Research of Two Separated Pulse Tube Cold Heads Driven by a Single Compressor

X.J. Chang[1, 2], L.W. Yang[1], J.T. Liang[1], J.H. Cai[1], Y. Zhou[1] and G.T. Hong[1]

[1]Technical Institute of Physics and Chemistry of CAS, Beijing, 100190, China
[2]Graduate University of Chinese Academy of Sciences, Beijing, 100049, China

ABSTRACT

Using two separated pulse tube cold heads driven by a single compressor is a potential method to achieve refrigeration at two different positions with a simple system. A program has been set up to simulate the complex effects of two parallel cold heads and to optimize the results. An experimental system has been fabricated for further investigation and comparison. Both simulation and experimental results prove the feasibility of achieving a refrigerating capacity of around 0.5 W at 60 K and 0.5 W at 80 K, simultaneously, in the system.

INTRODUCTION

A unique feature of pulse tube cryocoolers (PTCs) is that there are no moving parts at the cold tip, so PTCs often display long life and high reliability [1,2]. For this reason, a system with duplicate compressors only could be a method of prolonging the lifetime of the system. Generally, pulse tube cryocooler systems include a single cold head, except for multi-stage versions [3,4,5]. If one requires refrigeration at two different positions—for example, 0.5W/80K and 0.5W/60K at positions 0.5m apart—one could use a single compressor to drive two cold heads at the same time. This method will simplify the design and decrease the complexity of the PTC system.

This paper describes research into such a system. Firstly, a program has been developed to simulate the characteristics of two pulse tubes driven by a single compressor. Then, an experimental system was set up, which includes one compressor and two different pulse tube cold heads. The effects of average pressure, frequency, and input power have been examined.

SIMULATION PROCESS

Our heritage simulation program used for modeling PTCs is mainly based on thermodynamic nonsymmetrical theory [6,7,8], and it has been optimized continually over the past ten years. It simulates the PTC working processes so as to compute system performance for different conditions. However, the program does not have the ability to simulate a system with two cold heads driven by one compressor. Therefore, a new program was developed to simulate

Cryocoolers 15, edited by S.D. Miller and R.G. Ross, Jr.

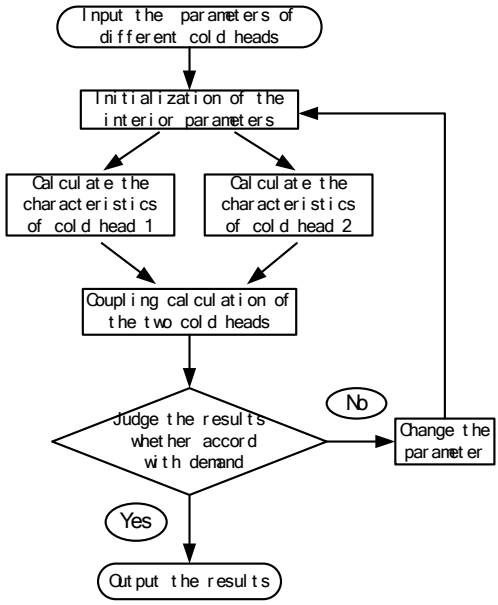


Figure 1. Main frame of the program.

two PTCs at the same time, and the parameters of the two PTCs in the program can couple with each other. The program lays a foundation for exploring the interior working mechanisms of PTC systems under different conditions. Figure 1 illustrates the overall flow of the program.

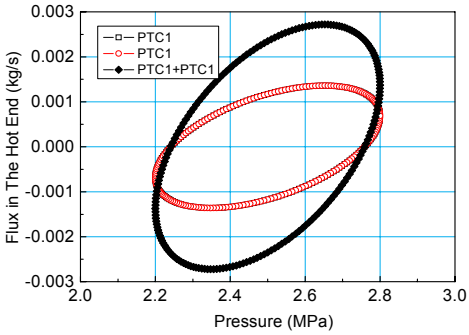
The program contains several steps. First, the parameters of the cold head are input; this includes the size of the pulse tube, the performance demand, run-time parameters, and so on. Second, the characteristics of the different cold heads are predicted using an iterative calculation. This calculation process mainly uses the previously existing program. Third, a coupling calculation of the two cold heads is carried out to assure that the inlet pressure wave to the two cold heads is the same, i.e., the outlet pressure wave of the compressor has only one value. Finally, a PV plot is generated for the compressor pressure wave and mass flux. From this, we can get the input power of the compressor. Further iterative calculations depend on specific demands.

FLOW CHARACTERISTICS IN THE SIMULATION

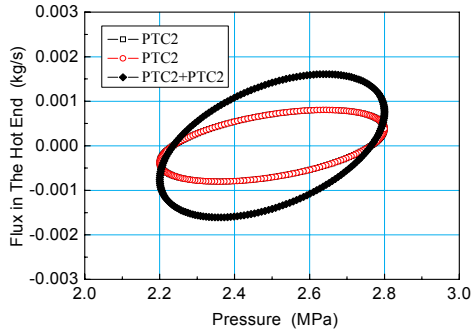
The parameters for the two PTC cold heads used in the program were made the same as the PTCs used in the experiment. The diameter of PTC1 is 14mm, and the refrigeration expectation is 0.5W at 60K. The diameter of PTC2 is 10mm, and the refrigeration expectation is 0.5W at 80K. The results of the simulation program depend on the size of the pulse tubes.

In order to validate the feasibility of the program, we compared the curve of mass flow versus pressure at the hot end of pluse tube for different conditions.

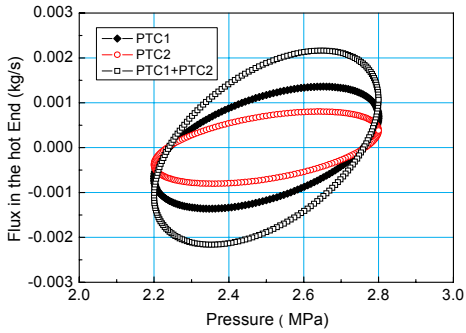
Shown in Figure 2(a), (b), (c) and (d) are the curves of mass flux vs. pressure. Figure 2(a) and (b) are the results for two PTC1 and two PTC2 coldheads, respectively. Both PTCs have almost the same mass flux, and the mass flux of the combination is the sum of the two. The average mass flux over one cycle is zero. Figure 2(c) is the simulation result for the combination: one PTC1 plus one PTC2. The phase of PTC1 nearly equals that of PTC2. The pressures are nearly equal when the mass flux is zero. The combination of two unequal pulse tubes makes the mass flow larger, just like with two identical PTCs.



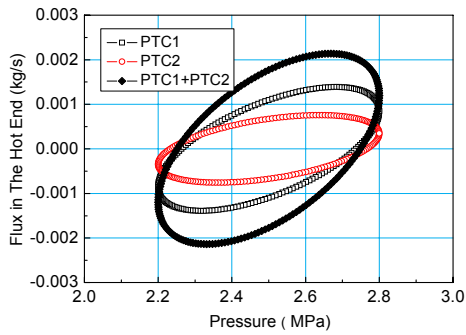
(a) Simulation results for PTC1+PTC1.



(b) Simulation results for PTC2+PTC2.



(c) Simulation results of PTC1+PTC2.



(d) Simulation results for PTC1+PTC2.

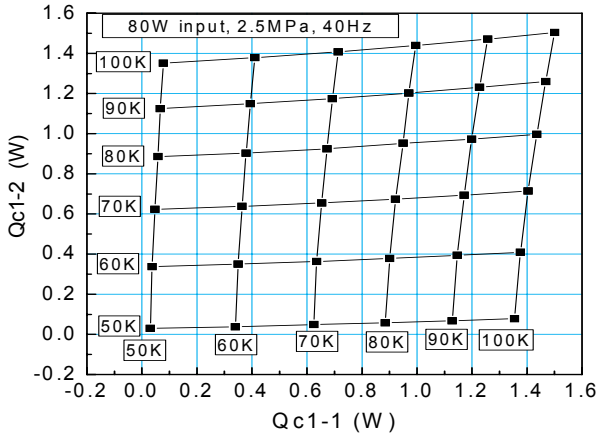
Figure 2. Relationship between outlet flux and pressure wave of compressor

For further analysis, the phase adjusting parameter of PTC2 was changed, and the new combination results are shown in Fig. 2(d). The significant parameter change made at the PTC2 pulse tube hot end resulted in only a very small change at the compressor outlet. When compared to Fig 2(c), the pressure is seen to be a little smaller at zero flux. The combination of the two pulse tubes is quite like the curve of Fig 2(c). Therefore, the main feature of the system is determined by the PTC dimensions, though phase adjusting is also an important parameter. Design of different PTCs at the beginning is important for different cooling targets.

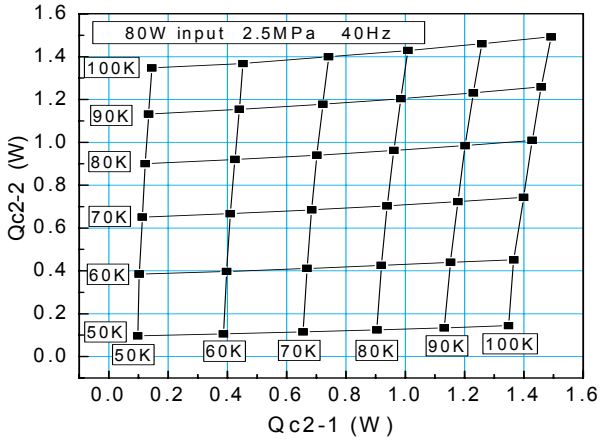
SIMULATION RESULTS

Using the above program, the coupling features of the two pluse tubes were computed. Typical results are shown in Figures 3(a), (b), and (c). During the simulation, typical simulation parameters included an input PV power of 80W, a working frequency of 40 Hz, and an average pressure of 2.5 MPa.

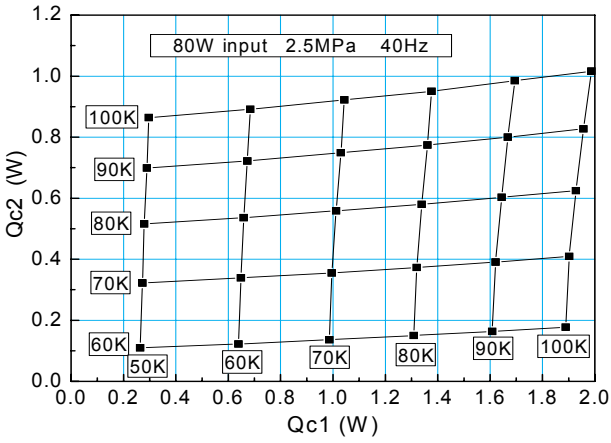
Figure 3(a) shows the refrigeration characteristics of PTC1+PTC1, and Figure 3(b) shows the refrigeration characteristics of PTC2+PTC2. The first impression of these two figures is that they are very similar. For example, the refrigeration capacities are both about 0.95W when the refrigeration temperatures are 80K/80K, and both are 1.5W when the refrigeration temperatures are 100K/100K. The main reason for this is that PTC1 and PTC2 have similar performance at the same input power. However, there is also a little difference. For example, the refrigeration capacity of the two-PTC1 combination is about 0.02W when the refrigeration temperatures are 50K/50K, and about 0.35W when the refrigeration temperatures are 60K/60K. The refrigeration capacity of the two-PTC2 combination is about 0.1W when the refrigeration temperatures are 50K/50K, and about 0.4W when the refrigeration temperatures are 60K/60K.



(a) PTC1+PTC1



(b) PTC2+PTC2



(c) PTC1+PTC2

Figure 3. Refrigeration characteristics

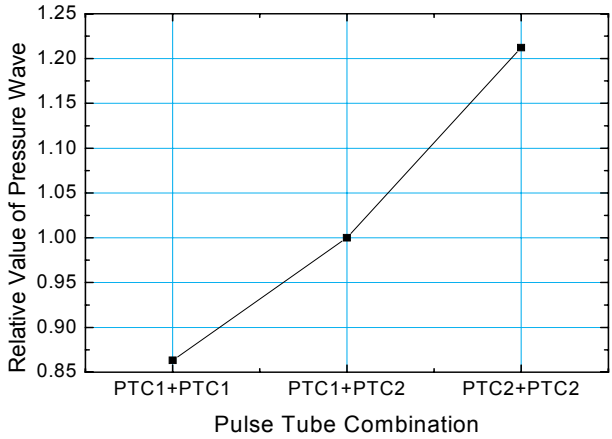


Figure 4. Relative value of pressure wave amplitude at compressor outlet for different PTC groups.

Our research objective is to optimize the PTC system to supply the refrigeration capacities of 0.5W at 60K and 0.5W at 80K, respectively. From Figure 3(a), the refrigeration capacities of the PTC1+PTC1 system are about 0.38W/0.90W when the refrigeration temperatures are 60K/80K. From Figure 3(b), the refrigeration capacities of the PTC2+PTC2 system are about 0.42W/0.90W when the refrigeration temperatures are 60K/80K. Obviously, the refrigeration capacities at 60K are less than those at 80K. The conclusion from the simulation is that reaching the target of 0.5W at 60K and 0.5W at 80K is impossible with two identical PTCs.

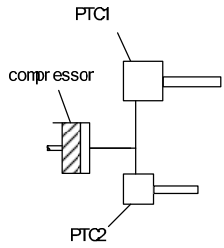
The simulated refrigeration characteristics of the PTC1+PTC2 system are shown in Fig. 3(c). There are obviously different characteristics for PTC1 and PTC2. The refrigeration capacities of the PTC1+PTC2 system are 0.65W/0.53W when the refrigeration temperatures are 60K/80K. The refrigeration capacities are 1.33W/0.58W when the refrigeration temperatures are 80K/80K, and for 100K/100K, cooling capacities are 2.0W/1.0W. Obviously, much more gas goes into PTC1, and more refrigeration capacity is gained with PTC1. From Figure 2(a) and (b), PTC1 needs more mass flux than PTC2 with the same pressure wave. When one compressor drives two or more PTCs, more gas will be distributed to the larger one in order to keep the same compressor outlet pressure.

Figure 4 dispalys the relative value of pressure wave amplitude in the compressor outlet for different PTC combinations. For PTC1+PTC2, the pressure wave is 10% greater than that with two PTC1s, and the pressure wave is 20% less than that with two PTC2s. From the viewpoint of power distribution, this means PTC1 consumes more input power than PTC2 in the PTC1+PTC2 combination.

From the simulation results, the PTC1+PTC2 combination should meet the refrigeration need of 0.5W at 60K and 0.5W at 80K, respectively.

DESCRIPTION OF EXPERIMENTAL SYSTEM

In order to verify the above analysis, an experimental system consisting of two PTCs driven by one compressor was set up; a schematic diagram and photo are shown in Figure 5. The pressure wave generator is a dual-piston linear compressor that can generate an oscillating pressure. Both cold heads utilize a coaxial configuration with an inertance tube to provide the phase shift at the hot end of the pulse tube. For simplicity, both PTCs were fixed for their initial optimization, and there was no phase adjustment during the test. The regenerator diameter of PTC1 is 14mm, and that of PTC2 is 10mm. The regenerator matrix consists of 400# stainless steel wire mesh. Both reservoirs with inertance tube inside are mounted on the PTCs' hot-end flanges.



(a) Schematic diagram

(b) Photo

Figure 5. Two PTCs driven by one compressor

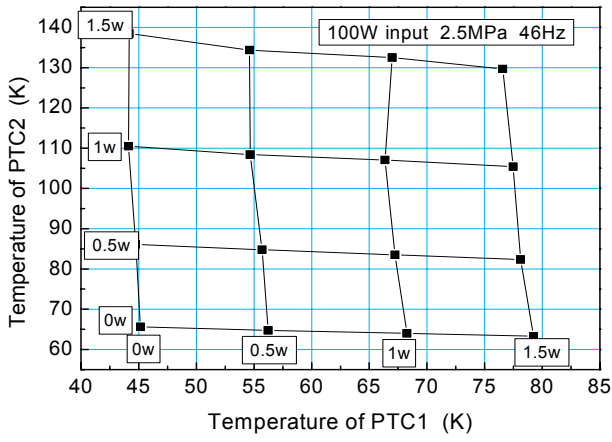
EXPERIMENTAL RESULTS AND DISCUSSION

In order to investigate the coupling effect between the compressor and the two pulse tubes, and to understand the characteristics of oscillating flow in the different parts of the pulse tube, many experiments have been carried out. Typical performance parameters, such as input power, frequency, and average pressure, were changed during the tests.

Shown in Figures 6(a), (b), (c) and Figure 7 are the curves of refrigeration characteristics of PTC1+PTC2 in the experimental system. The difference between Figure 6 and Figure 7 is the input power to the compressor. The former is 100W, and the latter is 150W.

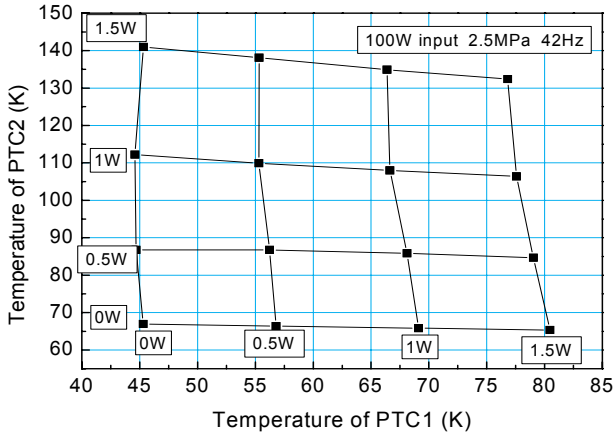
In Figure 6(a), the working conditions are average pressure 2.5MPa and frequency 46Hz. When the refrigeration temperatures are 60K/80K, the refrigeration capacities of the PTC1+ PTC2 system are about 0.65W/0.41W. When the frequency is changed to 42Hz, from Figure 6(b), the refrigeration capacities are about 0.67W/0.41W. While keeping 46Hz, when the average pressure is changed to 3.0MPa in Figure 6(c), the cooling power is about 0.53W/0.40W.

From Figure 6, the configurations are all close to the original target of 0.5W at 60K and 0.5W at 80K. Relatively, the refrigerating capacity is the highest with the condition of 2.5MPa and 42Hz. Because too much gas goes to PTC1, the cooling power of PTC2 should be increased; changing the frequency and average pressure is not effective in increasing the cooling power of PTC2 while decreasing or keeping unchanged the cooling power of PTC1. The PTC2 or PTC1 should be separately further optimized for better coupling. This is the next work step.

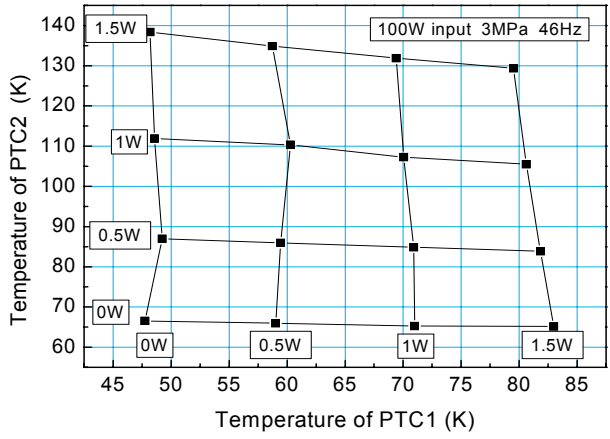


(a) 2.5MPa, 46Hz

Figure 6. Refrigeration characteristics of PTC1+PTC2 with 100W input power.



(b) 2.5MPa, 42Hz



(c) 3MPa, 46Hz

Figure 6. Refrigeration characteristics of PTC1+PTC2 with 100W input power.

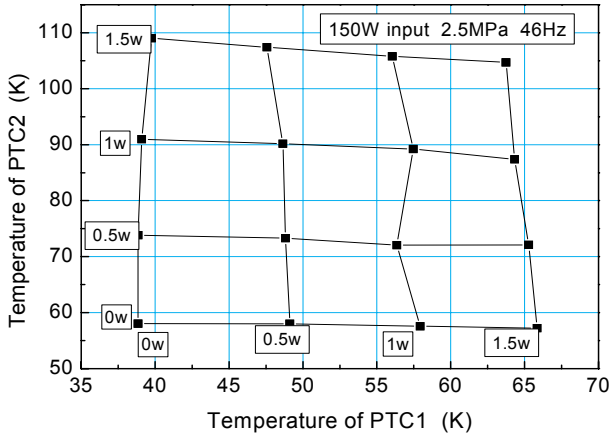


Figure 7. Refrigeration characteristics of PTC1+PTC2 with 150W input power.

When the input power is changed to 150W, as shown in Figure 7, the refrigeration capacities of PTC1+PTC2 are about 1.20W/0.75W at the refrigerating temperatures of 60K/80K; this is much higher than the target.

CONCLUSIONS

The method of two separated pulse tube cold heads driven by a single compressor has been investigated to meet the refrigeration demands at different positions in a system. This method has the merit of a simple design. Simulation results show that the PTC1+PTC2 combination is likely to achieve the 0.5W at 60K and 0.5W at 80K cooling load at the same time. The experimental results prove that two separated pulse tube cold heads driven by one compressor is a good method, and interactions between the two PTCs are limited at small cooling loads. At 2.5MPa and 46Hz, with 80W input power, 0.65W/60K and 0.41W/80K cooling was achieved at the same time. The experimental results generally agree with the simulation results.

ACKNOWLEDGMENT

The work is supported by National Natural Science Foundation of China (Grant No.50676100, No.50206025, No. 50176052) and Key Foundation (No. 50536040).

REFERENCES

1. Hou, Y.K., "Recent Development of Stirling Type Pulse Tube Cryocooler," *Vacuum & Cryogenics*, vol. 6, no. 2 (2002), pp. 63-70.
2. Ravex, A. and Trollier, T, "Recent Developments on Cryocoolers in Europe," *the 20th International Cryogenic Engineering Conference (ICEC20)*, Elsevier, Beijing (2005), pp. 127-135.
3. Liang, J.T., et al., "Study on Miniature Pulse Tube Cryocooler for Space Application," *Cryogenics*, vol. 40, no. 3 (2000), pp. 229-233
4. Yang, L.W. and Thummes, G. "High Frequency Two-Stage Pulse Tube Cryocooler with Base Temperature below 20 K," *Cryogenics*, vol. 45, no. 2 (2005), pp. 155-159.
5. Liang, J.T., Zhou, Y. and Zhu, W.X., "Development of a Single-Stage Pulse Tube Refrigerator Capable of Reaching 49K," *Cryogenics*, vol. 30 (1990), pp. 49-51.
6. Liang, J.T., Ravex, A. and Rolland, P., "Study on Pulse Tube Refrigeration, Part 1: Termodynamic nonsymmetry effect," *Cryogenics*, vol. 36 (1996), pp. 87-93.
7. Liang, J.T., Ravex, A. and Rolland, P., "Study on Pulse Tube Refrigeration, Part 2: Theoretical Modelling," *Cryogenics*, vol. 36 (1996), pp. 95-99.
8. Liang, J.T., Ravex, A. and Rolland, P., "Study on Pulse Tube Refrigeration, Part 3: Experimental Verification," *Cryogenics*, vol. 36 (1996), pp. 101-106.