A Study of the CryoTel® DS 1.5 Cryocooler for Higher Cooling Capacity

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INTRODUCTION

The CryoTel® DS 1.5 is a split type Stirling cryocooler which was developed by Sunpower for systems requiring compact size, high efficiency, and high reliability. The DS 1.5 has a nominal lift of 1.5 watts at 77 K with 30 watts of input power. The cooler design includes gas bearings on the pistons and displacer for non-contact operation, and achieves low vibration by using dual-opposed pistons inside the wave generator, and a passive balancer on the cold head to offset the displacer motion. The efficiency of the DS 1.5 is ranked highly compared to other cryocoolers at 14.2% Carnot efficiency. To evaluate the long life potential of the DS 1.5, one cooler has been running since October 2013, for a total of more than 12,460 hours without any failure and performance degradation, another cooler has been running since January 2015. Customers have been satisfied with its high efficiency, but there are some customers who would like more lift without increasing the size of the DS 1.5. Sunpower therefore decided to study the feasibility of producing an increased-cooling-capacity version of the DS 1.5 with a lift as high as possible without increasing its size and without making any major design changes. In this paper, we will explain how we determined the new design parameters. We will also explain the benefits of the high-capacity DS 1.5.

Increasing the PV Work of the Wave Generator

To meet those requirements, Sunpower has focused on increasing the PV work of the current DS 1.5.

The pivot cross sectional area, the piston amplitude, the pressure amplitude, and the operating frequency are factors to increase the PV work.

We chose the charge pressure and operating frequency for this study because they are the methods least likely to require major design changes.

Increasing operating frequency produces higher PV work but it increases the regenerator losses (such as the heat transfer between the regenerator material and the gas) and increases the pressure drop across the regenerator.

Through structural and magnetic analysis, we had found the maximum point of charge pressure increase.

The disadvantages of higher pressure are the increases of the clearance seal flow and gas bearing pumping losses, higher magnetic stress on the iron, and the reduction of the motor efficiency.

Prototype Test Results

A prototype of the high-capacity DS 1.5 design was built by modifying an original DS 1.5. The test shows a lift of 2.1 W at 77 K with 43 W of input power, which means that it has 1.4 times greater lift than the original DS 1.5, and has 96% of the efficiency of the original DS 1.5. Those results are in line with the prediction.

The increase in the mass of the high-capacity DS 1.5 is less than 0.2%. Also, the specific mass (mass per unit of cooling power) of the original DS 1.5 is 0.8 kW, the specific mass of the high-capacity DS 1.5 is 0.57 kW, 30% better than the original DS 1.5.

The overall vibration levels of the original DS 1.5 and the high-capacity DS 1.5 are about the same with the passive balancers installed; about 2 N peak is mostly from the high harmonics because the passive balancer was designed to tune out a single frequency vibration, therefore, some of the high harmonic vibrations still exist.

With a passive balancer on either cooler, the vibration on the high-capacity DS 1.5 becomes about 1.7 times greater than the vibrations on the original DS 1.5 because the inertia force of the moving displacer increases with the square of the operating frequency.

CONCLUSION

A prototype of high-capacity DS 1.5 was tested with excellent performance in the original DS 1.5. The test shows a lift of 2.1 W at 77 K with 43 W of input power, which means that it has 1.4 times greater lift than the original DS 1.5, and has 96% of the efficiency of the original DS 1.5. Those results are in line with the prediction.

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In the tests, the original DS 1.5 took 16.2 hours with 1,350 kJ of input energy, and the high-capacity DS 1.5 took 13.9 hours with 1,990 kJ of input energy; that’s about 22% less input energy consumption, but it took 37% less time to reach the target cold tip temperature. The predicted cold-down times and energy consumptions are close to those measured in the tests.

The cold tip, rejector, and wave generator thermal modeling used with their thermal paths to the ambient temperature. The predicted cold-down times and energy consumptions are close to those measured in the tests.

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