Experimental study of wall temperature distribution of stirling type pulse tube refrigerator (SPTR)

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In this paper, the experimental study on wall temperature distribution of a Stirling type pulse tube refrigerator has been carried out. The influences of structural and working parameters on performance of SPTR have been studied, especially on wall temperature distributions of pulse tube and regenerator. Through a number of experiments, the rule of wall temperature distributions and the relationship of it's dependence on structural parameters and working parameters has been found, giving some hints to further improve the performance of a given SPTR, and DC flow has also been validated from temperature distribution curve.

INTRODUTION

Gifford and Longsworth [1] developed the original pulse tube refrigerator. Mikulin et al. [2] and Zhu et al. [3] proposed new concepts known respectively as orifice type and double inlet type. It is well known that pulse tube refrigerator is a good alternative to Stirling and G-M refrigerators, because there is no moving part in the cold head. In order to further improve the performance of Stirling type pulse tube refrigerator, it is important to study the wall temperature distribution curve of pulse tube and regenerator of SPTR. The wall temperature distribution curve of the regenerator can be regarded as an experimental criterion if the design and cooling capacity of SPTR is the best.

EXPERIMENTAL EQUIPMENT

High-performance pulse tube refrigerator usually has an inline arrangement. However, in inline configuration the cold head is located in the middle, which makes the cooling of thermal interfacing with the device rather difficult. Therefore, for some practical reasons and experimental demand we have chosen a U-shaped configuration. A schematic view of the setup is shown in Figure 1.

In our experiments, SPTR was driven by oil-less-lubricated and valve-less helium compressor, whose frequency was adjusted from 5 to 30Hz by a transducer (FRN1.5G9S—4CE type). The regenerator was composed of a stainless steel tube with a wall thickness of 0.2 mm, an inner diameter of 14 mm and a length of 88 mm packed with 250-meshes stainless steel screen. The pulse tube was made of stainless steel tube with a wall thickness of 0.2 mm, an inner diameter of 10 mm and a length of 118 mm. At the end of the regenerator and the pulse tube, two copper heat exchangers were connected with them and cooled by water. The connecting tube in experiment was made of a standard copper tube with outside diameter of 6 mm and a wall thickness of 1 mm. The orifice valve and the double-inlet valve were adjustable needle valve for space application. The reservoir with a volume of about 500 cm^3 was connected to the hot end of pulse tube through the orifice valve. The regenerator and the pulse tube were placed in a vacuum vessel with a pressure of 1 mmPa and were maintained for thermal insulation from the environment at the room temperature.

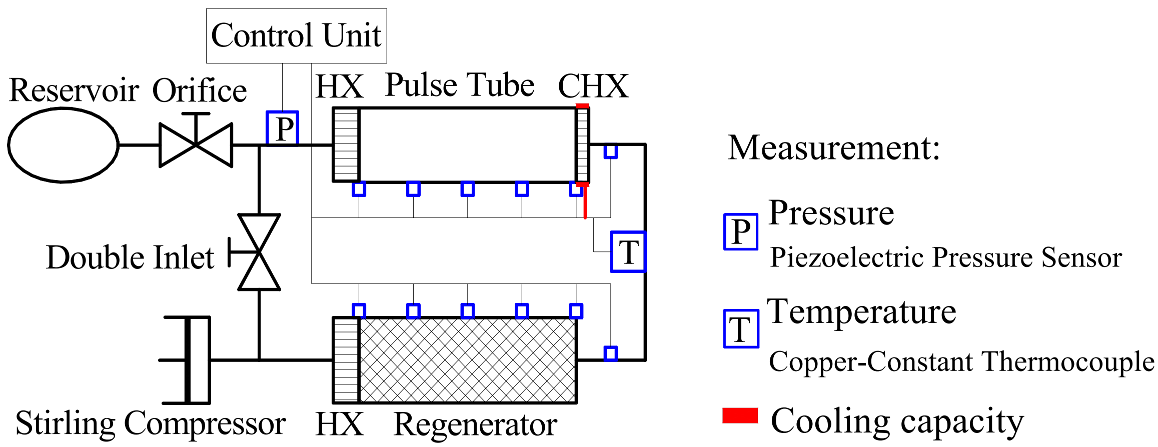


Figure 1 Schematic of Stirling-type PTR with U-shaped configuration

Measurement probes for pressure and temperature were installed as shown in the figure 1. A piezoelectric pressure sensor (CYG-1105 type) was installed at the hot end of the pulse tube to monitor the dynamic pressure wave. Based on the heat balance method, manganin wires wrapped around the cold head, which are supplied by a 0-24V steady voltage power source, are used to measure the cooling capacity. Thermocouples of T-type (Copper-Constant) were soldered at five positions on the pulse tube wall and the regenerator wall. All data were recorded by a data acquisition system controlled by a personal computer.

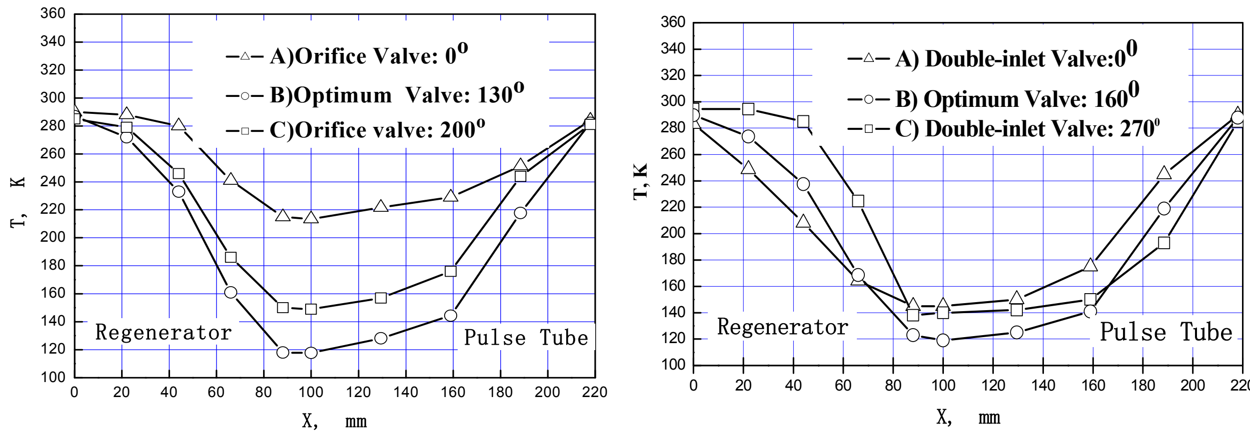
RESULTS AND DISCUSSION

In our experiment, we have obtained wall temperature distribution curves of SPTR depended on structural parameters (orifice valve and double-inlet valve), working parameters (working frequency and charging pressure), and cooling capacity of the cold head.

Effect of structural parameters on wall temperature distribution

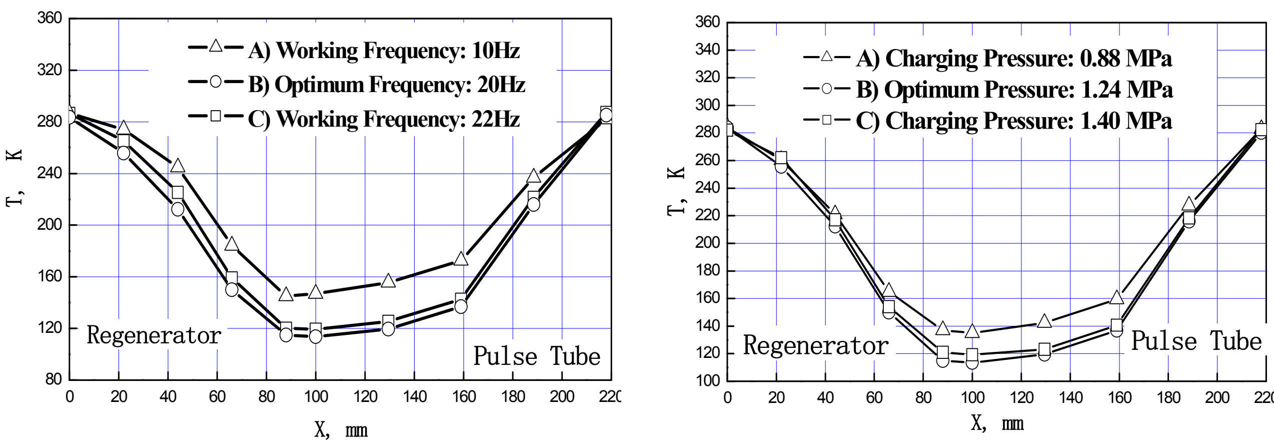
Figure 2 shows the experimental results of the dependence of wall temperature profiles of the regenerator and the pulse tube on the openings of orifice valve (a) and double-inlet valve (b). In condition of charging pressure of 1.24 MPa, working frequency of 15.7 Hz, we adjusted the orifice valve and double-inlet valve to find the optimum opening, and measured the temperature profiles on steady conditions at the same time. The optimum opening of the orifice valve is 130^0 and the one of the double-inlet valve is 160^0. From figure 2, it can be found that adjusting orifice valve and double inlet valve can all improve the cooling performance of the refrigerator. From figure 2a, temperature distribution of the regenerator approximated to ideal linear distribution. The effect of orifice valve on the temperature distribution of the regenerator and the pulse tube was regular.

However, the effect of double-inlet valve was not. From figure 2b, Temperature distribution was mostly deviated from linearity and become very irregular and complex. The temperature distribution of the pulse tube and the regenerator could become worse. The reason is that the double-inlet valve can arouse the airflow short-circuit, and then lead the more complex airflow in the refrigerator, such as DC flow and second flow. Temperatures along the regenerator and along the pulse tube are very sensitive indicators for change of DC flow. DC flow result in irregular change of temperature distribution. Therefore, we can validate DC flow in SPTR from temperature distribution curve.



(a) (b)

Figure 2 Temperature in regenerator and in pulse tube versus orifice valve (a) and double-inlet valve (b)



(a) (b)

Figure 3 Temperature in regenerator and in pulse tube versus working frequency (a) and charging pressure (b)

Effect of working parameters on wall temperature distribution

Figure 3 shows the experimental results of the dependence of the wall temperature profiles of the regenerator and the pulse tube on working frequency (a) and charging pressure (b). In condition of orifice valve of 130^0 and double-inlet valve of 160^0, we changed working frequency and charging pressure to find the optimum value and measured the temperature profiles on steady conditions. The optimum working frequency is 20Hz and the optimum charging pressure is 1.24 MPa. From figure 3, it can be found that working frequency and charging pressure can further adjust the temperature distribution. The experimental results shows that when the working frequency and charging pressure are in optimum condition, the wall temperature distribution of the regenerator and the pulse tube are better. Especially in the regenerator, temperature distribution is closed to ideal linear.

Effect of cooling capacity on wall temperature distribution

Figure 4 shows the experimental results of the dependence of the wall temperature profiles of the regenerator and the pulse tube on cooling capacity. In condition of charging pressure of 1.24 MPa, working frequency of 20 Hz, orifice valve of 130^0 and double-inlet valve of 160^0, we changed cooling capacity and measured the temperature profiles on steady conditions. From figure 4, we found that the cooling capacity only affect the slope of temperature distribution of the regenerator and the pulse tube when the structural parameters and working parameters were on the optimum valve.

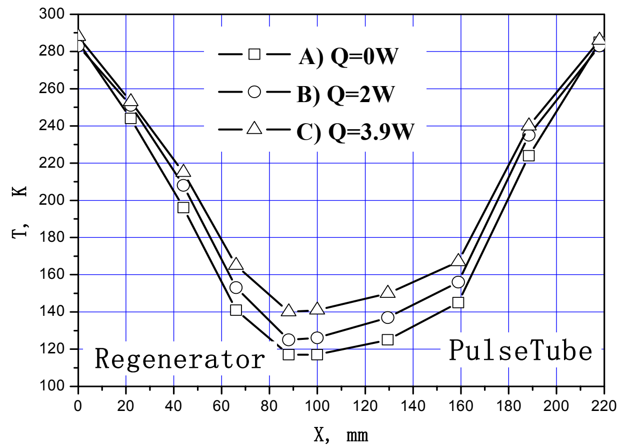


Figure 4 Temperature in regenerator and in pulse tube versus cooling capacity

CONCLUSION

Detailed experimental research on wall temperature distribution of the pulse tube and the regenerator of a Stirling type pulse tube refrigerator has been carried in this paper. Through analyzing our experimental result, we can not only find some general characteristic of SPTR, but also can we obtain the rule of wall temperature distribution and relationship of its dependence on structural parameters and working parameters. The experimental results show that wall temperature distribution curve of SPTR can be regarded as experimental criterion if the design and cooling capacity of SPTR is the best, and be helpful to further improvement and design of SPTR. At the same time, we can also validate DC flow from temperature distribution curve.

ACKNOWLEDGMENT

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