Temperature Hysteresis in a GM-Type Orifice Pulse Tube Refrigerator[1]

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Compared to the instability in some double-inlet pulse tube refrigerators due to the DC-flow in the cooling system, normally the single orifice pulse tube refrigerator (OPTR) is considered to operate stably. However, in recent experiments we found a new phenomenon, temperature hysteresis, in a single stage GM-type OPTR that depends on the heat load and on the adjustment of the needle valve connecting the pulse tube warm end with the buffer volume. The lowest temperature of this cooler, when operated on a 6 kW compressor, was 18.0 K with double inlet and 30.4 K with single orifice, respectively.

INTRODUCTION

The double-inlet mode introduced by Zhu et al. in 1990 [1] is one of most efficient configurations in pulse tube refrigerators. Nowadays the no load temperature can reach 13 K together with high cooling power in a single stage pulse tube refrigerator [2]. However, The double-inlet bypass opens up the possibility of DC-flow in a refrigeration cycle, which makes temperature instability in some pulse tube refrigerators [3,4]. Although some effective DC flow control methods are introduced in the system [5,6], the temperature instability are still exist, especially at high heat load.

Normally the single orifice pulse tube refrigerator (OPTR) is considered to operate stably compared to the instability in double-inlet pulse tube refrigerators. But in recent experiments we found a new phenomenon, temperature hysteresis, in a single stage GM-type OPTR. This paper describes the detail experimental results.

EXPERIMENT SET-UP

Figure 1 shows the schematic of a GM type single stage pulse tube refrigerator system, which consists of a helium compressor (Leybold, RW 6kW), a rotary valve and a single stage pulse tube refrigerator. The regenerator and pulse tube are made of stainless steel tubes with outer diameter, wall thickness and length of $\phi 48\times 0.9\times 200$ mm and $\phi 41\times 0.8\times 200$ mm, respectively. The regenerator matrix from hot end to cold end consists of 3/4 space stainless steel screens of 247 mesh and 1/4 space of lead balls of 0.25mm diameter. The pulse tube refrigerator is equipped with 2.5 l reservoir and three needle valves (Swagelok, SS-ORS3MM), one needle valve for the orifice (ORV), the other two parallel-placed needle valves with opposite flow direction (double-valved configuration, DIV1: PT→REG, DIV2: REG→PT) instead of conventional single-valved configuration for the double-inlet mode.

The temperature is measured by Pt100 resistance thermometers (T1, T2, T3, T5 in Figure 1) and Cernox thermometer (T4). Piezoelectric pressure sensors (Siemens, type KPY 46R) are used for monitoring the dynamic pressures at the hot ends of regenerator (P1) as well as in the reservoir (P0).

The cooler operates with a charge pressure of 17.5 bar (absolute pressure) and a frequency of 1.4Hz.

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[1] The work was carried out at Institute of Applied Physics, University of Giessen.

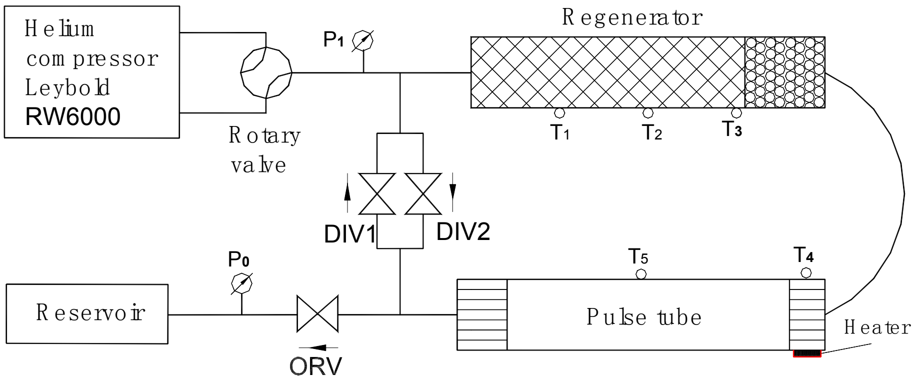

Figure 1 Schematic of a GM type single stage pulse tube refrigerator

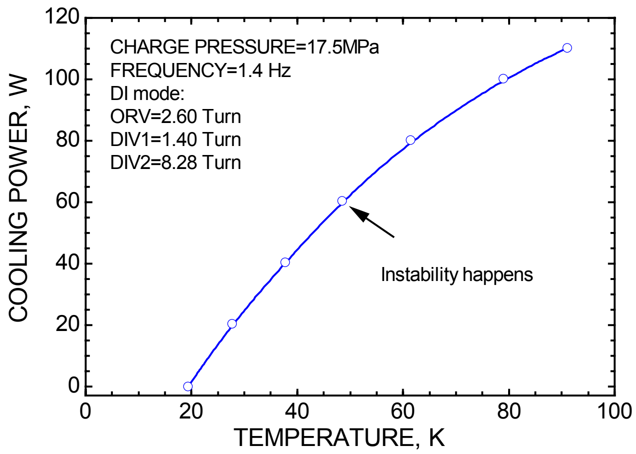

Figure 2 Cooling power vs. temperature in double-inlet mode (double-valved configuration)

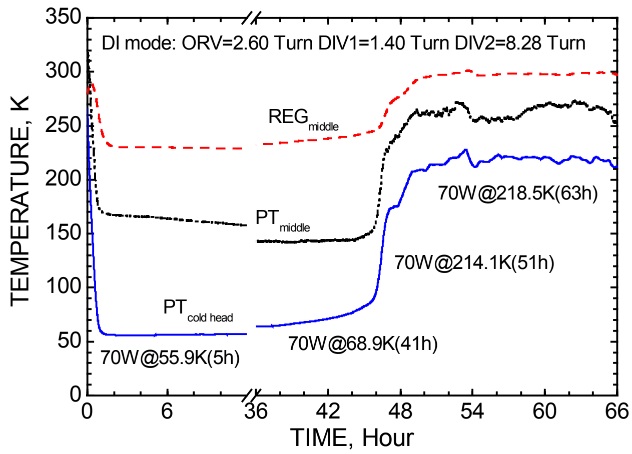

Figure 3 Instability with 70W cooling power

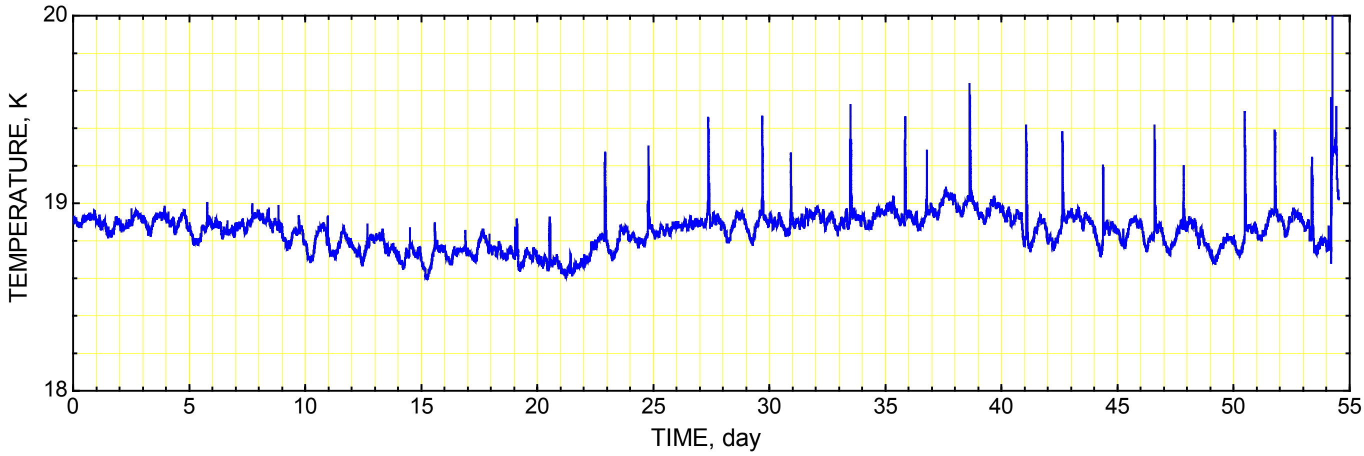

Figure 4 Temperature stability without heat load

EXPERIMENTAL RESULTS AND DISCUSSIOIN

Temperature instability in double-inlet mode

Figure 2 shows the cooling power of the cooler with double-valved configuration. The minimum temperature obtained is 19.3K and 100W at 79K.

However, the temperature instability happened when the cooling power is above 60W (48.5K). Figure 3 shows the temperature instability when the cooling power is 70W as an example. It indicates that the temperature increases slowly from 55.9K to 68.9K after 41 hours running, then rises sharply to about 220K and oscillates near 220K.

When the cooling power is below 40 W (37.7K), the temperature is stable for long time running. Figure 4 shows the temperature stability for nearly 55 days without heat load as an example. The temperature oscillation is less than 0.5K around the 18.8K.

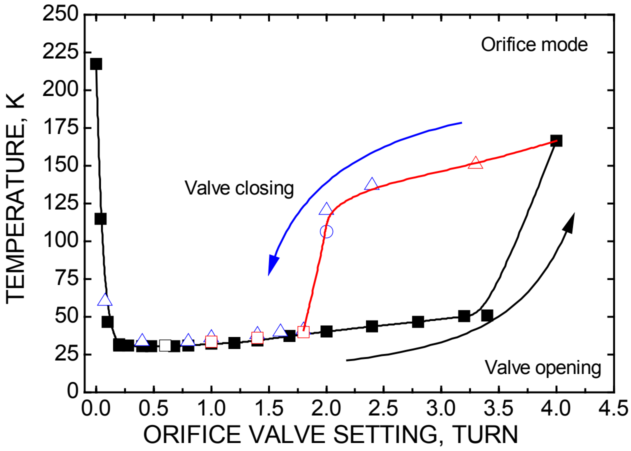

Figure 5 Temperature vs. ORV valve settings

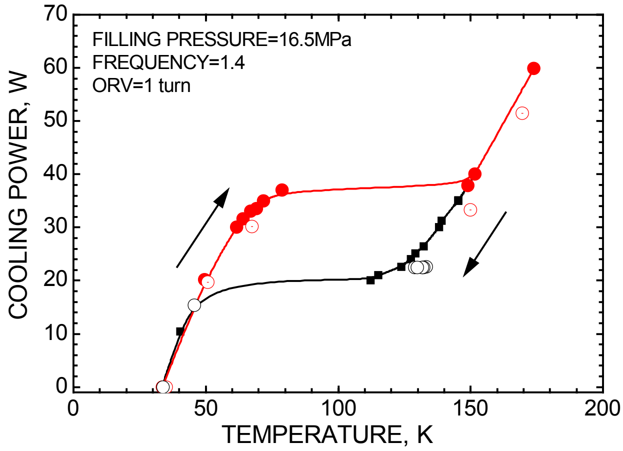

Figure 6 Cooling power vs. temperature in orifice mode

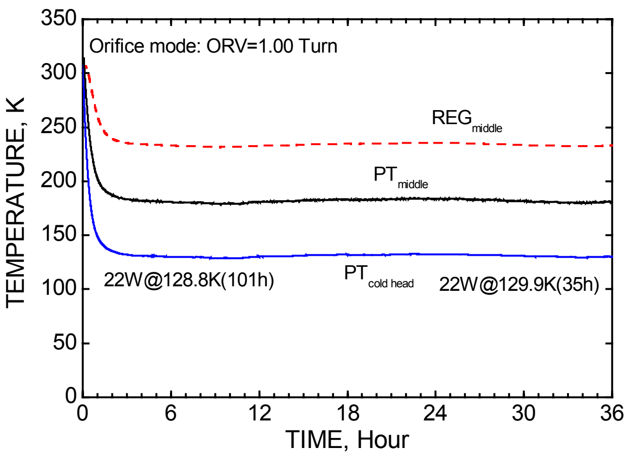

Figure 7 Temperature history with 22 W heat load at the beginning

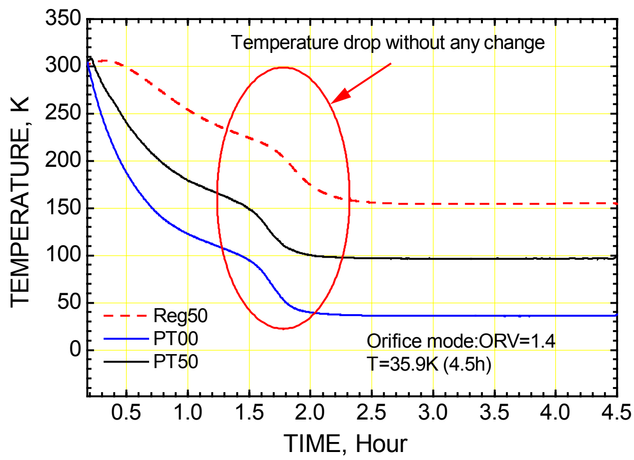

Figure 8 Cooling down process in orifice mode

It indicates that the double-valved configuration between the hot end of pulse tube and regenerator is good method to control the DC-flow and benefit for the cooler performance, especially below 40 W heat load but not enough for the heat load above 60W for the tested cooler system.

A new phenomenon: temperature hysteresis in orifice mode

When the two needle valves DIV1 and DIV2 close, the cooler system turns back to orifice mode. Unlike the other OPTR, a new phenomenon: temperature hysteresis, which depends on the orifice needle valve adjustment and on the heat load, is appearing in the tested cooler.

Figure 5 shows temperature character versus orifice valve settings. Starting with the cooler in basic mode that yields about the 217 K, the temperature at the cold tip of the pulse tube drops to a stable temperature of 30.4 K with the orifice valve opens by one turn. Upon further opening of the valve the temperature increase gradually to 51 K, corresponding up to about 3.5 turns valve opening. Then, at 4 turns the temperature rises sharply to 167 K, which is also accompanied by a hysteresis effect, i.e. in order to achieve the initial low temperatures the needle valve had to be closed again to about 1.8 turns.

The hysteresis is also seen upon cool down of the cooler when the orifice valve sets to more than 2 turns. The cooler then only cools to a higher stationary temperature level (above 120 K), and further valve closing below 1.8 turns is necessary to reach the initial low temperatures. That is, the temperature hysteresis occurs when the orifice valve setting is between 1.8 and 4 turns.

Normally, the shape of cooling power versus temperature in a cooler is like Figure 2 and independent on the heating process. However, a hysteresis is also found in the cooling power as function of temperature as shown in Figure 6. When the heating process is increasing from zero to 37 W, the cold tip of cooler has a temperature from 33.6K to 79 K with the orifice valve sets to 1 turn. With a slightly higher heat load the temperature increases rapidly to another stable state above 149 K. When the heating process is opposite, the heat load has to be decreased to below about 20 W to switch back to the initial load line. The temperature hysteresis occurs when the cooling power is between 20 and 38 W.

When cooling down the system with heat load of 22 W, the temperature can only reach 129 K, a high stable temperature level, as shown in Figure 7. That is, if there is enough cooling power, the cooler can overcome the heat obstruction and drop from high stable temperature to low stable temperature.

Temperature drops can also be found in the cooling down process with orifice mode, in the ellipse area as shown in Figure 8. The reason is the regenerator matrix of the tested cooler consists of stainless steel and lead sphere. The heat capacity of lead is larger than stainless steel when the temperature below 70K.

CONCLUSION

A temperature of 19K and 100W at 79K are obtained in a single-stage pulse tube refrigerator with double-valved configuration introduced in the double-inlet mode and the regenerator matrix from hot end to cold end consists of 3/4 space stainless steel and 1/4 space of lead sphere.

With the DC-flow controlled by double-valved configuration, the temperature can be stable when the cooling power below 40W. The temperature instability still exist in the cooler when the cooling power above 60W.

A new phenomenon, temperature hysteresis, in the orifice mode is observed. The hysteresis depends on the heat load and on the adjustment of the orifice valve settings. This phenomenon will be useful to understand the instability in the double-inlet mode of pulse tube refrigerators.

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