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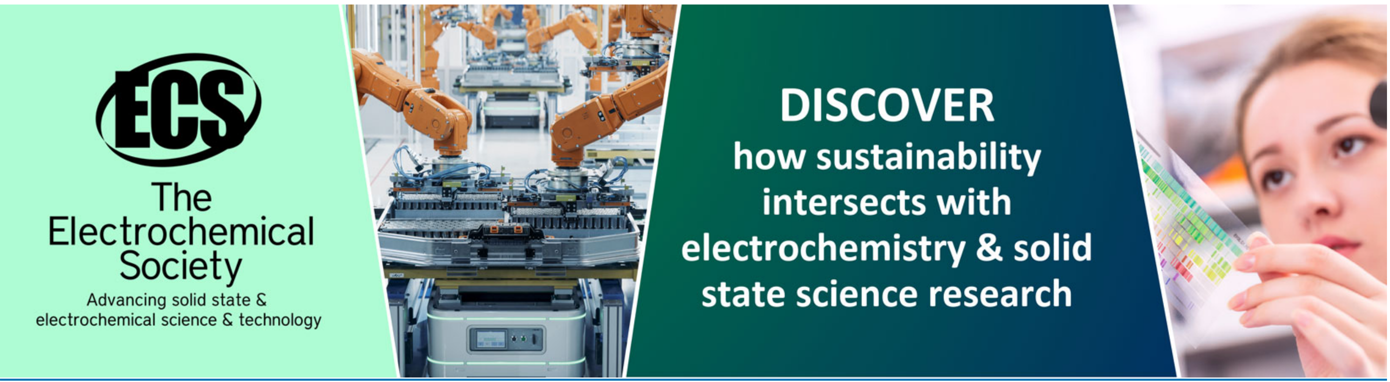

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Numerical studies on the effects of hot end temperature on a single-stage multi-bypass type pulse tube cryocooler

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Abstract. The performance of pulse tube cryocooler is affected by the temperature of hot end, which is mainly influenced by the temperature of environment. Effects on a single-stage multi-bypass type pulse tube cryocooler are investigated by means of numerical simulation. For different opening of multi-bypass orifices, the refrigeration performances are studied when hot end temperature changed in a certain range, and some numerical results are provided and analysed. Together with the temperature at cold head and multi-bypass position, the mass flow rate through the multi-bypass orifice is affected significantly by the temperature of hot end, and the optimum opening of multi-bypass orifice decreases with hot end temperature increasing from 240 K to 320 K. Therefore, to select an optimal opening of bypass orifice according to the temperature of operating environment is necessary.

1. Introduction

Single-stage pulse tube cryocooler is widely used in many fields because of its high efficiency, low vibrations and compactness. Our laboratory is committed to the development and application of single-stage pulse tube cryocoolers. The inertance tube, gas reservoir and double-inlet configuration are used as phase adjusting mechanism in the single-stage multi-bypass type pulse tube cryocoolers (SMPTCs), the lowest refrigeration temperature of these SMPTCs achieved is lower than 15 K with a lot of work completed in recent years. At present, the lowest refrigeration temperature is 13.9 K and about 400 mW of refrigerating capacity was achieved at 20 K with 250 W of electrical input power [1-4]. This generation of pulse tube cryocoolers have been applied in many applications such as materials science, optical measurement and mechanical measurement. Since SMPTCs are used in different occasions, the environmental conditions especially environment temperature can vary with circumstances. Thus, researches on the effects of hot end temperature on the performance of SMPTCs are of great significance.

2. Cryocooler description

The schematic of the SMPTC is shown in Figure.1. A coaxial cold finger is driven by a linear compressor and the inertance tube is arranged passing through the compressor to connect to a gas reservoir. A single multi-bypass configuration is placed in the middle of regenerator to achieve a compact structure [5], and thus the bypass orifice is inside the regenerator. A needle valve is adopted

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to regulate the opening of the double-inlet configuration which is arranged at the hot end of the SMPTC [6]. When the SMPTC is working, the bypass orifice will be fixed at an appropriate opening, and the opening of double-inlet orifice will be regulated continuously to make sure the SMPTC working with an optimum performance. Therefore, for a certain SMPTC, the opening of bypass orifice (D_b) is significant to the overall performance since it is inconvenient to adjust when made. This paper will analysis the effects of hot end temperature (T_h) on the performance of SMPTC with needle valve of the double-inlet orifice closed.

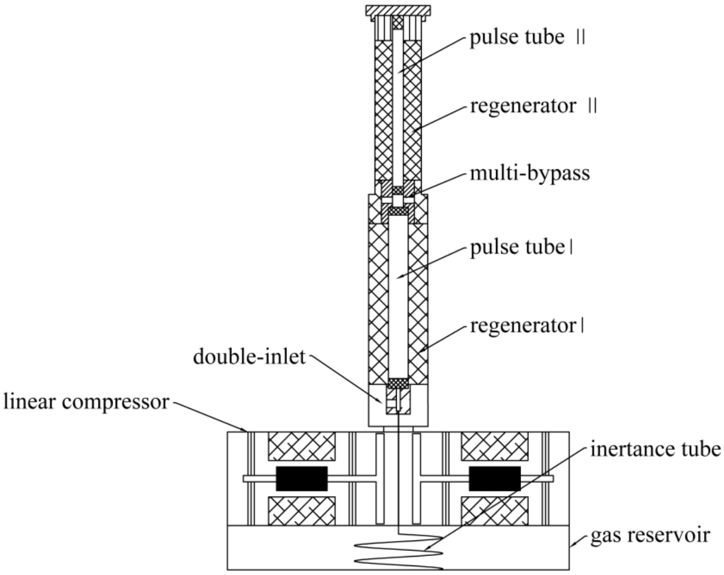

Figure 1. The schematic of the SMPTC.

Numerical simulation was completed with the software Sage [7], and investigations for cases multi-bypass orifice opened with constant opening and optimal opening were conducted respectively. Table 1 is the operating condition of SMPTC adopted in the numerical simulation. The specifics, dimensions and other parameters of the pulse tube cryocooler can be found in Ref. [1-2]. Temperature of compressor, hot end heat exchanger, inertance tubes and gas reservoir are set to be equal to the hot end temperature (T_h). Temperature of cold head (T_c) and multi-bypass position (T_b) are taken into account with output PV power of compressor kept at certain value.

Table 1. Operating condition of SMPTC.

Parameters	**Values**
Operating frequency	30 Hz
Filling pressure	2.2 MPa
Working gas	^{4}He
Double-inlet orifice	closed

3. Numerical results and discussion

Existing research shows that the performance of pulse tube crocoolers is affected by the opening of multi-bypass orifice [8], Figure 2 shows the detail D_b influence on the performance of SMPTC which was developed in our laboratory, it is easy to find out that there is an optimum opening of multi-bypass orifice to achieve a best performance. T_c decreases from 34.7 K to 25.9 K and then increases to 31.9 K when D_b changes from 0.2 mm to 1.2 mm, while T_b decreases from 163.0 K to 95.0 K monotonically. The optimum opening of multi-bypass orifice is a certain opening when the lowest temperature of cold head is achieved. For example, the optimum opening of multi-bypass orifice is 0.75 mm when T_h is 280 K and output PV power of compressor is 180 W.

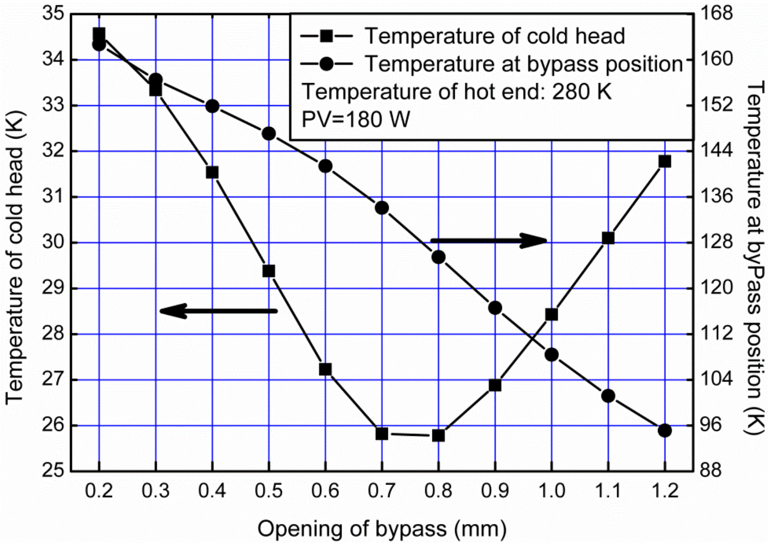

Figure 2. Influence of opening of bypass orifice.

To make sure the SMPTC operates in conditions when its performance is the best, the value of parameter D_b should be the optimum one when other geometry and operating parameters are invariable. 0.75 mm is an optimal opening of multi-bypass orifice for the SMPTCs when working on conditions the ambient temperature is about 280 K. However, most SMPTCs will work on conditions ambient temperature lower or higher than 280 K, and 0.75 mm may not be the optimum opening for all conditions. The optimum opening of bypass orifice when T_h changes from 240 K to 320 K is provided in figure 3. It is obvious that a higher hot end temperature corresponds to a smaller optimal opening of multi-bypass orifice in this temperature range.

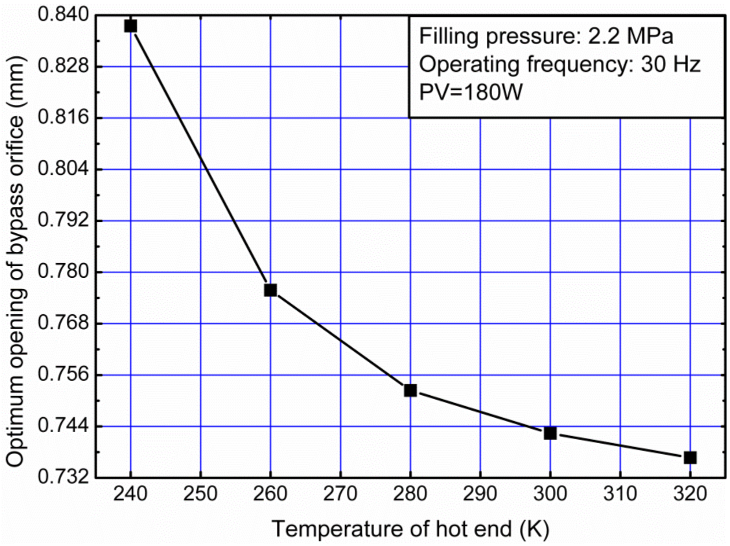

Figure 3. Influence of hot end temperature on the optimum opening of multi-bypass orifice.

Figure 4 shows the influence of T_h on the performance of SMPTC when D_b is optimal at each point of T_h. For each T_h, when PV power is set always to be 180 W and D_b to be optimal, both T_c and T_b increase with T_h changing from 240 K to 320 K with increment of 14.6 K and 42 K , respectively.

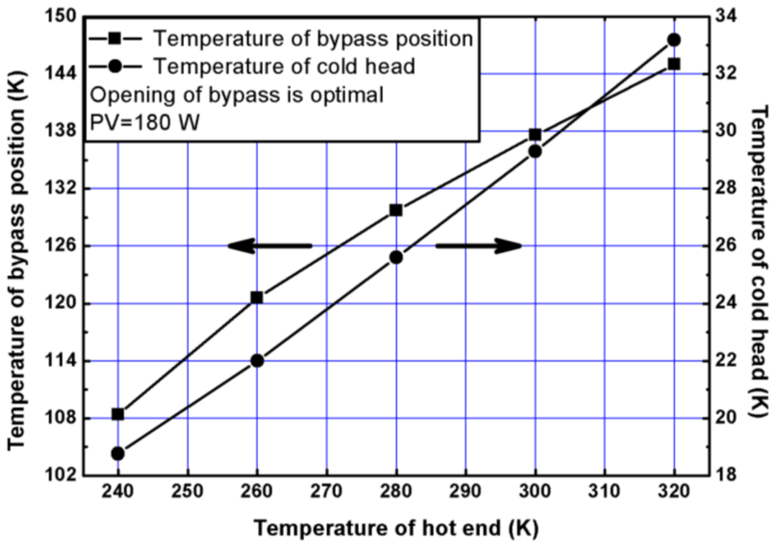

Figure 4. Influence of hot end temperature on the performance of SMPTC (D_b is optimal for each T_h).

Actually, the opening of bypass orifice is inconvenient to adjust since the bypass orifice is inside of the regenerator. Thus, an appropriate constant value of D_b should be chosen to fit most conditions. Figure 5 shows the influence of T_h on T_c when D_b is kept at constant 0.5 mm, 0.7 mm and 0.9 mm , respectively, and T_c corresponding to each T_h with D_b optimized is shown in this figure too. For certain working condition, any value of D_b diffident to an optimal one will lead to a poor performance of a SMPTC, and no value can be optimal in all conditions. However, some values of D_b acquiring a performance approach to a best one on most occasions is a best choice for the SMPTCs. For example, 0.7 mm would be a commendable choice for this kind of SMPTCs when T_h changes between 240 K and 320 K. For some applications when T_h can be lower than 240 K at most time, 0.9 mm would be appropriate for D_b although it will result in poor performance when working at room temperature.

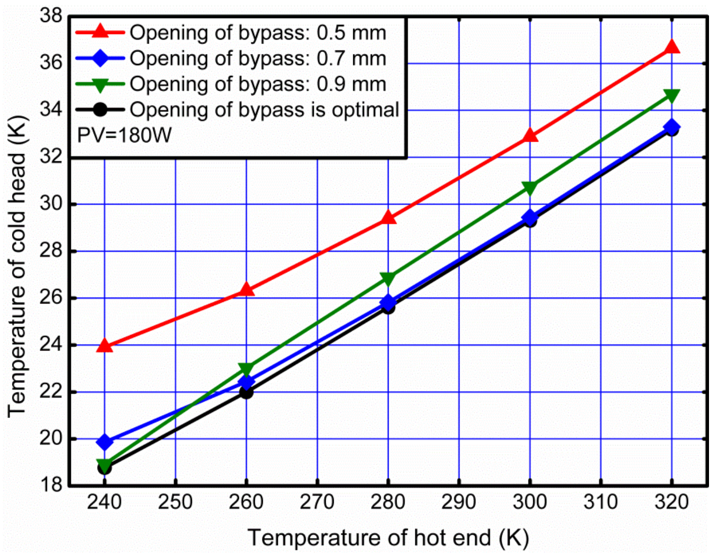

Figure 5. Influence of hot end temperature on the performance of SMPTC (D_b= 0.5 mm, 0.7 mm, 0.9 mm and optimum).

To investigate the detail T_h affects the performance of SMPTCs, mass flow rate through multi-bypass orifice is studied. The multi-bypass orifice plays an important role in dividing gas flow in the regenerator into two streams, of which one gets into the middle of pulse tube (the mass flow rate is defined as $\dot{m}_b$), and the other into the regenerator II (the mass flow rate is defined as $\dot{m}_r$). Thus, the percentage m defined as $m = \dot{m}_b/(\dot{m}_b + \dot{m}_r)$ reflects the regulation function of multi-bypass orifice. Since mass flow rate changes with time periodically in an oscillating flow, $\dot{m}_b$ and $\dot{m}_r$ are replaced by amplitudes in the calculation of m, respectively. Figure 6 shows the influence of T_h on the percentage m with different opening of multi-bypass orifice. The SMPTCs will attain a best performance when m is between 12% and 13.5%. However, for a certain opening of multi-bypass orifice, the percentage m will increase with T_h changing from 240 K to 320 K.

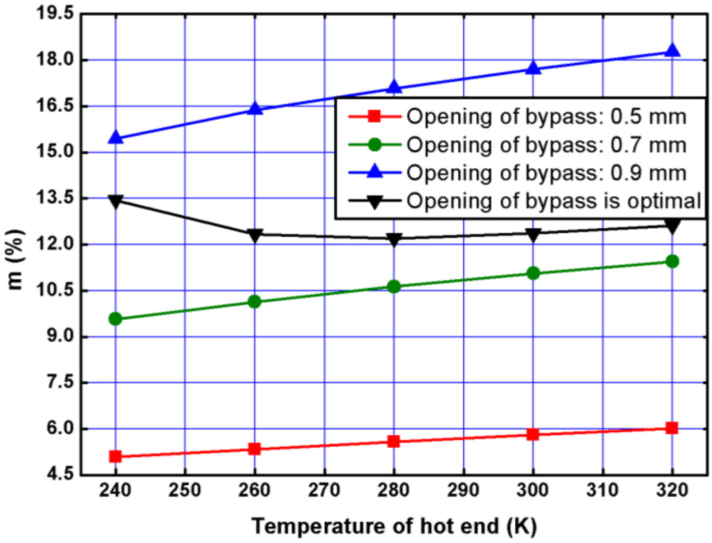

Figure 6. Influence of hot end temperature on m.

According to the common sense, the flow resistance is positively correlated with the viscosity, and the viscosity of helium is positively correlated with temperature. On one hand, a higher T_h would lead to a higher T_c and T_b as mentioned earlier, thus the average temperature of helium in the regenerator II should also be higher, which would produce larger flow resistance in regenerator II. On the other hand, the mass flow rate through multi-bypass orifice will increase because of the increase of flow resistance in regenerator II. For this reason, the percentage m will increase with T_h when PV power and D_b are both constant.

4. Conclusions

Numerical studies on the influence of hot end temperature on performances of SMPTCs have been conducted with software Sage. The changes of temperature at hot end have great influence on the temperature and mass flow rate distribution inside of SMPTCs. Inevitably, when the double inlet orifice is closed and PV power are kept the same value, the lowest temperature achieved would be different with a difference of at least 14.6 K when the temperature of hot end changes from 240 K to 320 K. The temperature of hot end also affects the optimal opening of multi-bypass orifice, and a negative correlation was found in the relationship between hot end temperature and optimal opening of multi-bypass orifice. Therefore, to ensure the optimal performance of a certain SMPTC, the opening of bypass orifice should be adjusted to a larger value when ambient temperature is lower than the designed one, and vice versa.

5. Acknowledgements

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6. References

[1] Chen L B, Jin H, Wang J J, Zhou Y, Zhu W X and Zhou Q 2013 18.6 K single-stage high frequency multi-bypass coaxial pulse tube cryocooler *Cryogenics* **54** 54-8
[2] Chen L B, Zhou Q, Jin H, Zhu W X, Wang J J and Zhou Y 2013 386mW/20K single-stage Stirling-type pulse tube cryocooler *Cryogenics* **57** 195-9
[3] Jin H, Zhu W X and Wang J J 2012 Experimental research of A 19.3 K single stage multi-bypass high frequency pulse tube refrigerator *J. Eng. Thermophys.* **33** 1119-21
[4] Zhou Q, Chen L B, Zhu X S, Zhu W X, Zhou Y and Wang J J 2015 Development of a high-frequency coaxial multi-bypass pulse tube refrigerator below 14K *Cryogenics* **67** 28-30
[5] Zhou Y, Wang J J, Zhu W X and Cai J H 1994 Multi-bypass pulse tube refrigerator *U.S. Patent* **No.5295355**
[6] Zhu S W, Wu P Y and Chen Z Q 1990 Double inlet pulse tube refrigerators: an important improvement *Cryogenics* **30** 514-20
[7] Gedeon D 1995 SAGE: object-oriented software for cryocooler design *Cryocoolers* **8** 281-92
[8] Cai J H, Wang J J, Zhu W X and Zhou Y 1994 Experimental analysis of the multi-bypass principle in pulse tube refrigerators *Cryogenics* **34** 713-5