Conference naam | Cryogenic Engineering Conference  
Conference year | 2003  
Title of paper | Experimental Characterisation Of A Pulse Tube Cryocooler For Ground Applications  
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ABSTRACT

Developments on high frequency high heat lift pulse tubes are carried out at CEA/SBT. Based on a previous study on an in line configuration, two new pulse tube cold fingers have been manufactured: a coaxial configuration and a U-shape configuration. These two configurations were tested with a conventional linear compressor. Measurements performed with the coaxial configuration have demonstrated cooling power in excess of 6 W at 80 K with 140 W of mechanical input power. The results obtained with these two configurations are presented. The impact of the rejection temperature has also been studied and is discussed. In parallel, a new compressor with pistons supported by flexure bearings has been designed and manufactured. This compressor has been coupled with the pulse tube. Tests performed with the new developed flexure-bearing compressors and a conventional compressor are presented and compared. The pulse tube cold finger associated with the new compressor leads to a reliable and low vibration cooler.

INTRODUCTION

There is a need for reliable large heat lift cooler (4 to 6 W at 80 K) for ground applications. Pulse tube cold finger coupled with flexure bearing compressor is a credible alternative to Stirling or GM coolers. CEA/SBT has developed various pulse tube coolers (low and high frequency) and has now extended its cooling range to 10 W for high frequency pulse tube. Results achieved with an in line prototype have been presented elsewhere. This paper presents the results obtained with the new integrated prototypes. These new prototypes have been coupled with a flexure-bearing compressor.

DESCRIPTION OF THE PULSE TUBE PROTOTYPES

Based on the optimal geometries previously found with the in line prototype, a U-shape and a coaxial shape pulse tube cold fingers have been designed and manufactured.

Figure 1: Coaxial and U-shape demonstrators
DESCRIPTION OF THE COMPRESSOR CONFIGURATION

Two different types of compressors were used to drive the pulse tubes during the tests:

The UP 8220 compressor
This is a conventional, dual opposed piston, linear compressor with moving coils. This compressor was designed for driving a 20mm Stirling cold finger. Due to the moving coil configuration, the motor efficiency of this compressor is high (86%). Due to the high damping of a pulse tube compared to a Stirling cold finger, the swept volume of the compressor is much too large and thus the efficiency of this compressor coupled with a pulse tube cold finger is lower (73%) than with a Stirling cold finger. Because the UP 8220 compressor is a conventional compressor which means that the pistons make contact with the cylinder lining, the lifetime of the compressor is limited mainly due to the wearing of the piston liners (MTTF=8000 hours). Therefore no redesign was done in order to optimise the compressor to the pulse tube. To make a reliable pulse tube cooler with a long lifetime (>24000 hours) a non-wearing compressor must be used.

The LPT 9310 compressor
This is a dual opposed piston, linear flexure-bearing compressor with moving magnets. The LPT 9310 compressor is a member of the LSF cooler family from Thales Cryogenics (reference). The main features of this family which improve the reliability are:

- Flexure-bearing support at both sides of each piston in order to avoid contact between the piston and the cylinder
- No flying leads are needed
- No glass feed throughs are needed
- Coils are out of the helium gas circuit which reduces the risk of contamination

Because the pulse tube was not fully developed/optimised at the time the test campaign began, only the piston diameter of the LPT 9310 was changed to adapt the resonance frequency of the system to the optimal operating frequency of the pulse tube. This lead to a motor efficiency of 56%. This lower efficiency compared to the UP8220 is mainly due to the limited maximum stroke because of the flexure-bearings, which leads to a high system damping. This maximum stroke is defined by the maximum stresses in the flexure-bearings. Furthermore, the Eddy current losses in a moving magnet motor are higher than in a moving coil motor. However, since the pulse tube is optimised at this stage of the project, the compressor can be redesigned in order to increase the efficiency.

Future work on the LPT 9310 compressor
In order to improve the motor efficiency of the compressor, the following changes in the design can be made:

- The piston diameter will be decreased in order to decrease the system damping.
- Different spring steel with better fatigue properties will be used for the flexure-bearings to enable a larger piston stroke with the same margin for fatigue.
- Magnet material with higher magnetic induction will be used.
- Special magnet iron will be used in order to decrease the eddy current losses.

These changes will lead to a total calculated motor efficiency of 70% for the flexure bearing compressor optimised to drive the pulse tube.
COLD FINGER PERFORMANCES

The 2 demonstrators pulse tubes have been designed to work in inertance mode only [1,2]. They have been first tested with the same “conventional” UP8220 compressor (Thales) which was used for in line prototype optimisation. The cooling curves obtained with the optimum inertance are presented in Figure 2. The compressor and the pulse tube body are water-cooled. A transfer line of more than 200 mm is used to connect the cold finger to the compressor. The cooling power at 80 K is 6.56 W for the coaxial shape and 5.40 W for the U-shape. At 80 K, the total electrical power supplied to the compressor is less than 190 W which leads to a PV work of less than 140 W. These results have to be compared with the in line prototype which produces 7.7 W at 80 K [3]. The losses between in line and integrated pulse tube configurations represent 15 % for the coaxial shape and 30 % for the U-shape. For the coaxial shape the results are fairly good and the efficiency loss was expected due to dead volume and pressure drop added into the cold part. The demonstrator shows that it is possible to build a compact, user friendly and efficient pulse tube cooler. Better performance were expected for the U-shape. This lack of performance is possibly due to brazing problem, which partially obstructed the hot heat exchangers. This is still under analysis.

![Figure 2: Cooling power for U-shape and coaxial shape, water cooling, split pipe > 200 mm, frequency 50 Hz, electrical power to the compressor at 80 K: less than 190 W](image)

EFFECT OF TEMPERATURE REJECTION

Theses coolers were also characterized with no water cooling on the pulse tube warm end. The performance is strongly affected by the temperature increase. Without water cooling, the pulse tube hot end skin temperature raised from 20°C to around 70 °C. The load curve achieved with the coaxial shape is presented in the Figure 3. The cooling power at 80 K falls down from 6.56 to 4.57 W, which represents a decrease of 30 %. The ultimate temperature increases of 8.7 K in the 50 K range. In the 80 K range this increase is 12.7 K: 4 K at ambient corresponds to 1 K at 80 K. These values are similar to the one reported by R.G. Ross [4]. Similar results were obtained with the U-shape configuration.
COOLER PERFORMANCES

The pulse tube cold fingers were then tested with a LPT 9310 flexure-bearing compressor. The cooling power achieved with this compressor is lower than for the UP8220 compressor (Figure 4). It was not possible to use the same input power at low temperature due to current limitation. In the 80 K range the same level of input power (188.7W) gives a cooling capacity of 5.54 W, i.e. 1 W (15%) less than with the conventional UP8220 compressor. This result was expected as explained in the compressor description paragraph here above. On the pulse tube cold finger side, it should be noted that this cooling power is obtained with 106.3 W of PV work. The thermodynamic specific power of the cold finger is 19 W/W (14 % of Carnot).

Figure 3: Effect of rejection temperature for the coaxial shape pulse tube. Split pipe > 200 mm, frequency 50 Hz, electrical power to the compressor at 80 K: less than 190 W

Figure 4: Cooling power for coaxial shape with flexure bearing compressor, water cooling, split pipe > 200 mm, frequency 45 Hz, electrical power to the compressor at 80 K : less than 190 W
EFFECT OF ORIENTATION

All the results presented before have been obtained with the PT cold end down. For integration propose it could be interesting to work in horizontal position. Measurements have been carried out to quantify the degradation due to convective effect. The test bench is presented on Error! Reference source not found.. The level of degradation is very low, less than 1 K in all the range from ultimate temperature to 80 K. Larger degradation (around 10 K) observed on a smaller high frequency pulse tube [5] have not been found again due to a better aspect ratio of the pulsation tube. Larger degradation could occur for up side down position as reported by Thummes [6].

Figure 5: Test bench in hor. position

COOLING DOWN TIME

For some applications the cool down time could be critical. The cooling power at ambient temperature where most of the enthalpy has to be removed has to be large enough. Cool downs have been recorded with and without a known load (365 g cooper block) mounted on the cold end (Figure 6). The comparison of the two curves allows estimation the cooling power at each temperature. The cooling power at 300 K is around 27 W for an electrical input power of 150 W. The cooling power is almost linear down to 50 K.

Figure 6: Cool down time of the coaxial pulse tube with and without load
TOWARDS A COMMERCIAL PRODUCTS

For the two demonstrators the buffer volume was not integrated. In order to make the handling and interfacing of the pulse tube easier, the buffer space needs to be integrated in the warm end. A 3D model of this design is depicted in figure 7. Because of the good results and the more compact design of the coaxial pulse tube, this configuration will be developed further to a commercial product, which is planned to be in production by the second half of 2004 at Thales Cryogenics.

Figure 7: 3D model of the commercial design of the coaxial pulse tube with integrated buffer

ACKNOWLEDGMENTS

The authors would like to thank A. Coynel, L. Miquet, B. Molinari for participation to design, assembly and measurements. This research was carried out under partial funding from the French ministry of industry in the framework of Supracom project.

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