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High frequency two-stage pulse tube cryocooler with base temperature below 20 K

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Abstract

High frequency (30–50 Hz) multi-stage pulse tube coolers that are capable of reaching temperatures close to 20 K or even lower are a subject of recent research and development activities. This paper reports on the design and test of a two-stage pulse tube cooler which is driven by a linear compressor with nominal input power of 200 W at an operating frequency of 30–45 Hz. A parallel configuration of the two pulse tubes is used with the warm ends of the pulse tubes located at ambient temperature. For both stages, the regenerator matrix consists of a stack of stainless steel screen. At an operating frequency of 35 Hz and with the first stage at 73 K a lowest stationary temperature of 19.6 K has been achieved at the second stage. The effects of input power, frequency, average pressure, and cold head orientation on the cooling performance are also reported. An even lower no-load temperature can be expected from the use of lead or other regenerator materials of high heat capacity in the second stage.
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1. Introduction

Many cryogenic instruments require cooling at two different temperature levels, as for example for the simultaneous cooling of detectors and their low-noise electronics, or for the cooling of radiation shields and electrical leads at an intermediate temperature in order to reduce unwanted heat loads to the coldest stage. Multi-stage cryocoolers can meet the requirements of such applications. With respect to reliable and low-noise cooling, pulse tube cryocoolers (PTCs) are most attractive because of their mechanical simplicity and their inherent low-noise level.

Low-frequency (~1 Hz) two-stage PTCs of the Gifford–McMahon-type are now well established, providing temperatures down to below 4 K [1]. In case of single stage low frequency PTCs a lowest temperature of 12.9 K has been achieved [2], while single stage high frequency PTCs (HFPTCs) have only reached a minimum temperature of 29 K [3]. Further lowering of the refrigeration temperature calls for a multi-stage design of the cooler.

In contrast to single stage HFPTCs (e.g. [1]), research and development of two- and three-stage HFPTCs (30–50 Hz) has only begun a few years ago. Recently, Nast et al. [4] achieved a no-load temperature of 19.8 K by means of a two-stage HFPTC developed for space applications. For other two-stage HFPTCs the reported no-load temperatures are close to 25 K [5,6]. For HFPTCs, so far, the lowest temperature is 5.35 K, which has been obtained by means of a three-stage configuration [7].

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In the present paper, we report on the design and test of a two-stage HFPTC that is driven by a Stirling-type linear compressor (Leybold Polar SC7) with nominal input power of 200 W.

2. Cooler design and test setup

Important design considerations for a two-stage PTC are the geometrical arrangement of pulse tube and regenerator and the thermal connection between the stages. For low frequency two-stage PTC systems, a U-shape configuration has been used for both stages [8]. This configuration has also been chosen for the present cooler.

For the thermal connection between the two stages, there are two choices which we denote as the conduction-coupled and gas-coupled configuration. The conduction-coupled version consists of two cooler stages, each of which employs its own gas inlet at ambient temperature. The cold tip of the first stage is thermally connected to the middle part of the second stage regenerator through solid-state conduction, in order to precool the gas entering the second pulse tube stage. The two-stage HFPTC of Chan et al. [5] is of the conduction-coupled type, while the staging configuration for the HFPTCs in [4,6,7] has not been reported.

For the present two-stage HFPTC we have chosen the version with gas-coupled stages, as illustrated in Fig. 1. Both stages have a U-shaped configuration with the warm ends of the pulse tubes located at ambient temperature. The regenerator of the first stage serves for precooling of the working gas of both stages. At the cold end of the first regenerator the gas is split into one fraction that flows through the first stage pulse tube and another fraction that enters the second stage.

A Leybold Polar SC7 linear compressor with a maximum input power of 250 W is used to drive the cooler. Based on this compressor, the cooler was designed for lowest achievable temperature at the second stage. The dimensional layout of pulse tube and regenerator of the two stages was guided by a one-dimensional numerical simulation program that extends a previous numerical model [9], and by previous experience gained from the development of single-stage HFPTCs [10].

Table 1 lists the optimised dimensions of the two regenerator and pulse tubes that are made of stainless steel. The regenerator matrix of the first and second stage consists of a stack of stainless steel screen of mesh number 400 and 500, respectively.

As indicated in Fig. 1, both stages are equipped with inertance line, buffer volume and second-inlet flow resistance for adjustment of the phase shift between pressure and mass flow oscillation. For control of DC flow, the second-inlet flow resistance of both stages consists of an in-house made needle valve arrangement with adjustable flow symmetry. The length of the transfer line that connects compressor and cold head is about 15 cm. A copper tube for water cooling is wrapped and soldered around the warm end of the cold head.

In the experiments, the temperatures of the first and second stage cold tips are measured by means of a calibrated platinum and Cernox resistance thermometer, respectively. The net cooling power of the second stage is measured by use of a resistive heater attached to the cold tip. Several layers of aluminised mylar foil are wrapped around the two stages in order to reduce radiation losses.

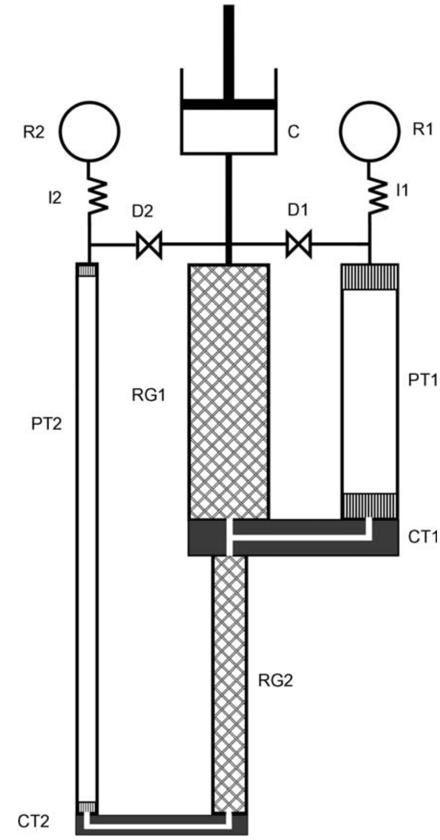

Fig. 1. Schematic drawing of the two-stage HFPTC with gas-coupled stages; C: compressor; R1, R2: reservoirs; PT1, PT2: pulse tubes of first and second stage; RG1, RG2: first stage and second stage regenerator, CT1, CT2: cold tips; I1, I2: inertance lines; D1, D2: second-inlet valves.

Table 1
Geometry of the regenerator and pulse tubes of the two-stage HFPTC; the listed dimensions are: outer diameter × wall thickness × length (all in mm)

	Regenerator	Pulse tube
First stage	$16 \times 0.2 \times 55$	$8 \times 0.2 \times 60$
Second stage	$9 \times 0.2 \times 60$	$4 \times 0.15 \times 120$

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