

Characteristics of 4 K pulse tube cryocoolers in applications

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Cryomech has developed and commercialized 4 K pulse tube cryocoolers, Models PT403, PT405, PT407 and PT410, which provide cooling capacities from 0.25 W to 1.0 W at 4.2K. The latest developments at Cryomech enabled the pulse tube cryocoolers to have almost the same capacity and efficiency as GM cryocoolers. The pulse tube cryocoolers have opened many applications and demonstrated their advanced features with respect to long meantime between maintenance, very low vibration and small magnetic field distortion from rare earth materials.

INTRODUCTION

The 4 K pulse tube cryocooler is a new generation of cryo-refrigeration system that can provide cooling capacities below 4 K. It has no moving parts at cryogenic temperatures and leads to advanced features over the 4 K GM cryocooler.

Cryomech, Inc. commercialized the world's first 4 K pulse tube cryocooler, Model PT405 in 1999¹. In recent years, we have continually developed and commercialized a series of 4 K pulse tube cryocoolers, Models PT403, PT407 and PT410 that provide cooling capacity from 0.25 W to 1.0 W at 4.2 K². These 4 K pulse tube cryocoolers have opened many challenging applications in cooling NMR and MRI magnets, precooling dilution refrigerator, ADR and sorption cooler, cooling sensitive devices like SQUID magnetometer, etc. These applications demonstrate great advantages of pulse tube cryocoolers over GM cryocoolers in the field.

This paper introduces the Cryomech 4 K pulse tube cryocoolers and their performances. The characteristics of the cryocoolers in applications are presented and compared with 4 K GM cryocoolers.

4 K PULSE TUBE CRYOCOOLERS

Figure 1 shows photographs of the 4 K pulse tube cryocoolers, Models PT403, PT405, PT407 and PT410. The configurations of them have been described in reference 1. The PT405 has the same layout geometry as the PT407. Their specifications are given in Table 1.

It has been confirmed that the vibrations in the pulse tube cold heads mainly come from the stretching of the tubes generated by gas compression and expansion². The rotary valve and motor have been integrated in the warm end for the standard cold heads. A special version with a remote rotary valve has also been developed for all of our two-stage pulse tube cryocoolers. In this version (see Figure 2), the rotary valve and motor is separated from the pulse tube expander by 3 feet through a S.S. flexible line. An electrical isolator made of non-metal material is mounted between the rotary valve and the S.S. flexible line to isolate the EMI and RF noise from the driving motor for the rotary valve. The performance of this split version is approximately 5% less than that of the standard integrated version. These split 4 K pulse tube cryocoolers are used for cooling sensitive devices, such as SQUID's magnetometer, etc.

The 10 K pulse tube cryocoolers developed at Cryomech have achieved the same cooling capacity and efficiency as the 10 K GM cryocoolers³. The latest improvements on a laboratory PT410 increases its performance to [1.2W@4.2K](#) and 45W@40K simultaneously for 7.8 kW power input. This unit provides almost the same capacity and efficiency as the 4 K GM cryocooler. This performance will enable the pulse tube cryocooler to replace the GM cryocoolers in many applications in the near future.

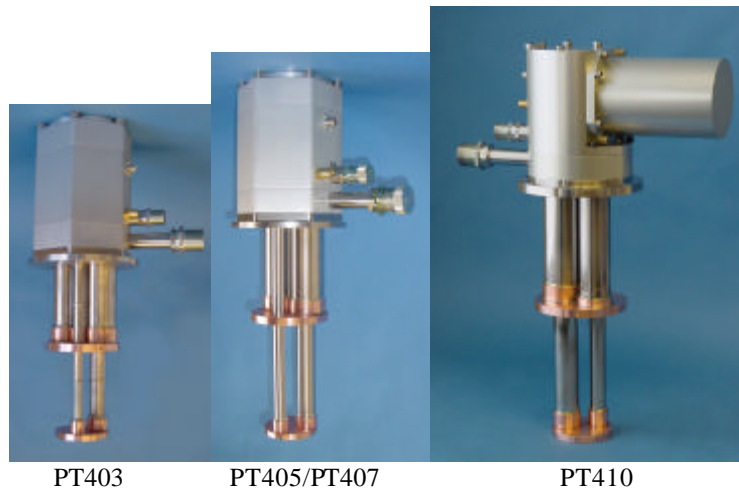


Figure 1. Photographs of the 4 K pulse tube cryocoolers

Table 1. Specifications of the 4 K pulse tube cryocoolers

	PT403	PT405	PT407	PT410
Specification	0.25W@4.2K & 10W@65K	0.5W@4.2K & 30W@65K	0.7W@4.2K & 30W@55K	1.0W@4.2K & 40W@45K
Power input	1 phase, 3 kW	3 phase, 4.6 kW	3 phase, 7 kW	3 phase, 8 kW



Figure 2. PT405/PT407 with remote rotary valve/motor

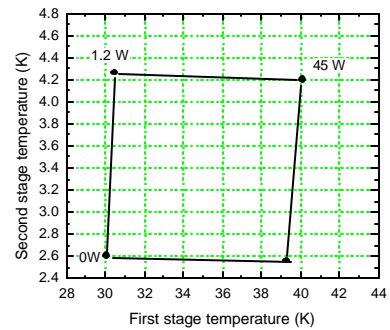


Figure 3. Latest performance of PT410

CHARACTERISTICS OF THE 4 K PULSE TUBE CRYOCOOLER

The 4 K pulse tube cryocoolers demonstrated their advanced features in the applications when compared with the 4 K GM cryocoolers. These features are presented below.

Magnetic field distortion

Small magnetic field distortion from the 4 K pulse tube cryocooler was found in NMR, MRI and SQUIDs systems. The amplitude of the magnetic distortion is approximately 20 nT compared to that of 200 nT from a SHI-SRDK408 4 K GM cryocooler. This magnetic field distortion is caused by the rare earth regenerative materials in the 2nd stage regenerator. Figure 4 shows the variations of magnetization of the rare earth materials of HoCu₂ and Er₃Ni at different temperatures. The rare earth materials were put into a very sensitive solenoid to measure their magnetization at external magnetic field of 0.1 Oe and 1 Oe. There are temperature oscillations of 2nd stage regenerative materials at the same frequency of refrigeration. The temperature oscillation could be a few Kelvins⁴ and generate a magnetic field fluctuation. This is schematically shown in Figure 5 (a). For a 4 K GM cryocooler (Figure 5 (b)), the magnetic field distortions are generated not only by the temperature swing, but also the motion of the rare earth materials with the displacer. The magnetic field distortion from a 4 K GM cryocooler is normally ten times higher than that from a 4 K pulse tube cryocooler.

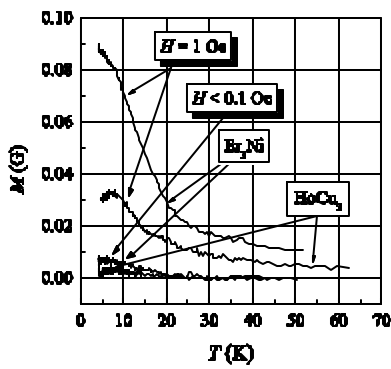
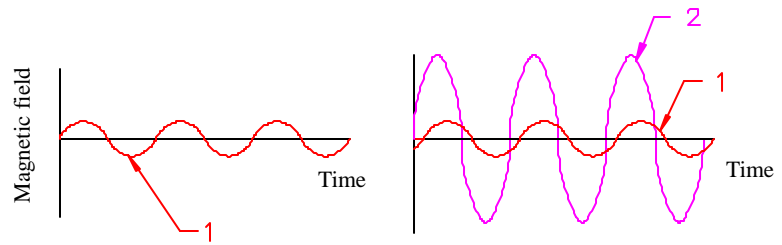


Figure 4. Magnetization of the rare earth materials of HoCu₂ and Er₃Ni



(a) Pulse tube (b) GM
Figure 5. Magnetic field fluctuation generated by the cryocoolers. 1. generated by temperature oscillation; 2. generated by motion of the GM displacer.

Vibration

Figure 6 shows the installation of the pulse tube and GM cryocooler on the cryostat. Vibration of 4 K pulse tube cryocooler is so small that in most applications it can be directly mounted on the cryostat.

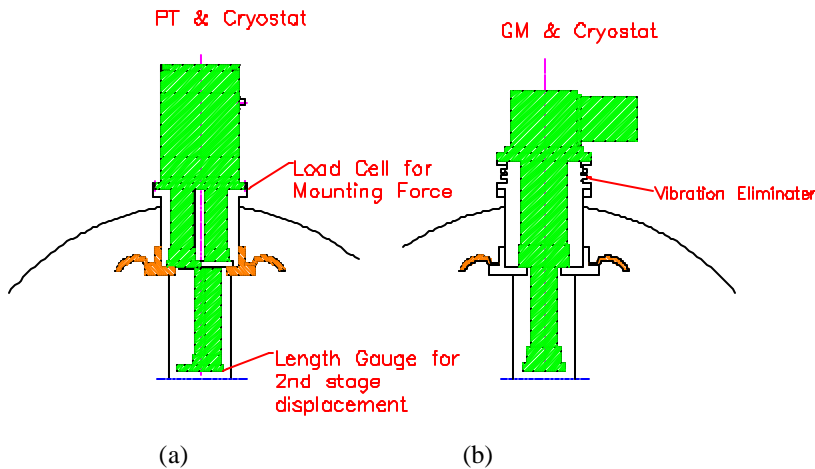


Figure 6 Installation of PT and GM cryocoolers on cryostat

Table 2. Vibration from PT and GM cryocooler

	Mounting force (amplitude)	2 nd stage displacement (amplitude)
4 K GM cryocooler (SRDK408)	38 Lb	42 μ m
4 K PT cryocooler (PT405)	1.0 Lb	11 μ m

For example, a PT405 pulse tube cryocooler was installed in a MRI cryostat. Spin echo testing was performed on it to check the various methods of vibration isolation used for the GM cryocooler before (see Figure 6 (b)). No vibration isolation methods were necessary for the Pulse Tube cooled MRI magnet. No magnetic fluctuations that come from vibration have been observed when directly mounting the pulse tube cryocooler on the MRI cryostat.

The vibration of PT and GM cryocoolers are compared and given in Table 2. A load cell, mounted under the room temperature flanges of the cryocoolers (see figure 6(a)), is used to measure the mounting force. A length gauge which contacts the bottom of the 2nd stage heat exchanger measures the displacement. The mounting force from the 4 K GM cryocooler is 38 times that of the 4 K pulse tube cryocooler, and the displacement is 4 times greater.

Meantime between maintenance (MTBM)

Currently, the maintenance interval of the 4 K GM cryocooler is ~10,000 hours. Cryomech's goal is to provide the 4 K pulse tube cryocooler with MTBM > 5 years (43,800 hours). Three possible service requirements for the 4 K Pulse Tubes in 5 years were investigated and given below.

1. Adsorber in the compressor package. The lifetime of the adsorber is mainly determined by the oil carryover which passes through the oil separator and reaches the adsorber. Figure 7 shows the oil carryover in the CP900 series compressors used for pulse tube cryocoolers. The CP900s are controlled to

have oil carryover of less than 80 mg/day (29 g/year). The adsorbers for the CP900s have been tested and have an ability to adsorb > 300 g oil. It ensures system operation for more than 5 years without service.

2. Lifetime of rotary valve and valve plate in the cold head. The rotary valve and valve plate in the pulse tube cryocooler have less wear since there are no wear particles generated from displacer seals in the GM cryocooler. The valve and valve plate material have been studied and selected. It was found that there was only 0.03 mm wearing away for the valve and no significant wear on the valve plate after 12,000 hours running. We predict that the valve and valve plate will last more than 5 years.

3. Contamination in the cold head. Impact of air contamination in a PT405 pulse tube cryocooler has been investigated and shown in Figure 8. The pulse tube cryocooler has less sensitivity than GM cryocoolers to air contamination (78% N₂, 20% O₂). After adding 600 Torr·Liter air in the system, the first stage lost 2W at the temperature of 65 K and the 2nd stage temperature increased by 0.1 K. This feature enables the pulse tube cryocooler to operate for a long time without needing cold head service.

Since the first PT405 pulse tube cryocooler was delivered to a user in July 1999, a few hundred pulse tube cryocoolers are working in the field. Many of them have operated for 15,000~25,000 hours. So far, there has been no report on the performance degradation of our pulse tube cryocoolers. All of this information supports us toward our goal of providing the Pulse Tubes with 5 years MTBM.

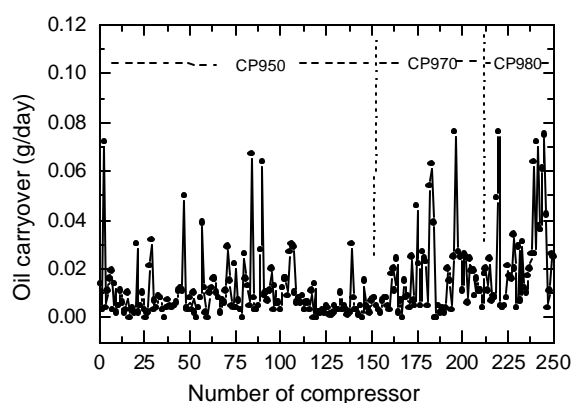


Figure 7 Oil carryover in CP900 series compressor

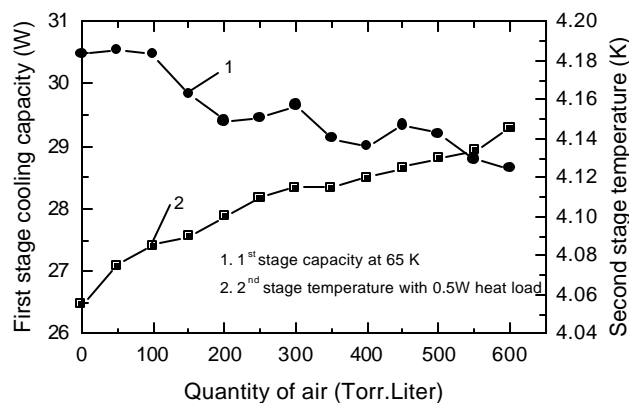


Figure 8. Impact of air contamination in the PT405

CONCLUSION

Cryomech has developed and commercialized 4 K pulse tube cryocoolers to provide cooling capacities from 0.25 W to 1.0W at 4.2K. The 4 K pulse tube cryocoolers have opened many challenging applications and demonstrated their advanced features with respect to very low vibration, low magnetic field distortion and long MTBM.

ACKNOWLEDGMENT

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