Pulse Tube Microcooler for Space Applications

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ABSTRACT

This paper describes a new small, low mass, pulse tube cryocooler designed for space flight cooling. The compressor is a scaled down version of Northrop Grumman Space Technology's existing line of flight qualified compressors with a mass of less than 500 grams. Because it is scaled from NGST's larger space compressors it has all their characteristics which result in very high reliability and low vibration. This includes the use of Oxford flexure springs and vibrationally balanced back to back compressor modules driven by voice coil motors. The cooler uses a split configuration with a remote coaxial cold head, although it can be readily reconfigured for an integral coldhead. The coaxial pulse tube coldhead was optimized to utilize the small swept volume of this compressor. At 298K reject, this cooler can lift 1.1 W at 77 K. This paper describes this cooler, its components and interfaces and presents test data over a range of input powers and reject temperatures.

INTRODUCTION

A very small pulse tube cryocooler is being developed which can provide a long life, low mass, cryocooler for many payloads that currently use heavier cold radiators. The payload performance, mass and cost could benefit from a very small cooler with high capacity. The payloads include large infrared focal planes, filters or cold optics. This cooler's low specific mass results from the scaling down of NGST's flight proven HEC design second-generation flexure compressor technology developed with Oxford University and productionized for NGST by Hymatic Engineering.[1] The same scaling relationships successfully used previously in scaling the HEC compressor up to a 26 cc compressor and down to a 1.8 cc compressor[2] were used to produce the design for this 0.65 cc compressor. All of the design features, materials and processes of the HEC compressor were retained in this scaled design, thus retaining the inherently robust characteristics of the compressor.[3] This non-contacting compressor design in conjunction with the no moving parts pulse tube coldhead allows the cooler to have a projected operating life of over 10 years. A developmental coldhead optimized for the small swept volume and high resonant frequency of the small compressor was designed, built and tested.

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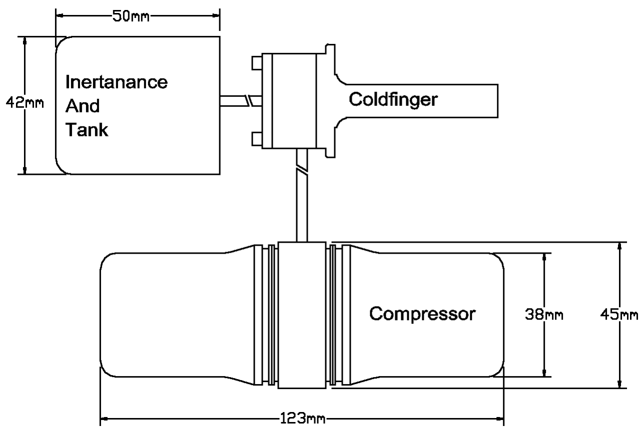

Figure 1. Outline dimensions of the micro cooler.

CRYOCOOLER

The developmental cryocooler utilizes an 'Oxford style' back to back linear compressor with flexure bearings in a split configuration with a coaxial pulse tube coldhead. The configuration and outline dimensions of the mechanical cooler in a flight like configuration are shown in Figure 1. Photographs of the compressor and coldhead in their laboratory configuration, e.g. with bolted flanges rather than welded flanges, are shown in Figure 2. The basic defining characteristics of the cooler are given in Table 1. The estimated mass of the mechanical cooler in a flight configuration is 0.8 kg, excluding the drive electronics. The input power to the compressor can be up to 50 Wac (depending on reject temperature). The compressor coil is wound for operation from a 28 Vdc bus, without the need for a DC-DC voltage up converter. The cooler operates near the approximately 100 Hz resonance of this small compressor.

The coldhead is a single stage coaxial pulse tube utilizing an inertance line to obtain the proper phasing. The cold tip is configured to remove heat from the circumference of the last 3 mm of the cold tip. This allows direct integration of an FPA onto the coldhead. A second version of the

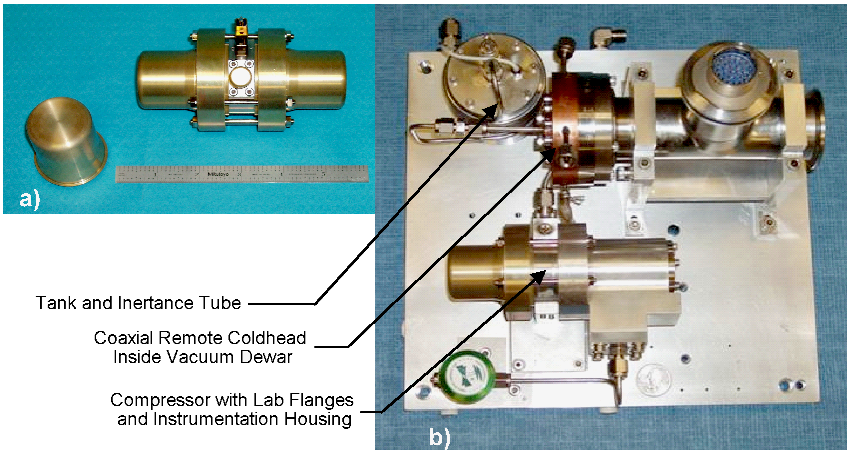

Figure 2. a) Photo of the microcompressor with laboratory pressure vessel flanges attached, and weld-on pressure vessel shown in the foreground; b) laboratory thermal vacuum test setup with piston position sensor attached on compressor in place of one of the pressure vessels.

Table 1. NGST Microcooler Parameter Summary.

Cooler mass	782	gm
compressor	*415*	*gm*
coldhead	*172*	*gm*
inertance+tank	*195*	*gm*
Compressor envelope		
diameter	45	mm
length	123	*mm*
Max Cooling at 77K (298K reject)	1.1	*W*
Max Cooling at 150K (298K reject)	4.0	*W*

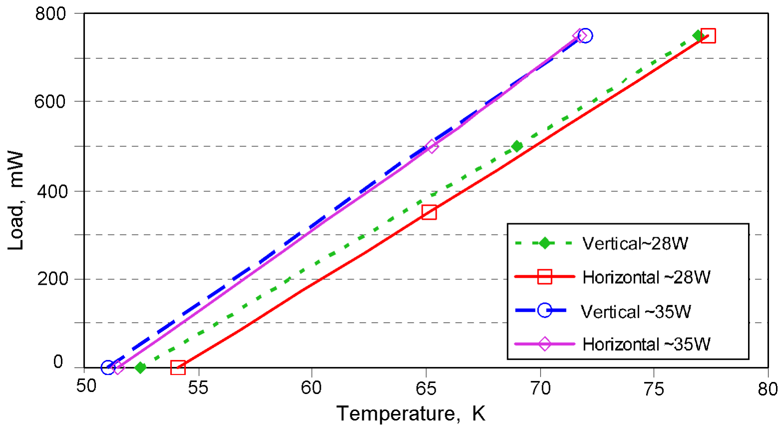

Figure 3. Measurements of orientation insensitivity of coldhead.

coldhead was built which has a copper cap at the cold tip to allow heat removal at the top or to allow a strap to be connected to the cold tip. These coldheads are essentially insensitive to orientation, as is expected for such a small pulse tube operating at such a high frequency. Tests comparing coldhead heat lift versus cold tip temperature with the cold head horizontal versus vertical relative to gravity are shown in Figure 3. This gravitational insensitivity is desirable because it significantly simplifies integration and ground test. The mass of the test coldheads was much larger than the projected flight weight because the test coldheads incorporated a large vacuum flange which allowed them to mate with our existing KF-40 based vacuum dewar. The test coldheads also incorporated an ambient heat exchanger for the recirculation fluid which adds to the test article mass.

The mechanical cooler's heat lift vs cold tip temperature was tested over a range of reject temperatures and input powers. In these tests a circulating fluid chiller set the reject temperature at both the compressor and the coldhead. The cooler surface temperatures are reported. The data from the load lines (heat lift versus cold tip temperature lines at constant power, similar to Figure 3) are plotted as isotherms of input power versus heat lift in charts which are commonly know as Ross plots. These charts also include line of constant specific power for reference. The cooler performance at 298 K is shown as a Ross plot in Figure 4, and the cooler performance at 248 K and 323 K are shown in Figure 5 and Figure 6. The optimum drive frequency varies with temperature, from 89 Hz at 248 K to 98 Hz at 323 K. The data in the Ross plots reflects operation at the optimum frequency. These data are at a constant fill pressure which allows operation substantially in excess of 348 K. If operation is limited to lower temperatures, a somewhat higher fill pressure can be used which allows the lift at maximum stroke to be increased slightly.

The off-state conduction of the coldhead was measured in the vertical down position, corresponding to zero-g operation, using the transient warm up time as a function of applied load. The measured off-state conduction is 415 mW.

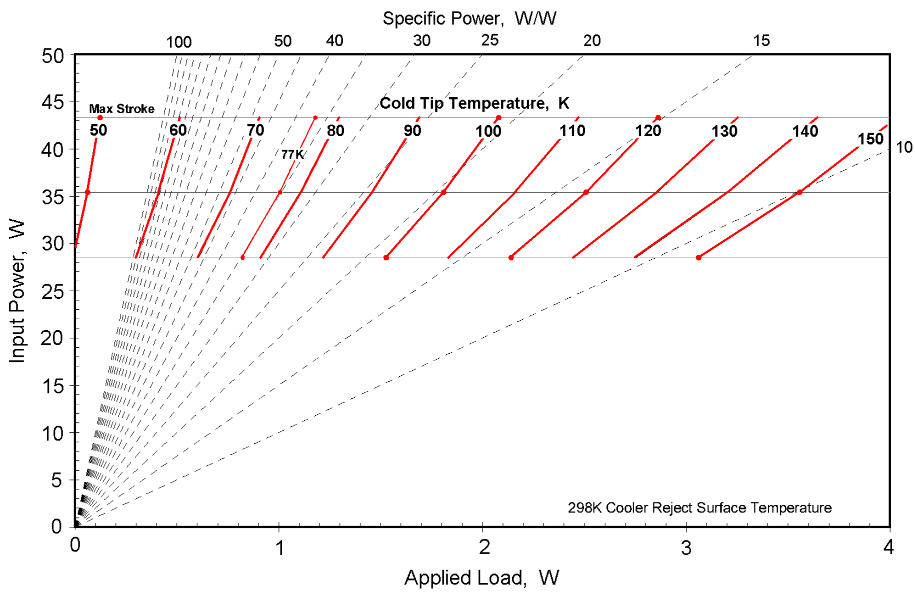

Figure 4. Cooler performance plot at 298 K cooler reject temperature.

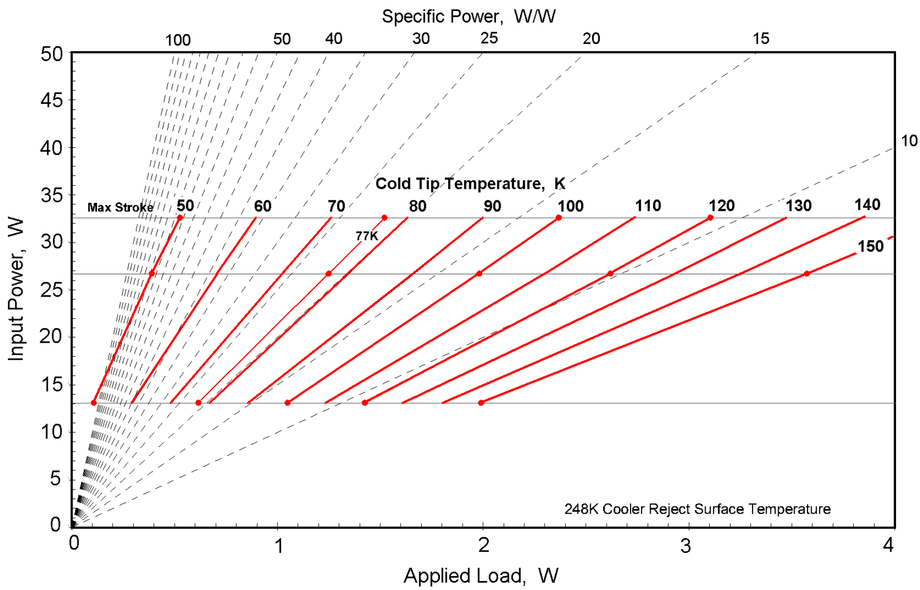

Figure 5. Cooler performance plot at 248 K cooler reject temperature.

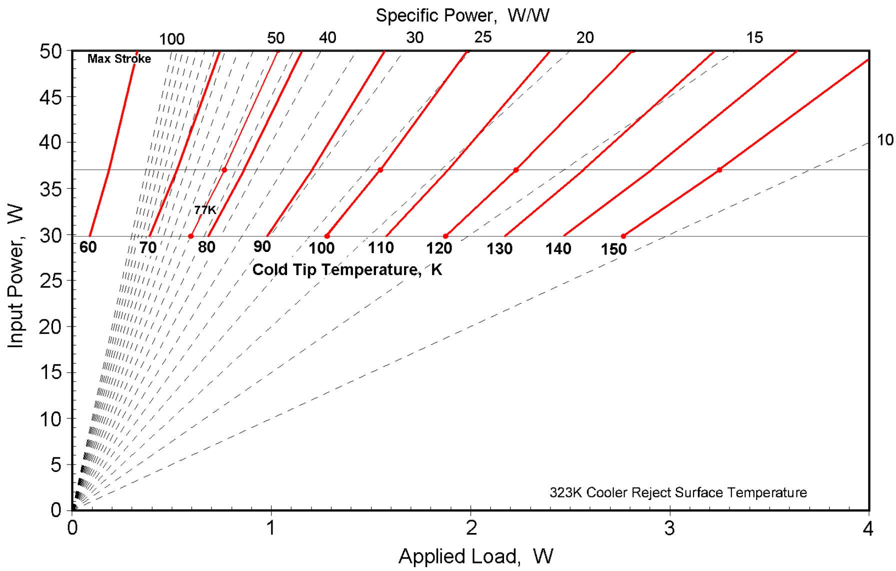

Figure 6. Cooler performance plot at 323K cooler reject temperature.

ACKNOWLEDGMENTS

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