The effect of timing ratio of injecting to rejecting on G-M type PTC's cooling temperature

Wang, Y-Y.[1,2], Cai, J-H.[1], Liang, J-T.[1]

[1]Technical Institute of Physics and Chemistry, CAS, Beijing 100080, PR China
[2]Graduate School of the Chinese Academy of Sciences, Beijing 100039, PR China

The compression to expansion timing ratio of gas in PTC has effect on the cooling temperatures. The timing ratio can be changed through changing the dimensions of rotary valve's heads. In this paper we will study the effects under different dimensions, and get different cooling temperatures. The lowest temperature has reached 35K by using the single-stage G-M type PTC. Finding the optimum dimensions of rotary valve's heads is helpful to get lower cooling temperatures of PTC and to improve the performance of the rotary valve, although these results are not universal.

INTRODUCTION

It is well known that there is a growing requirement of the cryocoolers, especially in the fields of superconducting devices, astronomy and military etc. G-M type pulse tube coolers (PTC) are one kind of cryocoolers that can get the temperature below the temperatures of liquid nitrogen (LN_2) and liquid helium (LHe). Nowadays the single-stage GM-type PTC has achieved the lowest temperature 14.7K and the multi-stage GM type PTC has achieved the lowest temperature 1.78K. The two-stage PTC produced by Cryomech has been in application.

Rotary valve is an important component in the G-M type pulse tube coolers as well as G-M cryocoolers. It can be used to adjust the compression-expansion time of working gas and the frequency in PTC，although this can be substituted by the solenoid valve which can be controlled more easily by computer. The advantage of rotary valve is that its frequency can be adjusted continuously, and has longer life than that of the solenoid valve.

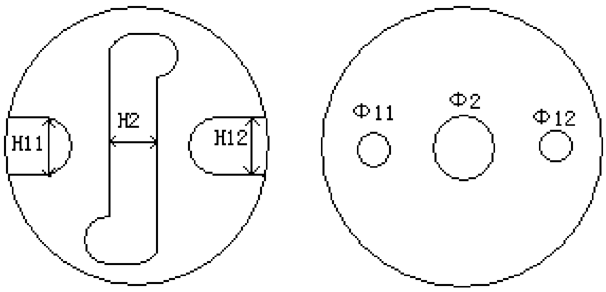
As well known that the ratio of compression to expansion time of gas in the PTC, that is to say the timing ratio has effect on the PTC's cooling temperature. In this paper the effect is analyzed. Firstly, the times of injecting and ejecting gas are computed respectively according to the dimensions and structure of the rotary valve's heads during a cycle. Simply to suppose that injecting time equals to the compression time of gas in PTC, and ejecting time equals to the expansion time. Then through doing the thermodynamic analysis about the compression and expansion processes, the different ratios of injecting to ejecting time of gas are got, and the ratios are analyzed to get the optimum. According to the thermodynamic analysis, the longer expansion time has higher COP and lower cooling temperature because this makes the gas expansion completely. While too long expansion time will make the compression time too short and result in less gas supply, which will affect the COP and cooling temperature of PTC. Therefore there exists an optimum timing ratio for the PTC. Secondly, we use a single stage G-M type PTC to test the above theoretical analysis. In experiment the DC flow wave of working gas is got, through which we can get the time ratios. Using different rotary valve's heads with different dimensions and structure we can get different DC flow waves with different time ratios and cooling temperatures. The experimental results indicate that the timing effect of the ratio exists under the nearly same other conditions, and the cooling temperatures have distinctive difference due to the effect of timing ratio. According to this we can analyze the optimal dimensions and structure of rotary valve's heads, and in the next the optional dimensions and structure of rotary valve to different PTC can be analyzed, so as to improve the performance of GM-type PTC.

There are two methods that can control the timing ratio in G-M type PTC. One method is controlled by the solenoid valves. The main advantage of this method is it's flexibility. It is also helpful to study the effects of wave form on the refrigerating performance, and can be used to find the optimal wave form of the PTC. This method is thought to be the most effective method to the application of the PTC. Of course there are some disadvantages using this method, such as short-life, noise, irreversible loss.

The other method is using rotary valve, which is modified through the rotary valve of GM cooler. It consist of an electric motor，rotary components (rotary heads) and valve body. Here there are also two methods to control the waveform. One is that the speed of electric motor is fixed but only the configuration of the rotary components may be changed, as depicted in this paper. The other is that the configuration of the rotary components is fixed while the speed of the electric motor may be changed. If we want to prolong the time of compressing gas, only the speed of electric motor need be slowed, and it is convenient to control this using a computer. The researchers of Giessen University have done some contribution in this aspect.

ANALYSIS

In the rotary valve the valve heads, which are the rotary parts include two components as depicted in Figure 1. In this figure, H11 and H12 are the high pressure inlets (where the dimensions of H11 and H12 are equal to each other.), and H2 is the low pressure outlet. In Figure 1 we can change the values of H11, H12 and H2, but the dimensions in Figure 1(b) are not changed. Therefore, the timing ratio is changed through the changes of the dimensions in Figure 1(a).



(a) rotary part (b)static part

Figure 1 The rotary valve heads

When H11 and H12 in Figure 1(a) fit in with Φ11 and Φ12 in Figure 1(b), the high pressure gas is injected into the regenerator. When H2 in Figure 1(a) fit in with Φ11 and Φ12 in Figure 1(b), the low pressure gas is rejected from the regenerator. This is a recycle. As well known, it includes two processes, as depicted in Figure 2. The injecting process and the rejecting process are depicted in Figure 2(a) and (b) respectively. In Figure 2(a), the high pressure gas is injected into the regenerator from point A to point B, and this process is synchronous with the gas compressing process in PTC. In Figure 2(b), the low pressure gas is rejected from the regenerator from point C to point D, and this process is synchronous with the gas expending process in PTC.

If T_1 denotes the time interval from point A to point B and T_2 denotes the time interval from point C to point D. We can simply suppose that T_1/T_2 is the ratio of injecting to ejecting time of gas in PTC.

Supposing rotary velocity to be n (circles/min), then

$$T_1 = 60\frac{\theta 1}{2\pi n} \quad (1)$$

$$T_2 = 60\frac{\theta 2}{2\pi n} \quad (2)$$

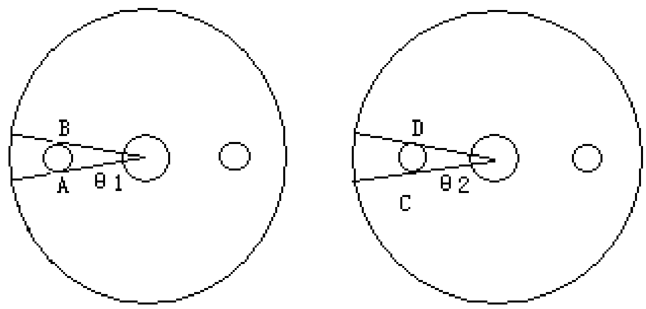
where θ1 and θ2 are angles of in the interval of injecting and ejecting gas. The change of dimensions of H11 and H2 leads to the change of θ1 and θ2. So we can get the different ratios T_1/T_2, which is connected with the ratio of H11 to H2.

In the interval of T_1 the gas is compressed and the heat released by gas is dissipated. In the interval of T_2 the gas in PTC expands and absorbs the heat. Suppose that

$$Q_{dissipated} = W_{compressing} = \int_{T1} d(pv) \quad (3)$$

$$Q_{absorbed} = W_{expanding} = \int_{T2} d(pv) \quad (4)$$

where $Q_{dissipated}$ is the quantity of dissipated heat in the hot end and $Q_{absorbed}$ is the quantity of absorbed heat in the cold end of PTC respectively.



(a) Injecting gas Process (b) Ejecting gas process

Figure 2 The time intervals of injecting and rejecting of gas

According to the thermal equilibrium of Q_{diss} and Q_{abs}, the more is Q_{diss}, the more is Q_{abs} .These two values relate to integrating times T_1 and T_2. If letting T_1 be longer , that is to say, letting the injecting time be longer, we can make the value of Q_{abs} be larger. But the longer compressing time means the shorter expanding time. If the expanding time is too short, the gas will expand not enough, which make the cooling temperature and the cooling power not optimal. So there is an optimum of timing ratio. Through changing the dimensions of H11, H12 and H2, we can approximate the optimum of T_1/T_2.

EXPERIMENTAL RESULTS

Firstly, the dimension of H11 is changed. Secondly the dimension of H2 is changed too. Under this we can get different ratios of H11/H2, which reflect the ratio of T_1/T_2.

In the experiments, the orifice and double inlets are adjusted in order to get the lower cooling temperature. The experiment results are depicted in Figure 3. The temperature is the average of several experimental results under the same conditions.

In Figure 1 we can see that with the rising of the ratio H11/H2 (that is to say with the rising of ratio of T_1/T_2) the cooling temperature begins lower. But cooling temperature begins rising when this ratio reaches approximately 1.25 with the rise of the ratio H11/H2. Therefore, we concluded that there is an optimum of ratio approximately equaling to 1.25. This also means that there is an optimum of the timing ratio. The ratio has effect on the cooling temperature and power of the PTC.

The reason is that when the injecting time is longer, the gas in PTC does more work which relates to the cooling power. In the more we can achieve the lower cooling temperature. While it will be opposed to this when the ratio is too large as we have observed in the experiment because of the insufficient expanding of gas.

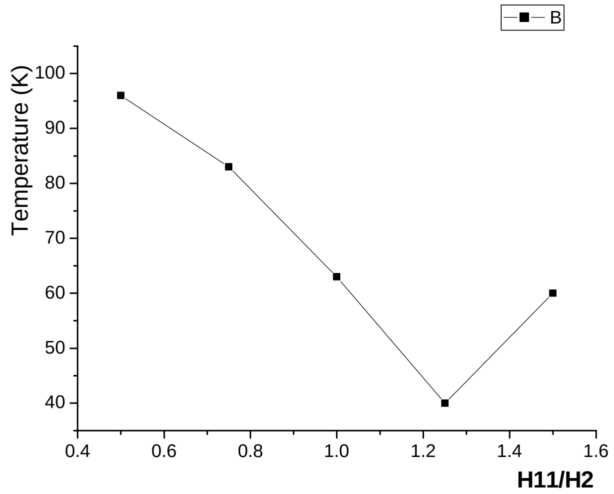


Figure 3 The relationship between the ratio H1/H2 and the cooling temperature

CONCLUSION

The effects of the timing ratio on the cooling temperature have been analyzed through analyzing the angles swept by the rotary valve heads. According to the experimental results the ratios of the H11/H2 have been obtained, which is connected with the timing ratio of injecting to ejecting time of gas and have effects on the cooling temperature of the PTC. And according to the experimental results there exists an optimum of this ratio. In this paper it is approximately 1.25. And it is helpful to find the exact optimal timing ratio and lower the cooling temperature of cold end of PTC. I think that the next step is to make the optimum is universal.

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