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A study on the in-line type inertance tube pulse tube cryocooler for cooling Superconductor filter

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Abstract-- **The Experimental results of the in-line type inertance tube pulse tube cryocooler for cooling superconductor RF filter are presented in this paper. The pulse tube refrigerator, which has no moving parts at its cold section, is attractive in obtaining higher reliability, simpler construction, and lower vibration than any other small refrigerators. The purpose of this study is to analyze the characteristics of in-line type inertance tube pulse tube refrigerator (IPTR), and to get main factor to improve the performance of the in-line type IPTR. Firstly, design parameters of the in-line IPTR are discussed by ARCOPTR program, and then to find optimal conditions of in-line type IPTR, cool down characteristics according to the variations of the charging pressure, inertance tube volume, regenerator volume and pulse tube volume are measured by the experiment. The lowest temperature of the cold end was about 50 K. Cooling capacity was the highest in the charging pressure of 32 atm. and 5W at 72K. On the other hand, COP of the in-line type IPTR was the highest in the charging pressure of 21 atm. and 0.018 at 77K.**

1. INTRODUCTION

The pulse tube cryocooler was first described by W.E.Gifford and R.C. Longsworth in 1964[1]. This type of the pulse tube cryocooler is now called as the basic pulse tube cryocooler. The performance of this pulse tube refrigerator has been greatly improved by introducing an orifice and a buffer volume added to the hot end of the pulse tube[2]. This type of the pulse tube refrigerator, which is called as the orifice pulse tube refrigerator, was modified by R.Radebaugh et al. in 1986[3].

In 1990, the double inlet pulse tube refrigerator, in which a bypass tube is connected between a pressure wave generator and the hot end of the pulse tube, was suggested by S.Zhu et al. [4]. The refrigeration power per unit mass flow rate through the regenerator was greatly increased in the double inlet pulse tube refrigerator.

Commonly used means to achieve the optimum performance of Stirling type pulse tube refrigerator is the inertance tube [5]. The use of the inertance tube (inertance pulse tube refrigerator, IPTR) is a simply way to generate the phase shift needed to make pulse tube refrigerators operate as efficiently as the Stirling refrigerator.

A more detailed analysis of the IPTR was reported by Zhu et al. [6]. They carried out analysis providing the performance as a function of the diameter and length of the long neck tube (inertance tube). The analysis was verified by an experiment in which a long tube was connected directly between the reservoir and compressor volume.

More recently, de Boer [7] showed that the performance of the IPTR is superior to that of the OPTR over a limited range of frequencies, and the rate of refrigeration of the IPTR is as a function of dimensions of inertance tube, volume of the pulse tube, and the conductance of regenerator, the charging pressure, and the frequency.

Ravikumar et al. [8] showed as frequency increased the "inertance tube" phase shifter enhanced the cooler performance in a region where orifice or double-inlet deteriorated the performance and the dependency of frequency of operation, inertance tube diameter and length was experimentally investigated using rotary valve along with G-M compressor.

In this paper, discussions about the net cooling with volume of the regenerator and the volume ratio of the regenerator to the pulse tube are discussed first by ARCOPTR (Ames Research Center Orifice Pulse Tube Refrigerator) program of NASA Ames Research Center and then the effects of the charging pressure, the volume of the regenerator and the diameter and length of the inertance tube on the cool-down characteristics of the pulse tube cryocooler are investigated by experiment.

2. DESIGN OF THE IN-LINE IPTR BY ARCOPTR AND EXPERIMENTAL DESCRIPTION

Experimental Schematic diagram of the in-line IPTR is shown in Fig. 1. The inertance tube pulse tube cryocooler consists of a linear compressor, transfer line, heat exchanger, regenerator, pulse tube, inertance tube, buffer and vacuum chamber. Linear compressor consists of linear motor, inner and outer yoke, permanent magnet, coil, cylinder, piston and flexure bearing. The pressure oscillation is generated by using a single acting helium compressor (Sunpower compressor revised by LG) for Stirling cryocooler.

Fig. 2, Fig. 3 and Fig. 4 show the net cooling capacity, compressor P-V work and COP of the IPTR at 77K with volume of the regenerator and the volume ratio of the regenerator to the pulse tube, respectively. When the length of the regenerator is shorter than 75mm, the pressure amplitude in the compression space decreases as the volume ratio decreases and the regenerator length increases. In this case, the compressor PV works decrease as the pressure amplitudes in the compression space decrease. In case of regenerator length of 75mm and regenerator diameter of 25.4mm, the pressure amplitudes in the compression space decrease but the phase angle between the piston and pressure increase as the volume ratio decreases. Therefore, the compressor PV works increase as the phase angles between the piston and pressure increase.

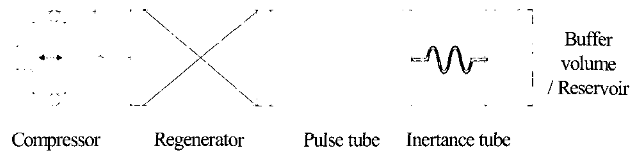

Fig. 1. Schematic diagram of the in-line type IPTR.

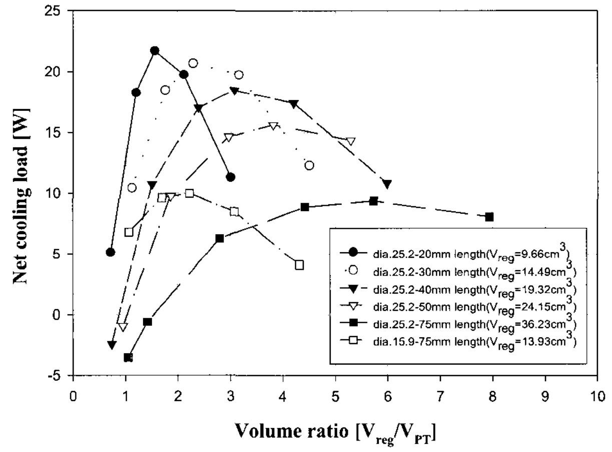

Fig. 2. Net cooling capacity of IPTR (at 77K).

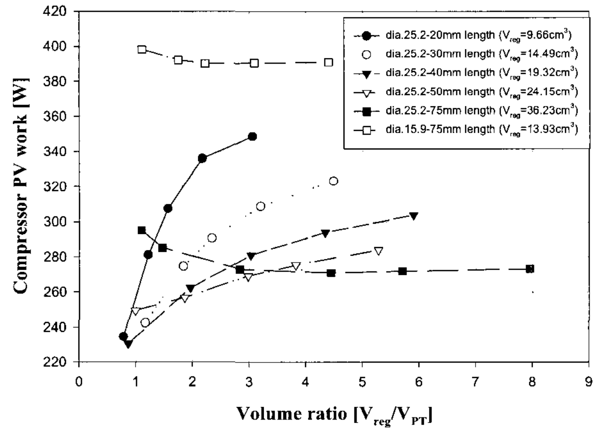

Fig. 3. P-V work of IPTR.

In case of regenerator length of 75mm and regenerator diameter of 15.9mm, the compressor PV works increase abruptly by large pressure drop in the regenerator regardless of phase angle between the piston and pressure. And, as the length of the regenerator decreases, maximum cooling capacity and COP increase and volume ratio at the maximum cooling capacity and COP decrease, but the range of the volume ratio at the maximum cooling capacity and COP is very narrow.

Therefore, although cooling capacity and COP are low, the IPTR is operated stably in the large volume of the regenerator. Operating frequency of the IPTR is 60 Hz.

Fig. 5 shows experimental apparatus of the in-line type IPTR. An AC power supply is used to supply and control

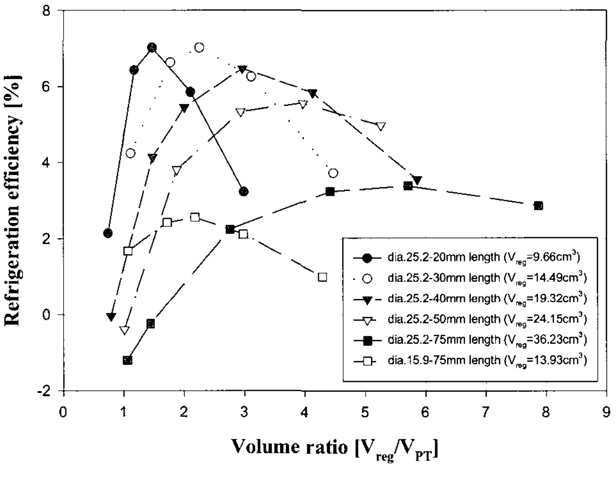

Fig. 4. COP of IPTR.

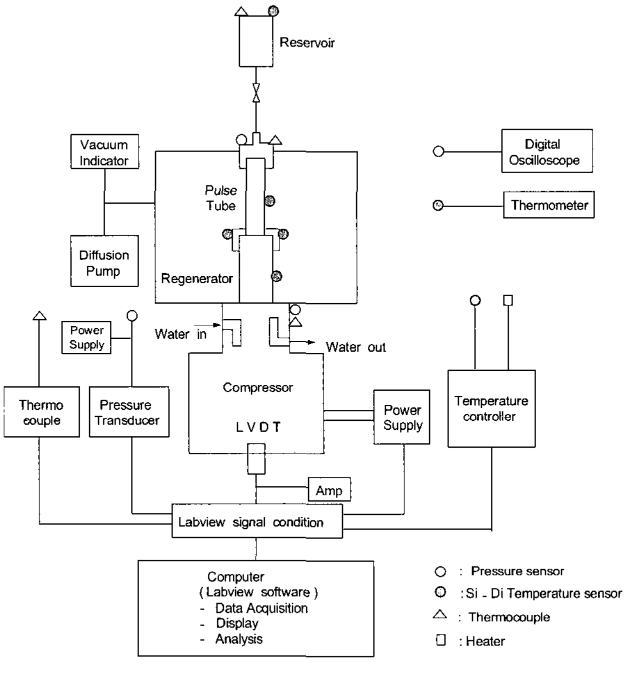

Fig. 5. Experimental apparatus of IPTR.

the operating frequency and input voltage of the linear compressor. Piezoelectric pressure sensors are installed on the exit of the compressor, hot end of the pulse tube and buffer to measure pressure waves. The silicon diode thermometer is attached to measure the temperature at cold end, and the heater is provided at the cold end of the pulse tube to measure the cooling capacity. The cold end is installed to vacuum chamber, and the pressure of the vacuum chamber is maintained below 10^{-5} Torr to reduce the thermal loss during measurements. After the regenerator of the pulse tube cryocooler is cleaned by evacuating and purging with clean high-pressure helium gas, the pulse tube cryocooler is connected to the compressor.

3. EXPERIMENT RESULTS

Fig. 6 shows the variations of the lowest temperature with length and diameter of the inertance tube and the charging pressure at the regenerator length of 40 mm. The lowest temperature was measured at the charging pressure of 21 atm. and inertance tube of 1.6 m in length and 3 mm in diameter.

Fig. 7 and Fig. 8 show the variations of the lowest temperature with length and diameter of the inertance tube and the charging pressure at the regenerator length of 50 mm, 60mm, respectively. As shown in Fig. 6, Fig. 7 and Fig. 8, the diameter and length of the inertance tube and length of the regenerator have significant effects on the performance characteristics of the pulse tube cryocooler, and high charging pressure leads lower temperature in the cold head of the pulse tube cryocooler. And, as the length of the regenerator increases, the lowest temperature of the cold head in the inertance tube pulse tube cryocooler decreases. In this study, diameters of the pulse tube and regenerator are 12.7mm and 25.4mm, respectively.

The lowest temperature in the regenerator length of 60 mm was measured at the charging pressure of 27 atm. and inertance tube of 1.6 m in length and 3 mm in diameter. That is to say, as the charging pressure increased, the lowest temperature decreased.

Fig. 9 shows cool-down characteristics of the in-line type IPTR at the cycle frequency of 60Hz with the charging pressure of 27 atm., inertance tube of 1.6 m in length and 3 mm in diameter and regenerator length of 75mm. The measurement of the cool-down characteristics was performed at the 75mm long regenerator by the results of the many experiments. The temperature of the cold head was about 80K in 12 minutes after operating of the pulse tube cryocooler. The lowest temperature of the cold head was about 50 K.

Fig. 10 and Fig. 11 show cooling capacity and COP of the in-line type IPTR with the charging pressure, respectively. In this case, the diameter and length of the pulse tube were 12.7mm and 70mm, respectively. And the diameter and length of the regenerator were 25.4mm and 75mm, respectively. Also, the diameter and length of the inertance tube were 3 mm and 1.6 m, respectively.

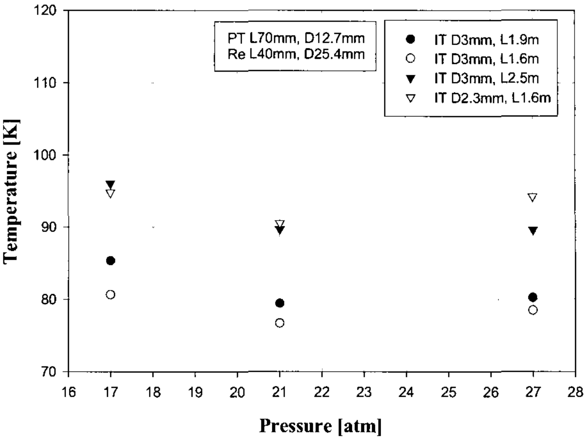

Fig. 6. The lowest temperatures with charging pressure and inertance tube (regenerator 40mm long).

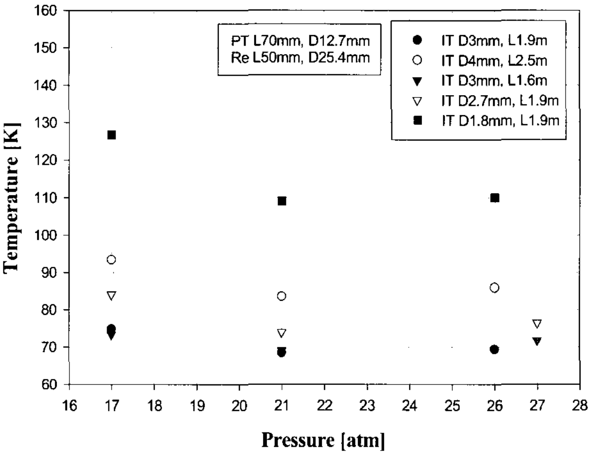

Fig. 7. The lowest temperatures with charging pressure and inertance tube (regenerator 50mm long).

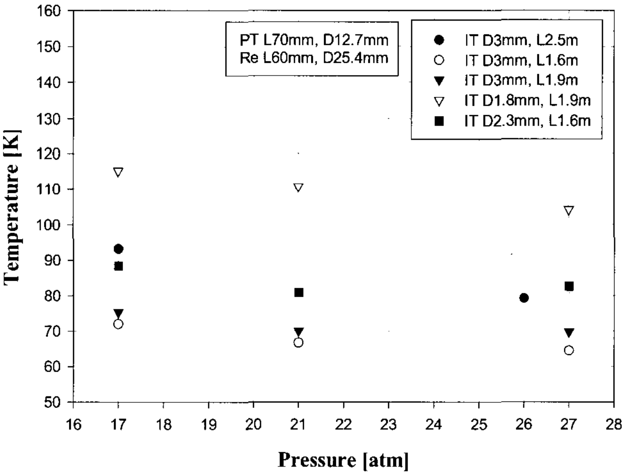

Fig. 8. The lowest temperatures with charging pressure and inertance tube (regenerator 60mm long).

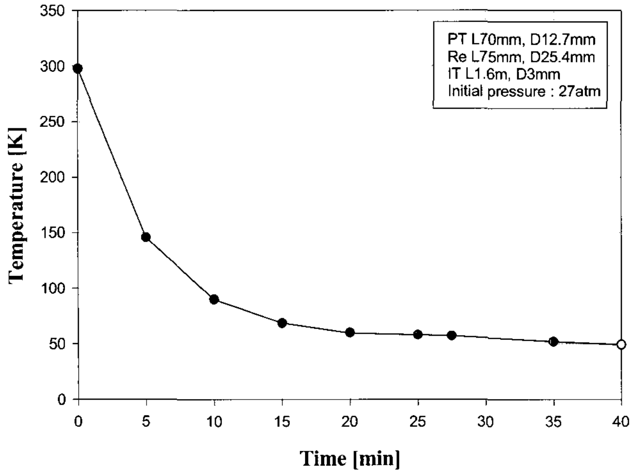

Fig. 9. Cool-down characteristics of IPTR (regenerator 75mm long).

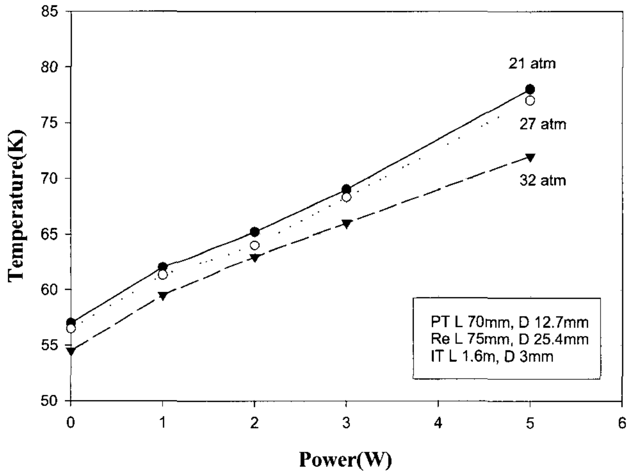

Fig. 10. Cooling capacity of IPTR(regenerator 75mm long).

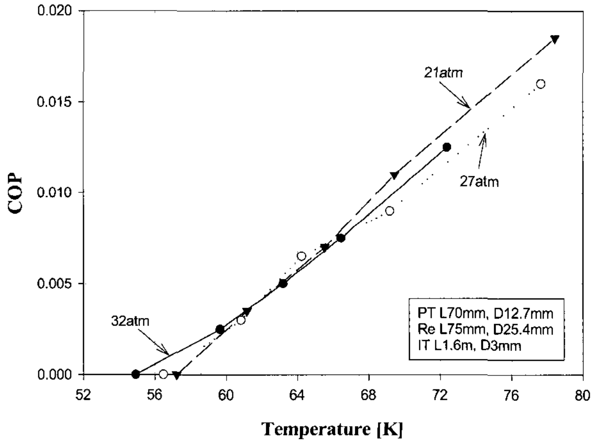

Fig. 11. COP of IPTR (regenerator 75mm long).

As shown in Fig. 10, the cooling capacity increases as the charging pressure increases. When the cryocooler has high charging pressure, the cryocooler could generate the larger pressure ratio. Therefore, the cooling capacity was the highest in the charging pressure of 32 atm. and 5W at 72K. On the other hand, as shown in Fig. 10, there was little difference in COP with the charging pressure to 65K at the cold head. But, COP of the in-line IPTR had the highest value at the charging pressure of 21 atm. for the higher temperature than 65K. . In this time, COP of the in-line IPTR was 0.018 at 77K.

4. CONCLUSION

We have undertaken the analysis on the net cooling with volume of the regenerator and the volume ratio of the regenerator to the pulse tube by ARCOPTR program. And then, the effects of the charging pressure, the volume of the regenerator and the diameter and length of the inertance tube on the cool-down characteristics of the pulse tube cryocooler were investigated by experiment. The following conclusions are drawn from the experimental results.

(1) In the analysis by ARCOPTR program, as the length of the regenerator decreased, maximum cooling capacity and COP increased and volume ratio at the maximum cooling capacity and COP decreased, but the range of the volume ratio at the maximum cooling capacity and COP was very narrow, therefore the IPTR was operated stably in the large volume of the regenerator.

(2) As the volume of the regenerator increased, the performances of the lowest temperature, cooling capacity and COP were improved.

(3) The diameter and length of the inertance tube and length of the regenerator have significant effects on the performance characteristics of the pulse tube cryocooler, and high charging pressure leads lower temperature in the cold head of the pulse tube cryocooler.

(4) Cooling capacity was the highest in the charging pressure of 32 atm. and 5W at 72K. On the other hand, COP of the in-line type IPTR was the highest in the charging pressure of 21 atm. and 0.018 at 77K

ACKNOWLEDGMENT

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