Development of A High Efficiency Pulse Tube Cryocooler Using Room Temperature Displacers for HTS Applications

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1. Introduction

The compact and high efficiency coolers working in the liquid nitrogen temperature region play an important role in HTS Applications. Stirling type pulse tube cooler servers as a promising candidate for cooling HTS devices for its advantages such as low vibration, high reliability and low cost due to absence of the moving parts in the cold head compared with traditional cryocoolers. However, phase shift mechanisms used in a conventional pulse tube cryocooler need to dissipate expansion power at the ambient end of the pulse tube, which leads to a lower thermodynamic efficiency than that of a Stirling cryocooler. In order to improve the efficiency and obtain a reliable cryocooler system, this article presents a pulse tube cryocooler which uses room temperature displacers as the phase shifter, which aims at providing more than 10 W cooling power at 77 K.

2. Cryocooler Configuration Description

As shown in the Fig.1 and Fig 2, the cryocooler consists of a linear compressor, a pulse tube cryocooler and dual-opposed warm displacers.

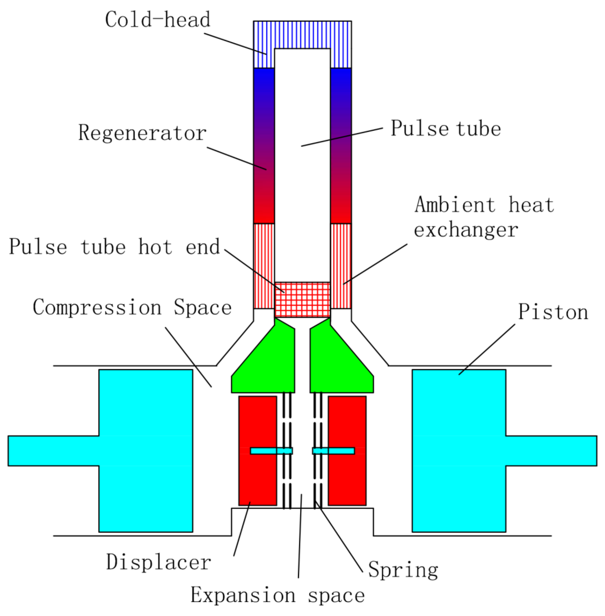

Fig.1 Illustration of pulse tube cryocooler using room temperature displacers

Fig.2 Photo of the pulse tube cryocooler

- ◆ Linear compressor
  - ✓The dual-opposed pistons and moving-magnet structure are utilized to form a compact and low vibration system.
  - ✓The compressor uses gas-bearing technology to ensure the clearance between the piston and the cylinder wall.
- ◆ Cryocooler
  - ✓ **A hollow pulse tube between the cold end heat exchanger and the displacers keeps advantage of no moving parts in cryogenic area.**
- ◆ Displacers
  - ✓Several optimized flexure springs are used to support displacer pistons.
  - ✓The displacers are also of dual-opposed configuration to minimize the vibration.
  - ✓**Rod-less ambient configuration is adopted to avoid two clearances and can ease the assembling process.**

3. Phasor Diagrams Analysis

To realize appropriate phase relationship, there is a delicate difference for the configurations with rod and without rod. The phasor diagrams are used in Fig. 3 for showing the different mechanisms.

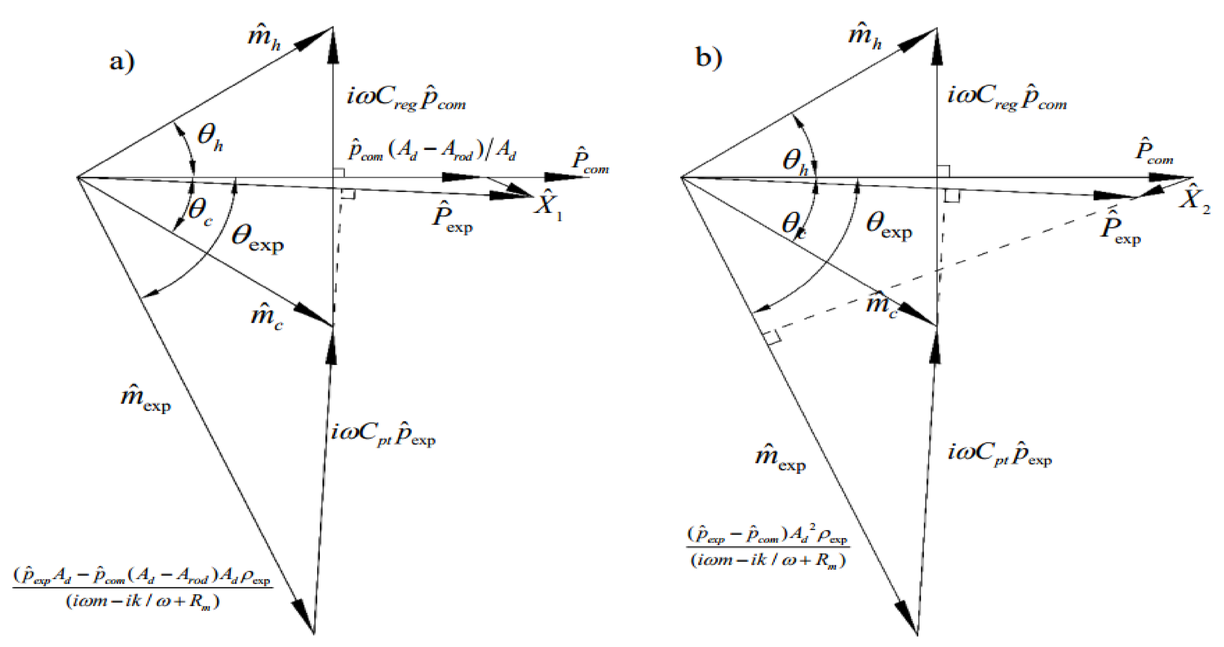

Fig.3 Phasor diagram illustrating the working mechanism for both the a) rod and b) rod-less displacer

- ◆ Rod configuration
  - ✓**The net force X_1 on the displacer is proportional to the mass flow and lag pressure phasor.**
  - ✓Operating frequency is close to the displacer resonance frequency.
- ◆ Rod-less configuration
  - ✓**Net force phasor X_2 on the displacer forms an obtuse angle with pressure phasor.**
  - ✓A larger spring stiffness must be used to tune the phase angle.

◆ Acknowledgement

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4. Numerical Model and Simulation Results

A numerical model based on the thermoacoustic model was developed to optimize the system operating and structure parameters.

Table 1. Main operating parameters and thermodynamic simulation results.

Parameters	Values	Parameters	Values
Cooling power	15W@77K	Ambient heat exchange temperature	23° C
Relative Carnot efficiency	37.8%	Operating frequency	75Hz
Consumed acoustic power	121W	Mean pressure	4.0 MPa

- ◆Fig.4 and Fig.5 shows the numerical comparison between the system using warm displacer and the system using the inertance tube.
  - ✓ **The results clearly shows the displacer could achieve a better performance.**
  - ✓**About 23% of input acoustic power can be recovered by displacers.**

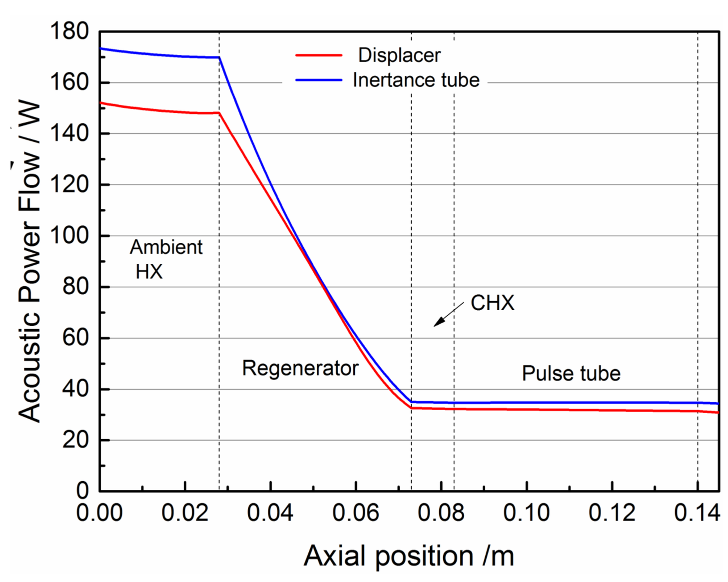

Fig 4. Axial distribution of acoustic power

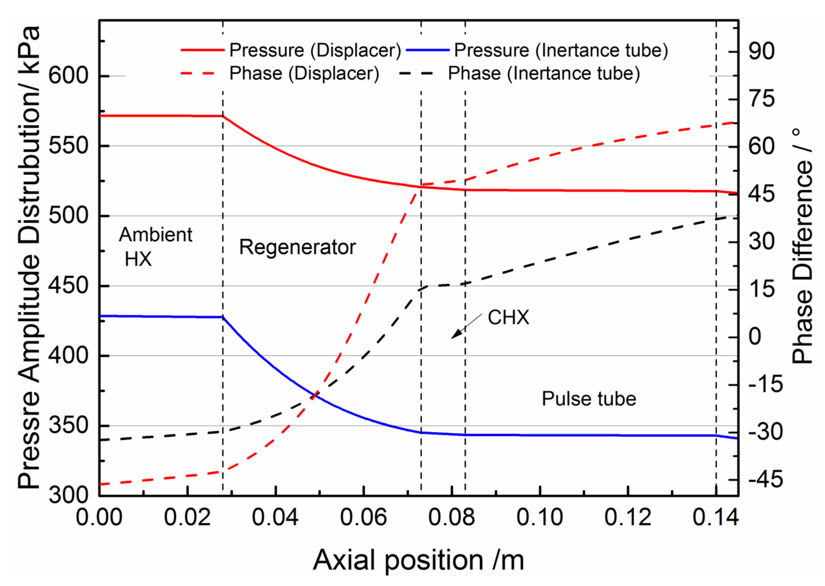

Fig 5. Axial distribution of pressure wave amplitude and the phase difference between pressure and volume flow

5. Experimental Results and Discussion

- ◆Fig. 6 shows the cooling power at 80 K with different compressor input electric power.
  - ✓**A maximum cooling power of 16.7 W can be obtained with an input electric power of nearly 294 W, which is corresponding to a relative Carnot efficiency of 15.6%.**
  - ✓It can also be seen that in the a relative lower input power the system acquired a highest relative Carnot efficiency of 18%.
- ◆Fig. 7 shows the cooling power at different cold-head temperature with an driving voltage of 26 V.
  - ✓A cooling power of 50 W at 120 K can be achieved, which means a highest relative Carnot efficiency of 21%.
  - ✓**A lowest second cold temperature of 44 K has been acquired.**

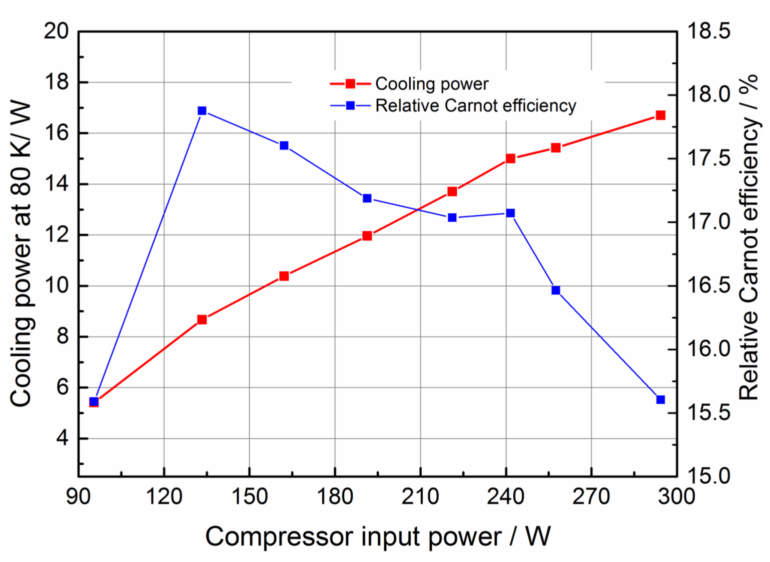

Fig.6 Cooling Power at 77K vs. Input Electric Power

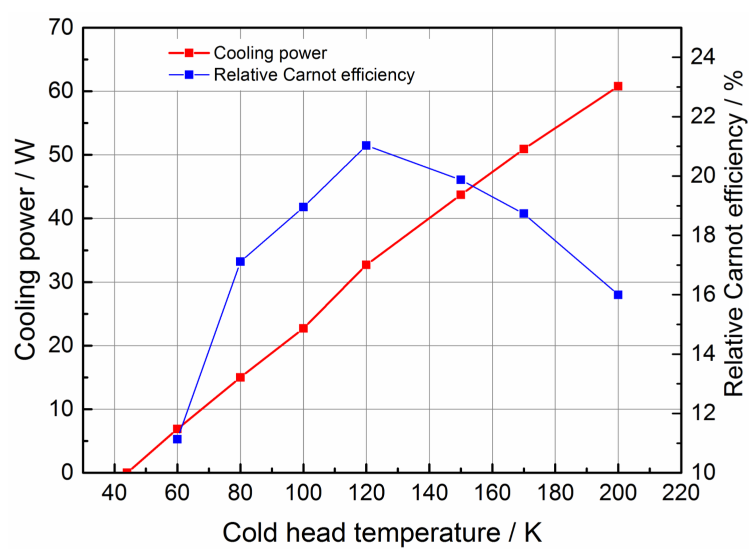

Fig. 7 Cooling Power vs. Cold-Head Temperature

6. Conclusions

- ◆This article mainly report the latest study on cryocoolers for HTS application. Dual-opposed room temperature displacers were used to achieve more efficient and reliable system.
- ◆The whole system has a total mass of 4.3 kg. At an optimum working point, a lowest no-load temperature of 44 K has been obtained and the cooling power at 80K reaches 15 W with an input electric power of 240 W, which means an efficiency of 17.1% of Carnot.
- ◆Numerical simulation and experimental results shows that room displacer could easily realize an appropriate phase relationship between the pressure wave and volume flow rate and improve efficiency.

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