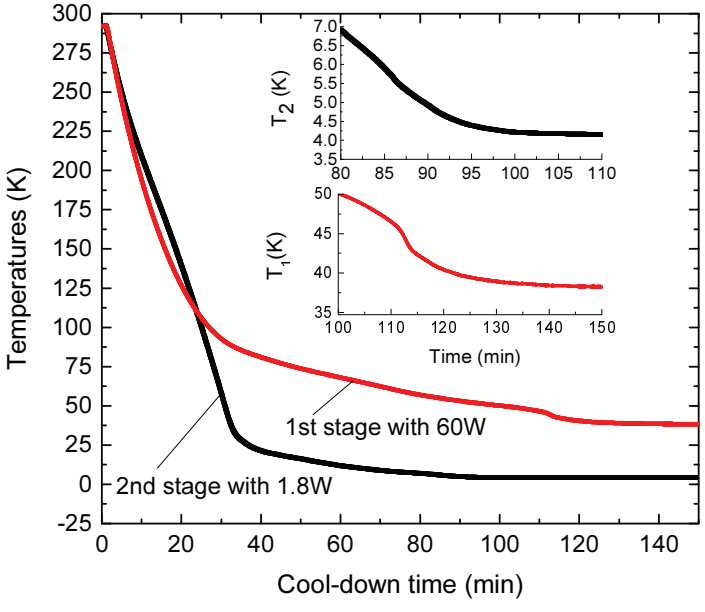

Figure 5. Cool-down curve of the PT420S

Performance of the remote motor model, PT420RM

Based on the improved performance of the PT420S, two remote motor pulse tube cryocoolers, Model PT420RM, were built for an OEM customer. They have comparable performance on both 1st and 2nd stages. Table 2 lists their performance. The cooling load map of #1 system is given in figure 6. It has bottom temperatures of 29.0 K on the 1st stage and 2.73 K on the 2nd stage. It provides 53 W at 45 K and 1.76 W at 4.2 K simultaneously with a power input of 11.34 kW. Comparing the results of the PT420RM with that of the PT420S, the 1st stage cooling capacity is significantly reduced from 83 W to 53 W at 45 K. This loss will be investigated later on.

Table 2. Performance of two PT420-RM systems

Cooling performance	#1 system	#2 system
1st stage at 45 K	53.0 W	52.6 W
2nd stage at 4.2 K	1.76 W	1.74 W

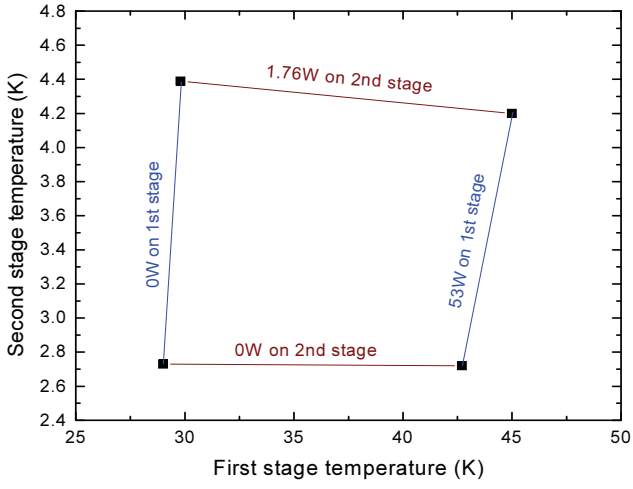

Figure 6. Cooling load map of the PT420RM

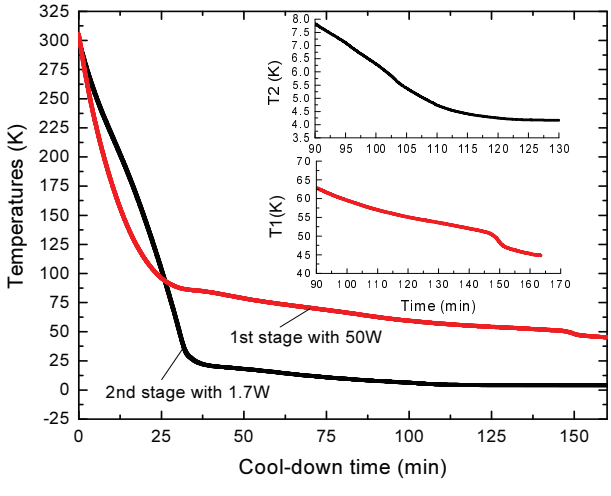

Figure 7. Cool-down curve of the PT420RM

Figure 7 shows the cool-down curve of the PT420RM with 50W on the 1st stage and 1.7 W on the 2nd stage. The PT420RM, with lower heat loads on the both stages, has a slower cooling down rate than the PT420S. It takes 125 min for the 2nd stage to reach a temperature of 4.14 K and 160 min for the 1st stage to reach 44.7 K.

Development of the PT420 pulse tube cryocooler is still ongoing to achieve better performance and a faster cool-down rate.

CONCLUSION

A high cooling capacity 4 K pulse tube cryocooler, with options of the standard and remote motor cold heads, is being developed at Cryomech, Inc. So far, this cryocooler can provide 2.01 W at 4.2 K and 52.6 W at 45 K using a standard cold head. Using a low vibration remote

motor cold head, it can provide 1.76 W at 4.2 K and 53 W at 45 K. Developments are ongoing to provide a final product with increased performance.

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REFERENCES

1. Wang, C., "Characteristic of 4 K Pulse Tube Cryocooler in Application," *Proceeding of ICEC20*, Elsevier Publisher (2005), pp. 265-268.
2. Uhlig, K., "Dry dilution refrigerator with pulse-tube precooling," *Cryogenics,* Vol. 44 (2004), p. 53.
3. Wang, C., "A helium re-liquefier for recovery and liquefying helium vapor from cryostat," *Advances in Cryogenic Engineering,* Vol.55A, AIP publisher, Melville, NY (2010), pp. 687-694.
4. Green, M.A. and Wang, S.T., "Tests of four PT415 coolers installed in the drop-in mode," *Proceedings of ICEC-22*, Published by KIASC, Seoul Korea (2008), pp. 105-110.