Numerical study of a VM type multi-bypass pulse tube cryocooler operating at 4K

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VM cryocooler is one kind of Stirling type cryocooler working at low frequency. At present, we have obtained the liquid helium temperature by using a two-stage VM/pulse tube hybrid cryocooler. As a now kind of 4K cryocooler, there are many aspects need to be studied and optimized in detail. In order to reducing the vibration and improve the stability of this cryocooler, a pulse tube cryocooler was designed to get rid of the displacer in the first stage. This paper presents a detail numerical investigation on this pulse tube cryocooler by using the SAGE software. The low temperature phase shifters were adopted in this cryocooler, which were low temperature gas reservoir, low temperature double-inlet and multi-bypass. After optimizing, the structure parameters and the best diameters of orifice, multi-bypass and double-inlet were obtained. With the pressure ratio of about 1.6 and operating frequency 2Hz, this cryocooler could supply above 40mW cooling power at 4.2K, and the total input power needs no more than 60W at 77K. Based on the highest efficiency of 77K high capacity cryocooler, the overall efficiency of this VM type pulse tube cryocooler is above 0.5% relative Carnot efficient.

Abstract

BACKGROUND

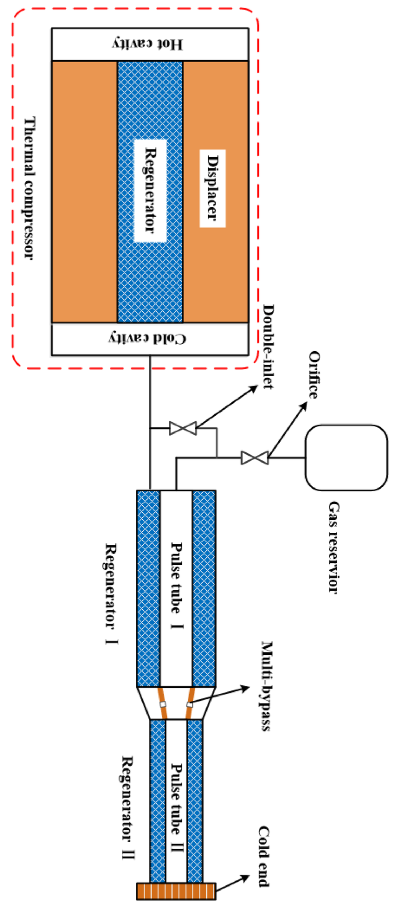
Single stage VM cryocooler: 7.35K

VM/PT hybrid cryocooler: 2.6K

VM multi-bypass PTC

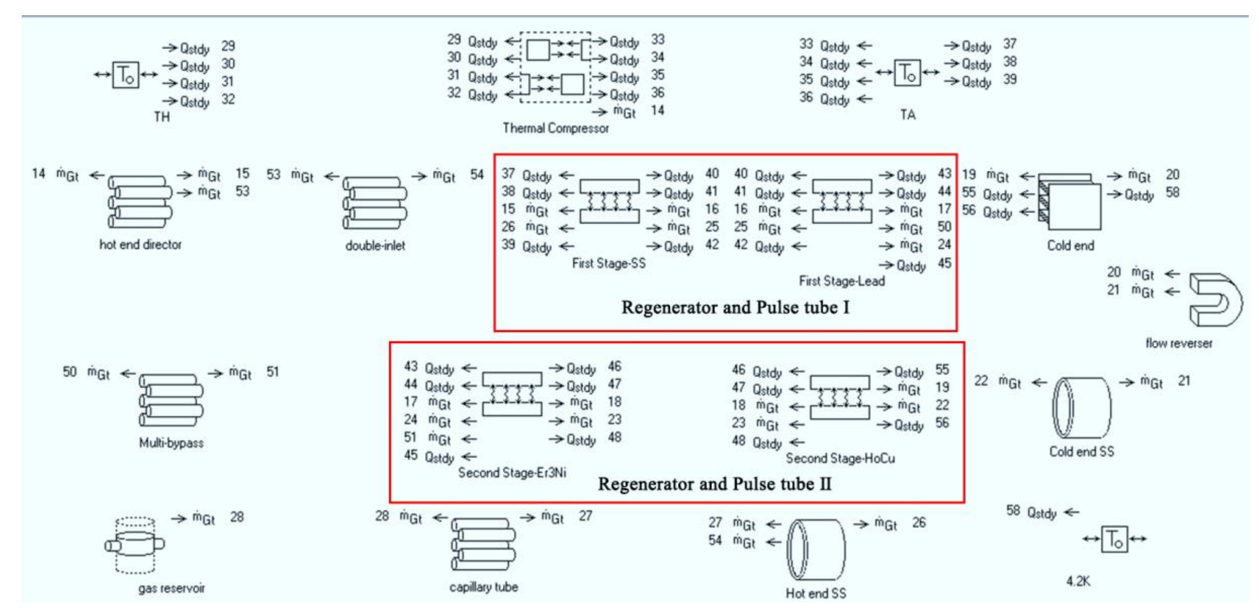
Cryogen free   Reliable   High efficiency

Structural parameters

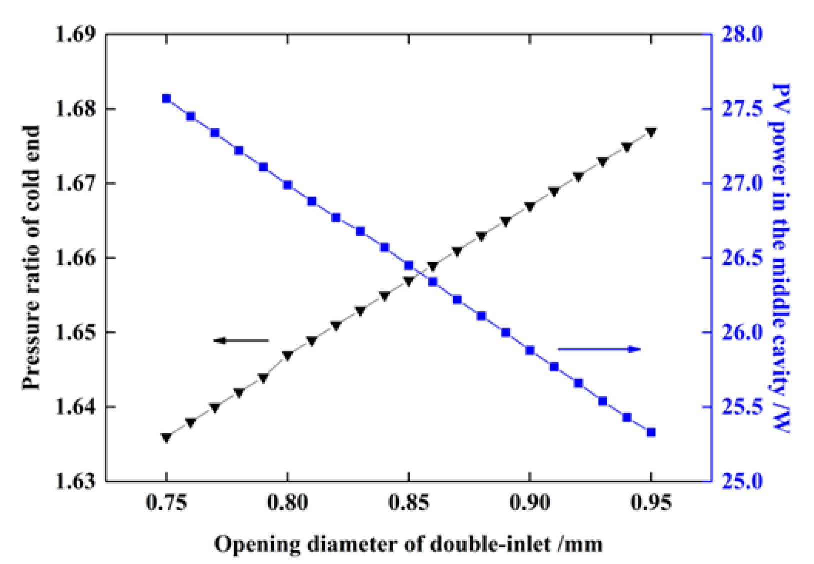


Thermal compressor		Pulse tube	
Diameter	95mm	Pulse tube I	D=12.5mm, L=100mm
Stroke	20mm	Pulse tube II	D=8.9mm, L=80mm
300K heat exchanger	D=5mm L=200mm	Regenerator I	D_{in}=12.5mm, D_{out}=20mm
77K heat exchanger	D=3mm L=200mm		40mm 200# SS screen 50mm 0.4~0.45mm lead sphere
Regenerator	D_{in}=26mm, D_{out}=44mm		
	80# SS screen L=120mm	Regenerator II	D_{in}=8.9mm, D_{out}=18mm
			40mm 0.2~0.25mm Er_3Ni 35mm 0.2~0.25$HoCu_2$

SAGE SIMULATION

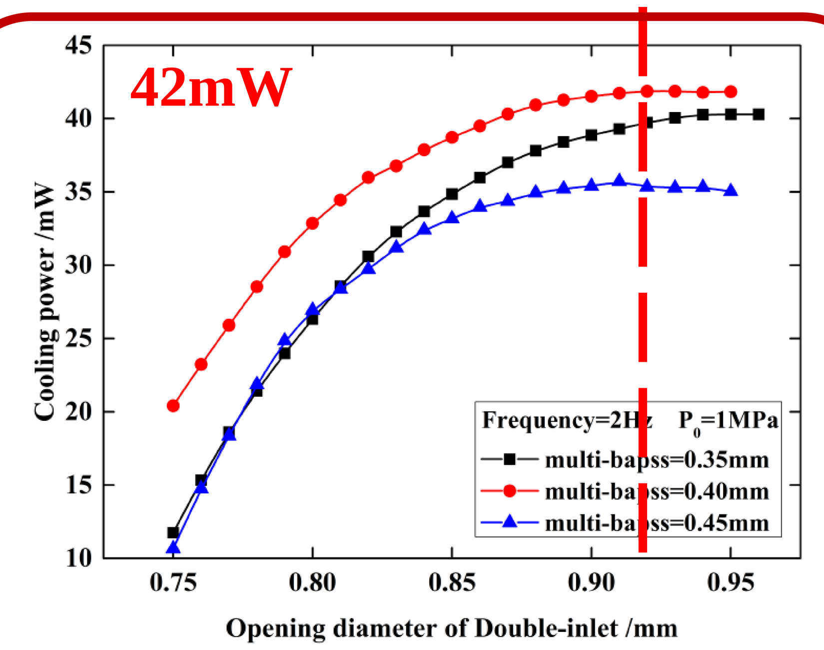


Pressure ratio & Acoustic power



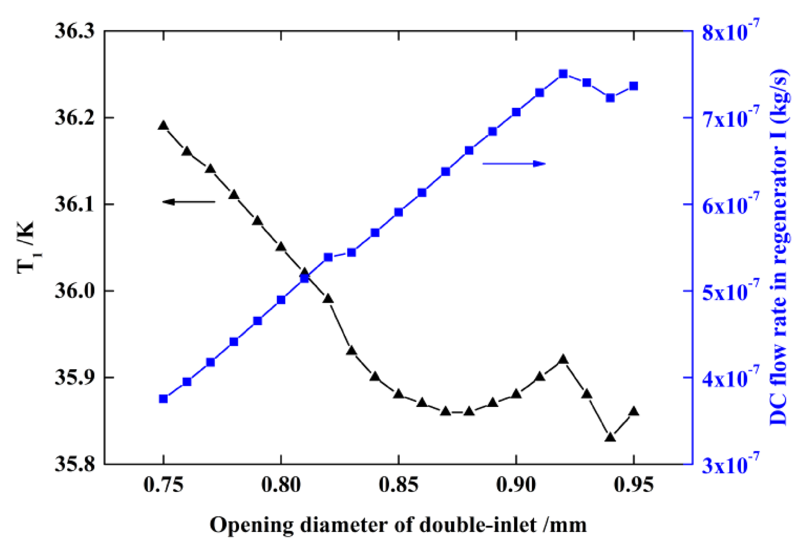
- The pressure ratio of cold end increased with the opening of double-inlet
- The input acoustic power decreased with the opening of double-inlet

Cooling power & Multi-bypass



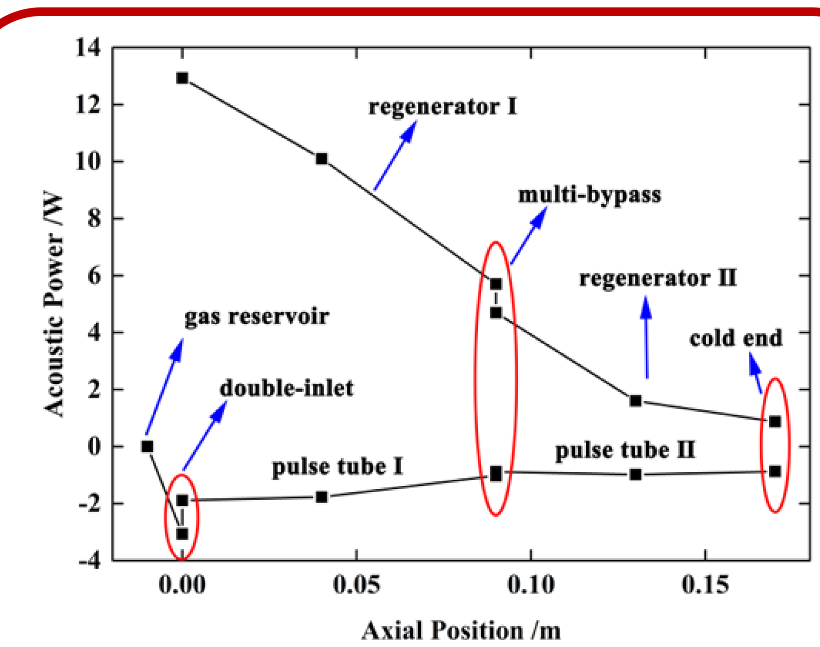
- The optimal multi-bypass is about 0.4mm
- The cooling power is about 42mW@4.2K
- Overall efficiency above 0.5% relative Carnot efficient

Middle temperature & DC flow



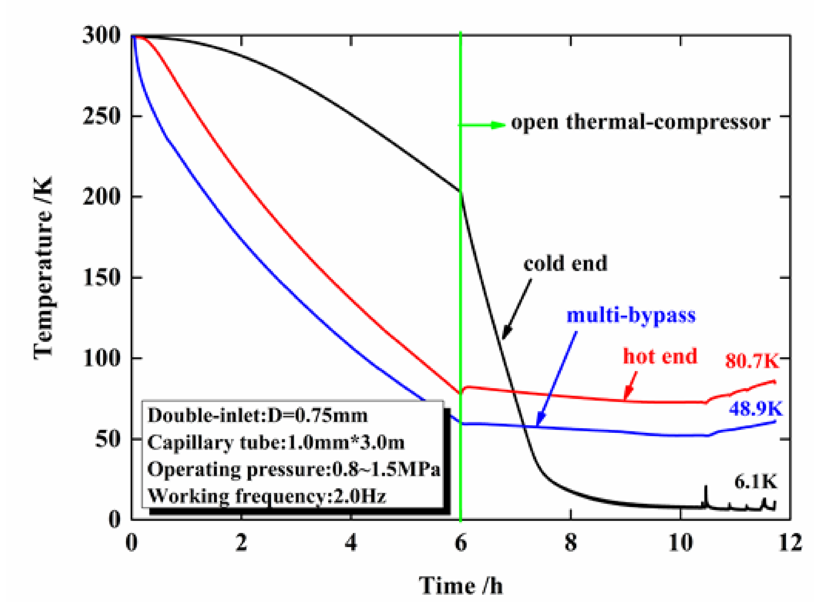
- DC mass flow rate increased with the opening of double-inlet
- DC mass flow rate would influence the temperature of multi-bypass

Acoustic power distribution



- Acoustic power was consumed about 7W in the regenerator I
- Acoustic power was consumed about 4W in the regenerator II
- 1W acoustic power flow through the double-inlet

preliminary Experimental result



- The lowest temperature of cold end was about 6.1K
- The temperature of multi-bypass was 48.9K
- The pressure ratio was about 1.6

This work was supported by the Postdoctoral Innovation Talent Support Program of China (Foundation No. BX201600173)