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Experimental investigation on regenerator materials of Stirling-type pulse-tube refrigerator working at 20 K

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Abstract

This paper will introduce our recent experimental results of cryogenic regenerator materials employed in Stirling-type one-stage pulse-tube refrigerator for the use at liquid hydrogen temperature. Thermal diffusion coefficient, according to which we choose the suitable regenerator materials, will prove to be a useful reference. We will also discuss the impact of resistance of sphere regenerator materials on the performance of the refrigerator and the method to improve it. Take an overall consideration, suitable-size Er_3Ni will be applied as the regenerator materials at the cold head and we achieve a remarkable 14.7 K no-load temperature.

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Keywords: Regenerator; thermal diffusion coefficient; Er_3Ni

1. Introduction

For the absence of moving parts in low temperature, pulse-tube refrigerator (PTR) has advantages of theoretic long-life use and low vibration of the cold head Radebaugh et al. (1990). Since its birth, PTR has made a great progress with a series of improvements, especially many ideas in creative components to adjust the phase between pressure

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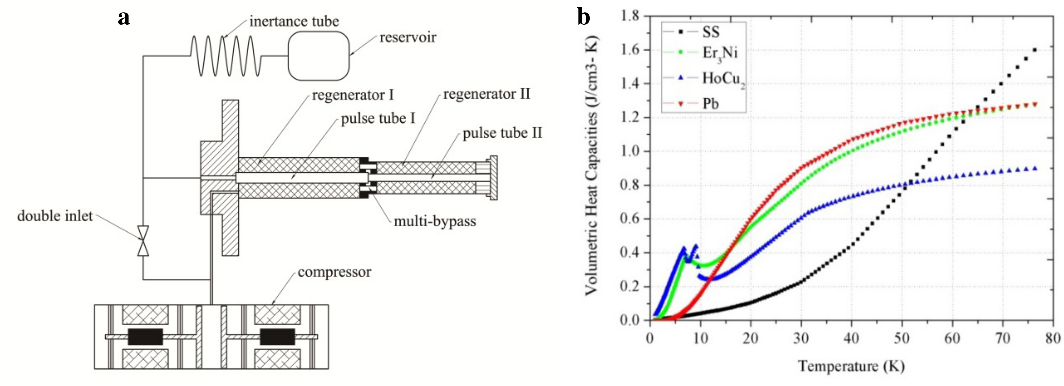

Fig. 1. (a) Schematic of the pulse-tube refrigerator; (b) The volumetric heat capacity.

and mass oscillation. PTR can be divided into G-M and Stirling-type based on its operating frequency. Stirling-type PTR (STPTR) is driven by no-valve compressor with a relatively high frequency. Nowadays, Stirling-type PTR can reach a temperature below liquid helium and distinguish itself in many fields such as optical detection for its superiority in small size, light weight, and high stability Olson et al. (2003), Olson et al. (2006), Nguyen et al. (2007), Nast et al. (2007), Qiu et al. (2011), Bradley et al. (2011).

In general, the efficiency of the STPTR under 20 K is extremely low which is mainly restricted by the efficiency of the regenerator. Below 40 K, the heat capacity of common-used stainless steel wire-mesh (SS) drops rapidly and lowers the efficiency of heat exchange. Sphere materials, such as Er_3Ni, $HoCu_2$, and lead, possess relatively high volumetric heat capacity and are always used as low temperature regenerator materials in low-frequency refrigerator such as G-M PTR. Questions emerge when spheres materials are employed in STPTR, such as the choice of suitable size and larger flow resistance to be overcome. In this paper, we address these questions in our lab-made Stirling-type one-stage coaxial PTR used for 20 K temperature range. The Schematic is shown in Fig.1. (a). The pulse tube is driven by a home-made linear compressor through a long tube. The cold head flange can be opened up conveniently to replace the regenerator. The detailed structure, including components to adjust phase relationship can be found in the reference Chen et al. (2013). When the whole second-segment regenerator employs SS as the regenerator, the refrigeration can reach a lowest temperature of 20.4 K and provide a cooling power of 1 W at 33 K with an input power 230 W.

This paper is organized as the following three parts:

- The first part will introduce the principle to choose the suitable size and type of the sphere materials; the experimental results of different sphere materials will be shown.
- The second part will discuss the difference between the flow resistance of sphere materials and that of wire-mesh.
- Finally, we will introduce the STPTR employing Er_3Ni as a part of regenerator which can reach a remarkable 14.7 K no-load temperature with an input power of 250 W, 29 Hz operating frequency and forced air cooling the hot end.

2. The selection of regenerator materials

The regenerator, which is one of the most important components of the refrigerator, heat is exchanged between helium gas and material. Therefore, specific heat capacity is an important parameter: a relatively high specific heat capacity means more internal energy participates in the heat exchange. Fig.1. (b) shows some frequently-used cryogenic