Numerical investigation on parameter influence in double- stage Vuilleumier type pulse tube cryocooler (VM-DPTC)

*Jue Wang[1, 2], Changzhao Pan[1, 3], Xiaotong Xi[1, 2], Liubiao Chen[1, *], Junjie Wang[1, 2, *], Yuan Zhou[1, 2]*

1. CAS Key Laboratory of Cryogenics, Technical Institute of Physics and Chemistry, Beijing 100190, China
2. University of Chinese Academy of Science, Beijing 100049, China
3. Laboratoire national de métrologie Et d'essais-Conservatoire national des arts et métiers (LNE-Cnam), F-93210 La Plaine, France

Technical Institute of Physics and Chemistry CAS（TIPC, CAS）

CHINESE ACADEMY OF SCIENCES

C1Po1C-05

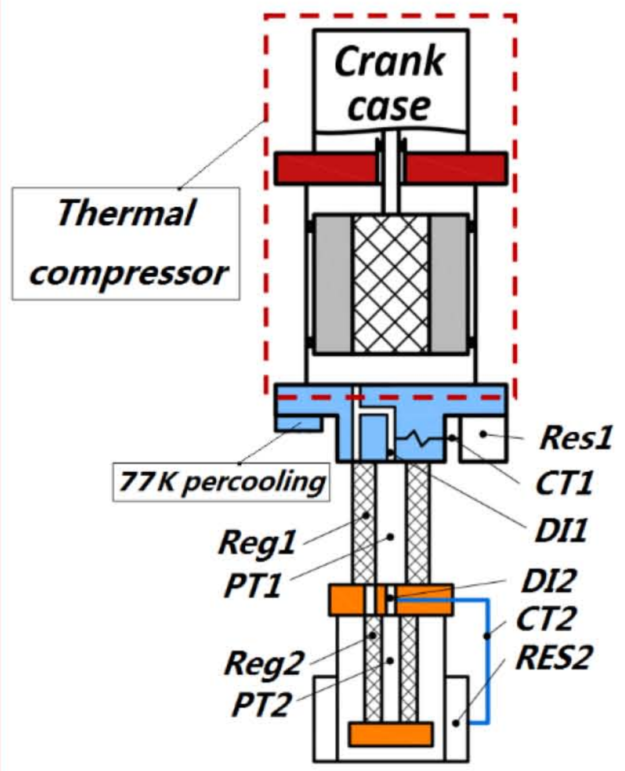
Background

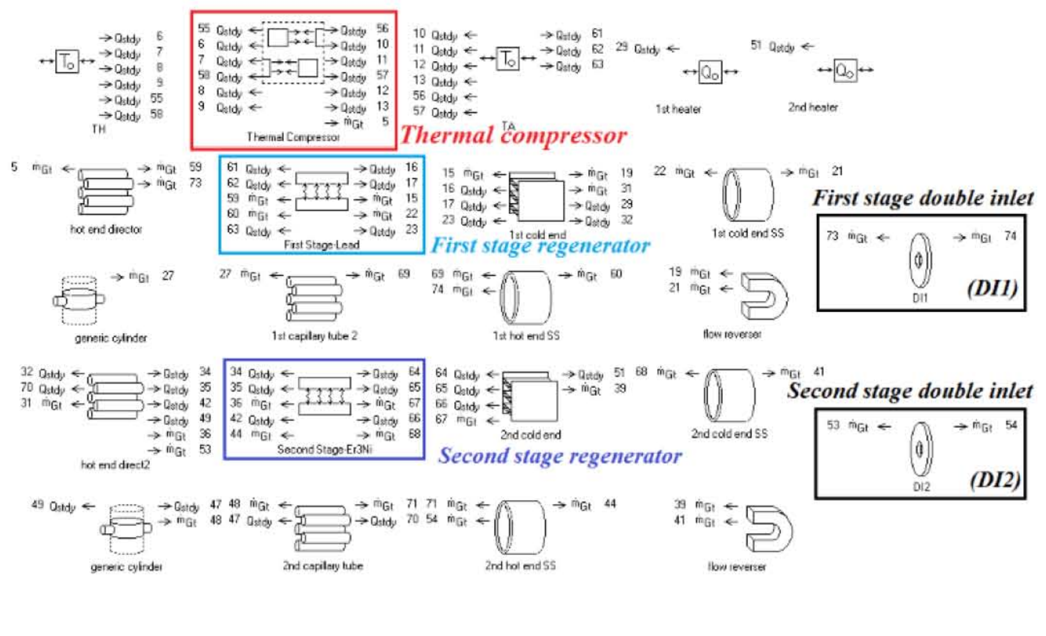
Vuilleumier-type cryocooler (VMC) driven by thermal compressor is usually regarded as a thermal-driven Stirling-type cryocooler, which haves the advantages of both low-frequency work pattern of GM-type cryocooler and the compactness of the Stirling cryocooler. It have been proved experimentally that the VMC including Vuilleumier-type single stage pulse tube (VM-SPTC) and Vuilleumier hybrid pulse tube cryocooler (VM-HPTC) were both capable to work at liquid helium temperature and even the VM-HPTC could hit the lambda line of the He4. The double-stage Vuilleumier type pulse tube (VM-DPTC) is modified form the previous VM-HPTC of TIPC and expected to have the similar superior performance like VM-HPTC. In this paper, a numerical model was built to estimate the influence of working parameters in VM-DPTC including average pressure, working frequency and precooling temperature. The loss compositions in the thermal compressor were carried out.

Conclusion

1. The VM-DPTC have the potential to work in the liquid temperature range numerically.
2. There both optimal average pressure and optimal frequency for both the second stage temperature and the cooling power at 5 K of the VM-DPTC. The increase of the average pressure and the working frequency will enlarge the heat rejection of the thermal compressor.
3. The increase or decrease of the precooling temperature from the initial point will both worse the lowest temperature, which is quite different from the effect in single stage VM –type pulse tube cryocooler.
4. The main loss in the thermal compressor are solid conduction loss and shuttle loss between the cylinder and the displacer in this case.

Basic structure and model



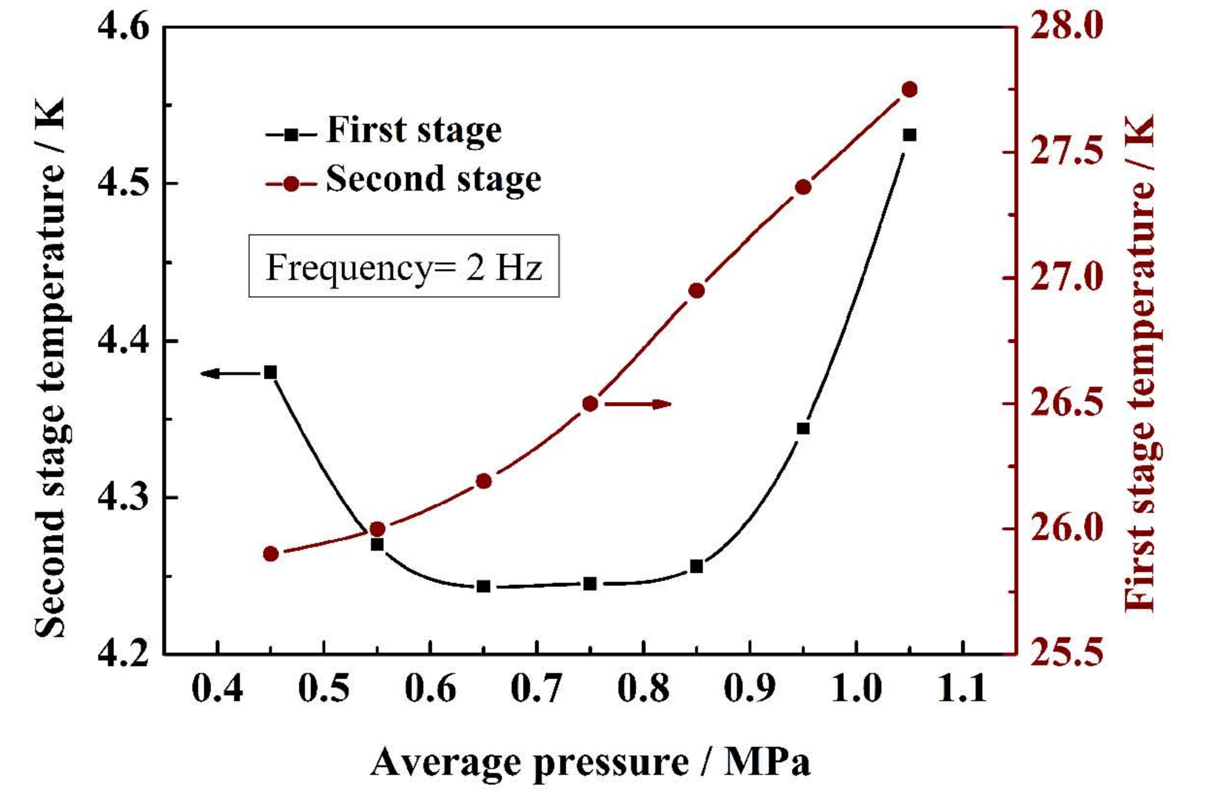


the optimized parameter of capillary tube and double inlet optimized by Sage10 software

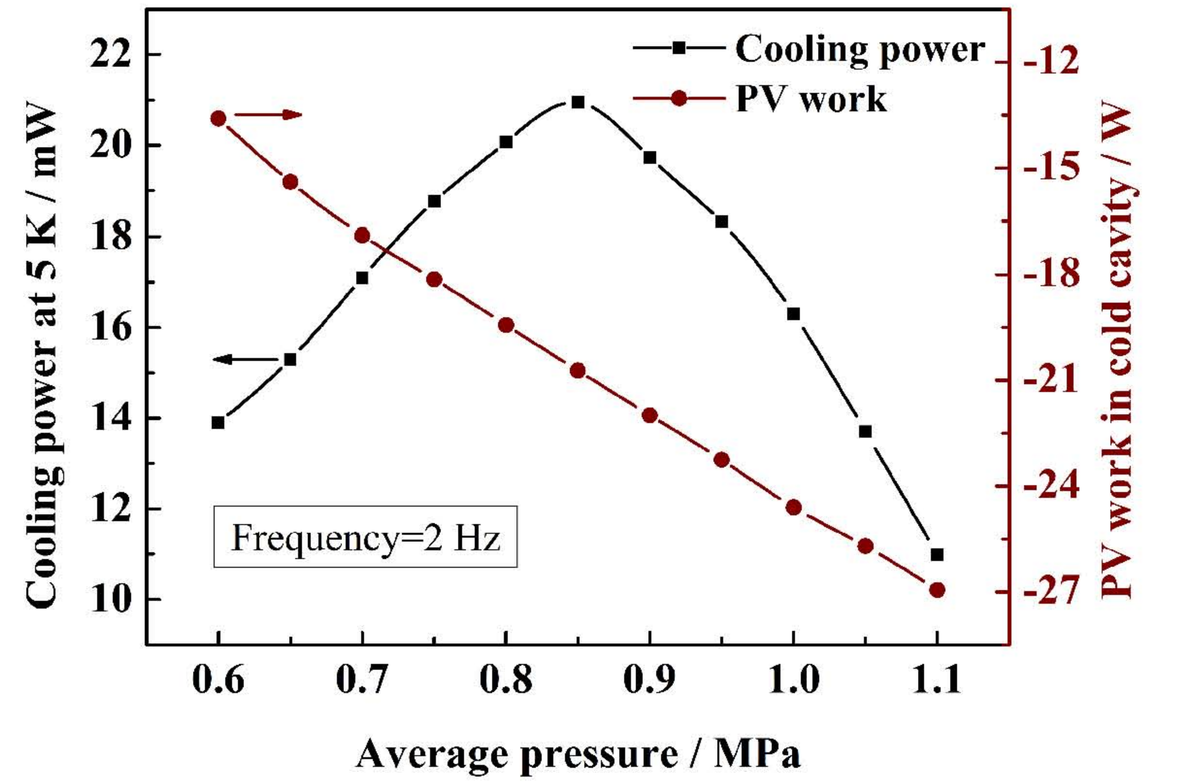
Frequency	Pressure	CT1 length	CT2 length	DI1 opening diameter	DI2 opening diameter
2 Hz	0.9 MPa	2.8 m	1.9 m	0.3 mm	1.0 mm

Equipment	Component	Parameter	Value
Thermal compressor	Cylinder	Diameter	95 mm
	Displacer	Stroke	20 mm
First stage pulse tube cryocooler (1st PTC)	Regenerator (Reg1)	Diameter	30 mm/12.5 mm
		Packing1 Packing2	200 mesh steel screen*60 mm Lead sphere (0.45 mm)*60 mm
	Pulse tube (PT1)	Diameter	12.1 mm
First stage phase shifter	Capillary tube 1 (CT1)	Diameter	0.6 mm
	Reservoir 1 Double inlet 1 (DI1)	Volume Opening diameter	500 mL 0-0.5 mm
Second stage pulse tube cryocooler (2nd PTC)	Regenerator (Reg2)	Diameter	18 mm/8.9 mm
		Packing1 Packing2	Er3Ni sphere (0.25 mm)*30 mm HoCu2 sphere (0.25 mm)*30 mm
	Pulse tube (PT2)	Diameter	12.1 mm
First stage phase shifter	Capillary tube 2 (CT2)	Diameter	0.6 mm
	Reservoir 2	Volume	100 mL
	Double inlet 2 (DI2)	Opening diameter	0-1.5 mm

Average pressure

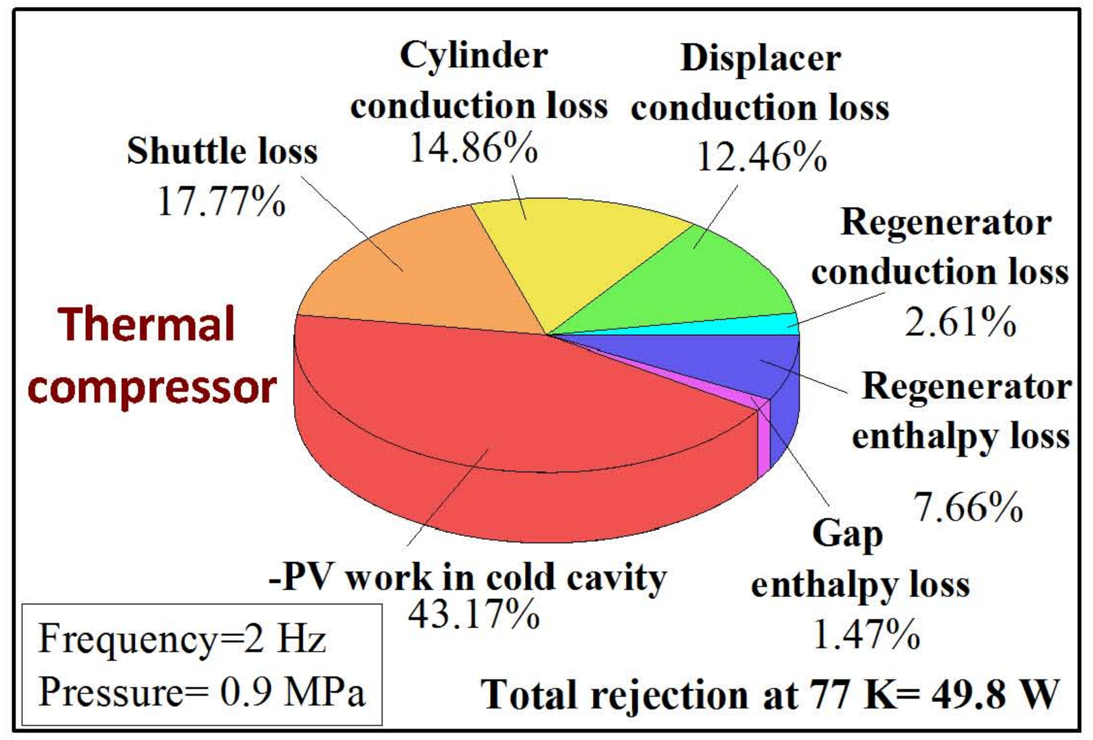


The increase of the average pressure will make the first stage temperature grow up while the second stage temperature has a minimum value. The optimal average pressure in the present case for the lowest temperature is about from 0.65 to 0.85 MPa. The pressure ratio in the total system is about 1.5. According to our previous experience, the optimal pressure will grow up when the resistance of the capillary grows up.



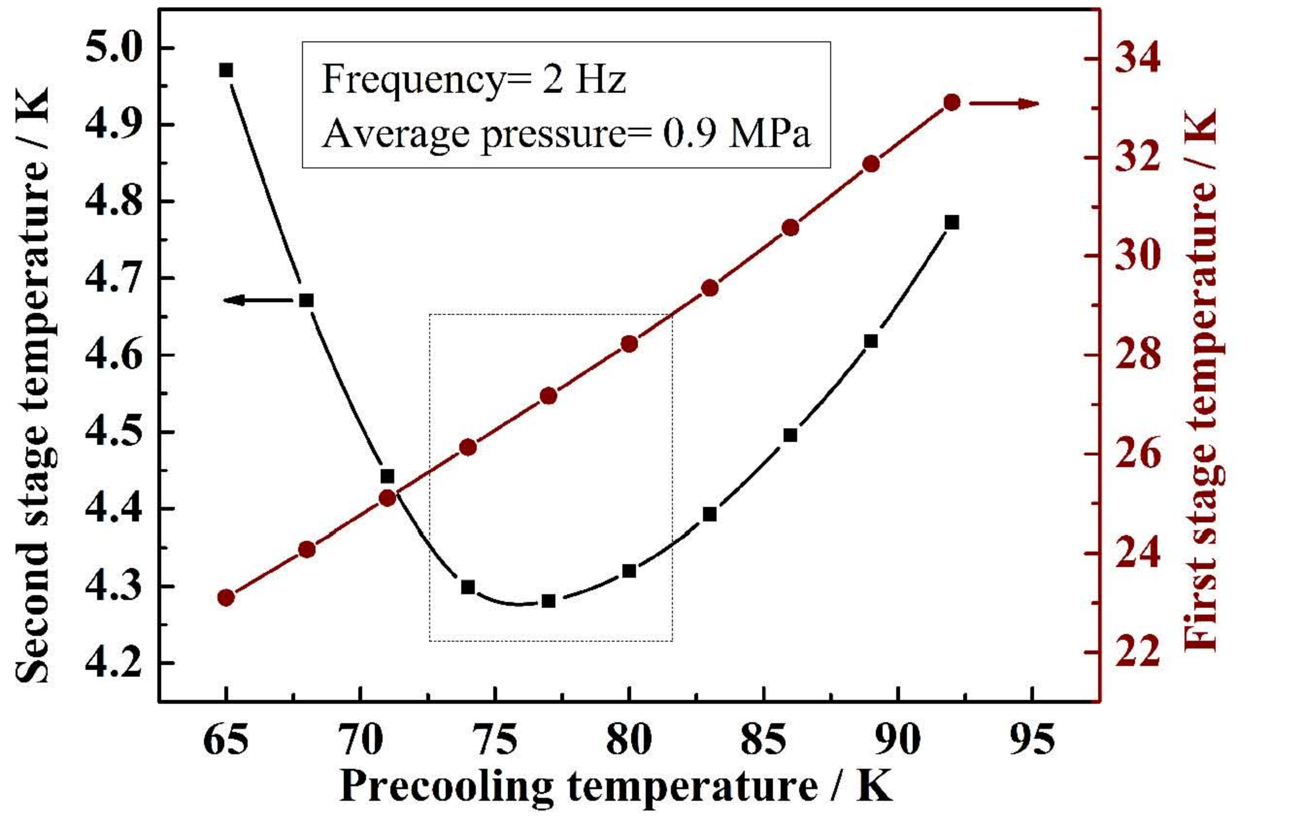
The increase of the average pressure will make the PV work in cold cavity grow up while the cooling power of the second stage cold end at 5K has a minimum value. The optimal average pressure of the cooling power at 5K is about from 0.8 MPa to 0.9 MPa, which is almost in the range of the optimal average pressure of the lowest temperature.

Loss composition analysis



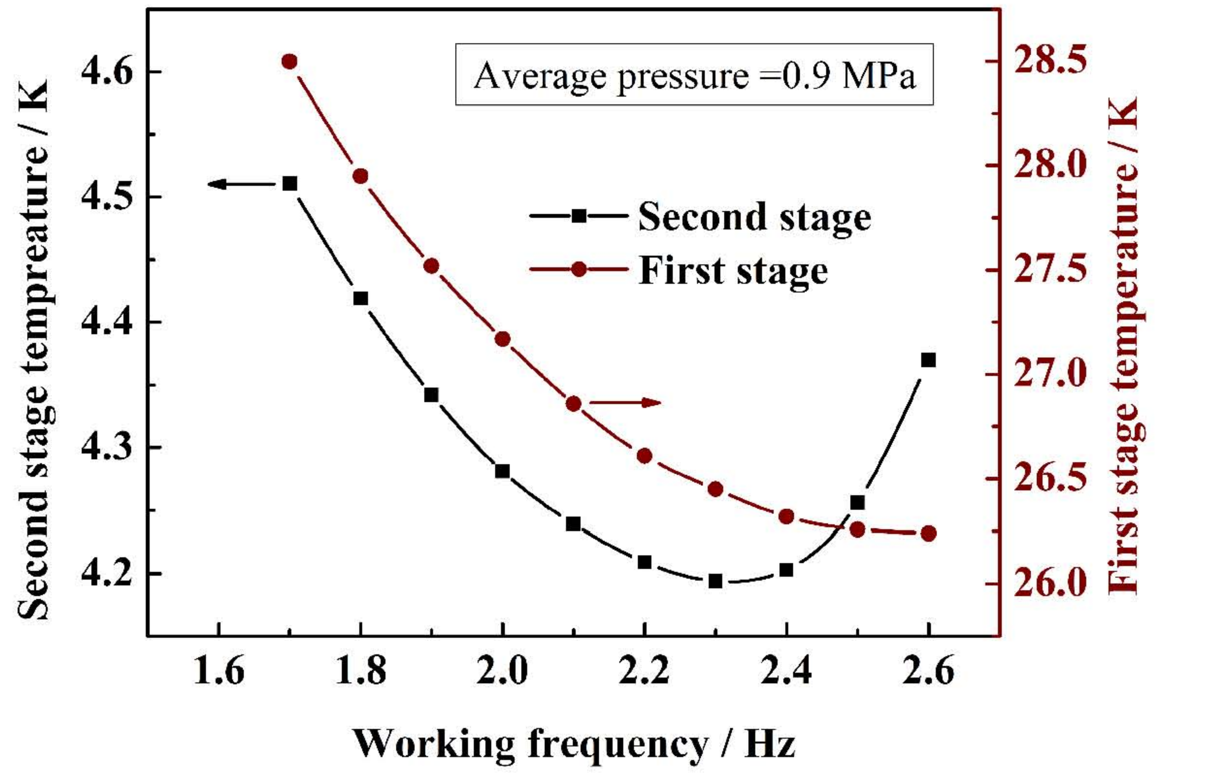
If there is no heat load attached on the pulse tube cryocooler, the total heat rejection of the VM-DPTC can be regarded coming from the thermal compressor in thermodynamics. The losses are very obvious in thermal compressor, especially the shuttle loss and solid conduction loss, which cause the great irreversibility in VM-DPTC system. It can be indicated that not only the double-stage pulse tube should be optimized, but also the thermal compressor should be optimized for higher efficiency.

Precooling temperature

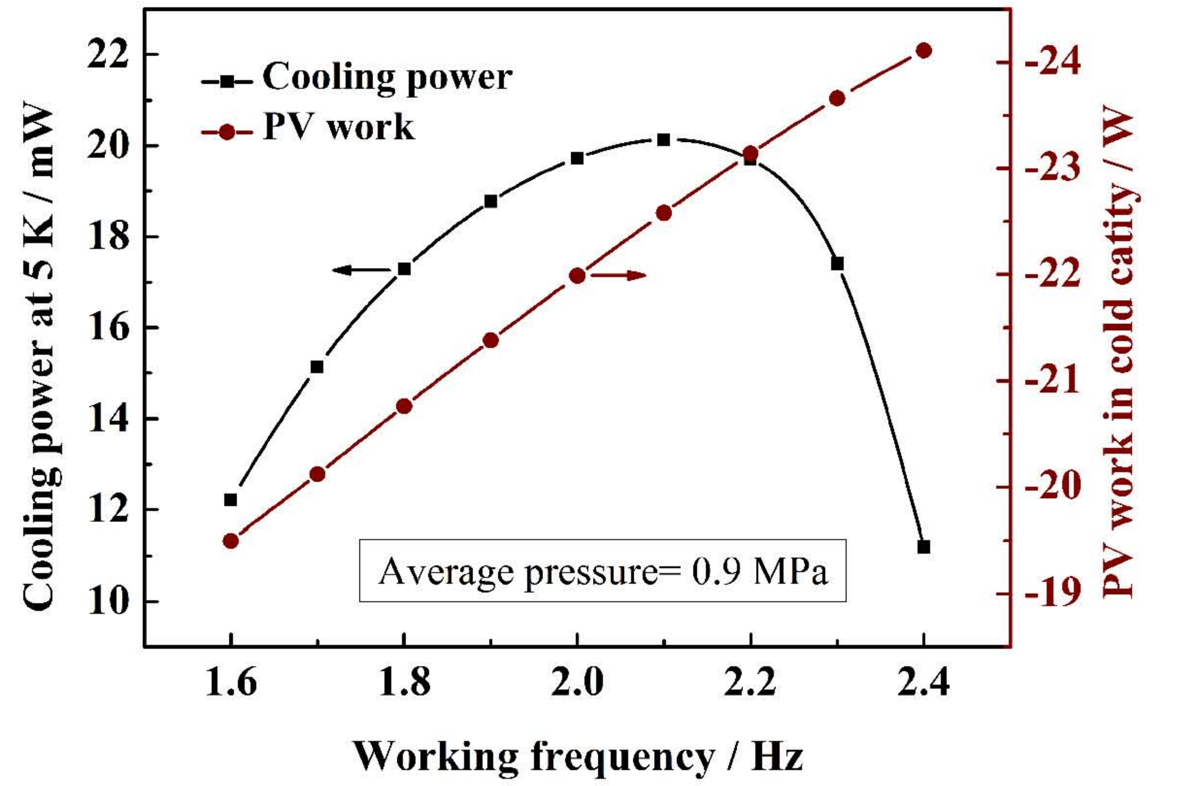


The decrease of precooling temperature reduces the first stage temperature. This is quite similar with the single stage VM cryocooler. However for the VM-DPTC, the decrease of the precooling temperature will not always reduce the temperature of the second stage cold end. It has a minimum value. The main reason is the precooling temperature will also affect the impedance of the second stage pulse tube cryocooler.

Working frequency



The increase of the working frequency will make the first stage temperature decrease while the second stage temperature has a minimum value. The optimal working frequency in the present case for lowest temperature is about from 2.2 to 2.4 MPa. Higher frequency means higher resistance in the capillary tube, so a shorter capillary may be more suitable for higher frequency.



The increase of the working frequency will make the PV work in cold cavity grow up while the cooling power of the second stage cold end at 5K has a minimum value. The optimal working frequency of the cooling power at 5K is about from 2.0 MPa to 2.2 MPa, which has little difference when compared with the optimal working frequency of the lowest temperature.

Email: cryowj@gmail.com & chenliubiao@mail.ipc.ac.cn & wangjunjie@mail.ipc.ac.cn