Development of CryoTel® DT Cryocooler

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ABSTRACT

A small split-type Stirling cryocooler, CryoTel® DT, has been developed for small and portable systems, where small size, light weight and low vibration signature become important. The split cold head equipped with a small passive balancer is coupled to a dual-opposed pressure wave generator in which two opposing twin pistons cancel the vibration of each other. The heat lift measured in the lab tests was 2.3 W at 77 K with 30 We of input power and 2.7 W at 77 K with 40 We, and the COP achieved a new record, 15% higher than that of the previous best efficiency CryoTel® CT. Three hermetically-sealed DT cryocoolers were built and tested in a certain customer's facility for the qualification. The test results confirmed that the DT cryocoolers were qualified by exceeding the performance specifications and satisfying all of the other requirements. The vibration acceleration of the cold head was also measured at less than 40 mG. This paper presents the features and the performance test data of the new cryocooler.

INTRODUCTION

The CryoTel® DT is a small split-type Stirling cryocooler driven by a dual-opposed pressure wave generator that is a new addition to Sunpower's commercial product line-up. The current CryoTel® models: the MT, CT, and GT are integral-type Stirling cryocoolers provide high performance, low cost and long life operation[1,2]. The CryoTel® family of cryocoolers, based on Sunpower's innovative technologies of free piston, linear motor, and non-contact gas bearing, offers unique solutions to various applications in the market and builds a solid reputation for unrivaled performance and quality.

The new cryocooler DT is an extension of the CryoTel® family that is designed to satisfy the following major requirements as requested by a specific customer: cooling capacity (heat lift, greater than 1.5 W at 77 K), light weight (total mass, lighter than 1.5 kg), small size (outside diameter, less than 3"), and low vibration. As shown in Figure 1, a split configuration along with a dual-opposed pressure wave generator was chosen for the inherent reduction of the vibration signature. The remaining vibration of the cold head is attenuated by a small passive balancer. Subsequently, another application for higher cooling power was added by the customer, which eventually resulted in two different CryoTel® DT cryocoolers, the DT55 and the DT60.

Sunpower launched the development program in 2011 and shipped three hermetically-sealed DT cryocoolers to a customer for the qualification test in early 2012. All of them passed the test and exceeded the requirements. The hermetically-sealed CryoTel® DT55 consists of a cold head

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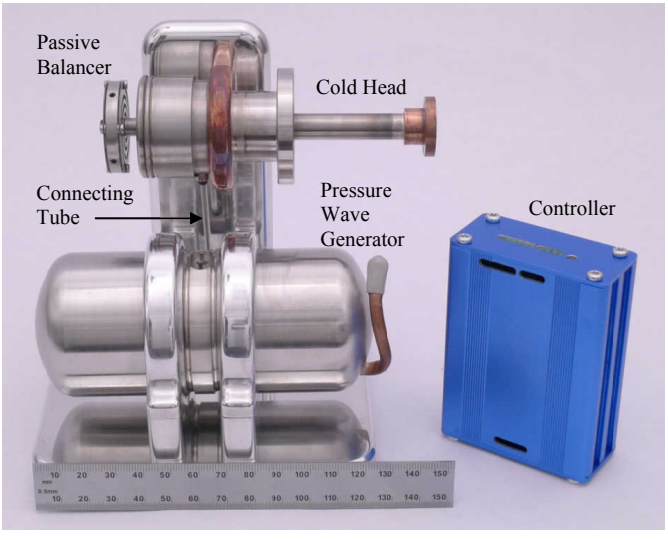

Figure 1. Hermetically-sealed CryoTel® DT55 and Controller

of 39mm in diameter and 128mm in length, and a pressure wave generator of 55mm and 127mm respectively. The total mass is 1.2 kg; the cold head weighs 0.2 kg and the pressure wave generator 1 kg. The hermetically-sealed DT60, which is being built for the upcoming qualification test, includes the same cold head as DT55 but a slightly larger pressure wave generator of 60mm in diameter; its total mass is 1.3 kg. Further optimization is now in progress for the DFM (Design for Manufacturing).

DESIGN FEATURES

The CryoTel® DT cryocooler was designed based upon the Sunpower Stirling technologies used in the current cryocooler products. The initial design began with the scaled-down dimensions of the MT, since the DT was aimed for a much smaller and lighter cryocooler than the current smallest, the MT. Subsequently, some key components and critical dimensions were upgraded to overcome the general tendency that the smaller the size, the lower the efficiency. If the piston/displacer bore size decreases maintaining the clearance between the piston/displacer and the cylinder unchanged, the area of leakage flow to the bore size increases. Likewise if the displacer bore size decreases maintaining the wall thickness of the cold finger tube unchanged, the area of thermal conduction to the bore size increases. Thus, the total loss due to the significant reduction of the bore size could become substantial enough to impact the performance. However, it is difficult to reduce the size of the clearance as well as the wall thickness at the same ratio as the bore size reduction, because of the limitation of machining capability and material strength. Therefore further improvements of the design are required to prevent the additional loss.

SAGE simulations[3] were performed with the new configuration for the design optimization, and significant effort was put into the management of leakage and conduction losses using technologies newly developed for the performance improvement as well as established in the existing CryoTel® manufacturing process. The clearance between the piston/displacer and the cylinder was minimized by high-precision machining, coating, and aligning process. The cold finger tube was made out of a Ti alloy, a low conduction material, and its length and thickness were optimized with respect to machining capability and material strength. However a stainless steel tube is also being tried in the DFM process despite conduction loss increase, for the performance is far greater than the requirements.

CONTROLLER

The controller for CryoTel® DT is also small, as shown in Figure 1, 84.5mm × 63.5mm × 30mm including the enclosure. It is a smaller version of the new 2nd generation controller for the CT, GT, and MT of the CryoTel® family, and so much of the circuitry and software is identical. The major differences lay in the selection of smaller power components and the use of components in smaller packages such as the processor being in a ball grid array (BGA) instead of a quad flat pack (QFP). Like the controllers for the CryoTel® family of cryocoolers, it is DSP-based providing closed loop temperature control using either an RTD or a diode with a stability of +/- 0.1 K, and RS-232 communications interface for monitoring and setting control variables such as target cold end temperature, near sinusoidal drive current, and a wide range of power control. Cooling power can be modulated over a range of 0 to maximum.

CONFIGURATION

The CryoTel® DT is a split-type Stirling cryocooler driven by an dual-opposed pressure wave generator, which is widely known to be the best configuration for low vibration. The pressure wave generator vibration is reduced to the minimum by two opposing pistons sharing a single compression space and canceling each other's vibration. In addition, the split configuration in which the cold head is coupled to the wave generator through a small diameter connecting tube, keeps the cold head away from the remaining vibration and the harmonics of the wave generator. The displacer assembly in the cold head which is much lighter than the piston assembly in the pressure wave generator, has near sinusoidal motion, and so its vibration contribution is attenuated with a small and light passive balancer. The vibration acceleration of the cold head measured in the customer's facility is less than 40 mG, which is only 20% of the existing CryoTel® cryocoolers.

Another advantage of the split configuration is the flexibility of the arrangement. The cold head and the pressure wave generator can be arranged in various configurations. Figure 2 and 3 show two different examples: the DT cryocooler in the parallel arrangement with 100mm long connecting tube versus the in-line arrangement with 150mm long connecting tube allowing the whole unit to fit into a cylindrical structure of less than 3" diameter. However the latter brings the heat lift down by 0.2W at 77 K in comparison.

Figure 2. CryoTel® DT55 in parallel arrangement with 100 mm long connecting tube

Figure 3. CryoTel® DT55 in in-line arrangement with 150 mm long connecting tube

PERFORMANCE TEST RESULTS

The CryoTel® cryocoolers, MT, CT, and GT offer different cooling power capabilities ranging from 5 to 15 W at 77K. All members have the same-size cold head, which was originally designed for the first model, the CT, holding the place of the best efficiency cryocooler of CryoTel® family. Likewise, the DT55 and the DT60 cryocoolers have the same-size cold head, optimized for the DT55, even though the DT60 was designed for higher cooling power. The various performance tests were performed in the lab using a cold head, a connecting tube of 100mm long and two different sizes of pressure wave generators; the DT55 accepts up to 30 We of input power, and the DT60 up to 40 We.

The test results of each of the DT cryocoolers are shown in Figure 4 and 5. The left-hand side of Figure 4 indicates that the DT55 lifts 2.3 W at 77 K with 30 We input power, and the no-load temperature reaches down to 32.4 K. The percentage of the COP to Carnot efficiency, % of Carnot, achieves 23% at 77 K, which is 15 % higher than that of the previous best cryocooler, the CT. The performance map curves at the right-hand side confirm that the performance of DT55 remains incomparable over the wide range of input powers and operating temperatures. The input power required to lift 1 W at 77 K is only 15 We, and the heat lift at 90 K with 30 We input power is over 3 W.

The DT60 lifts 2.7 W at 77K with 40 We input power, and the no-load temperature reaches down to 32.1 K as shown in figure 5. The efficiency curve of the DT60 is slightly lower than that of the DT55, but the performance map curves confirm that the DT60 offers higher cooling power, as it is designed for. The heat lift at 90K with 40 We input power is over 3.5 W.

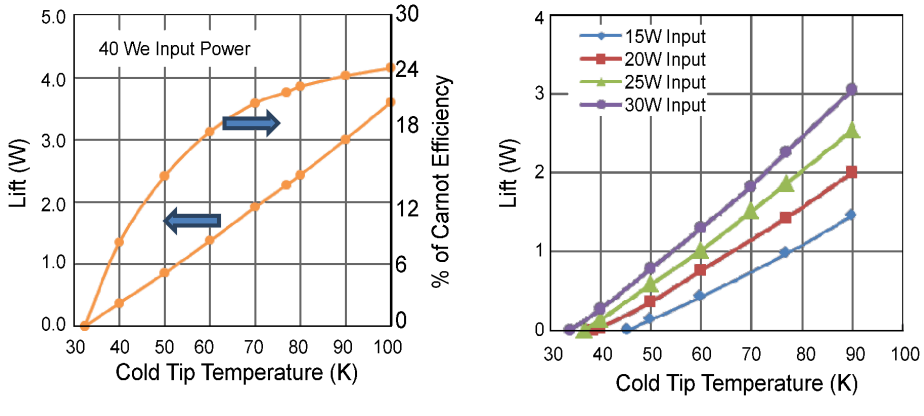

Figure 4. CryoTel® DT55 performance Test Data

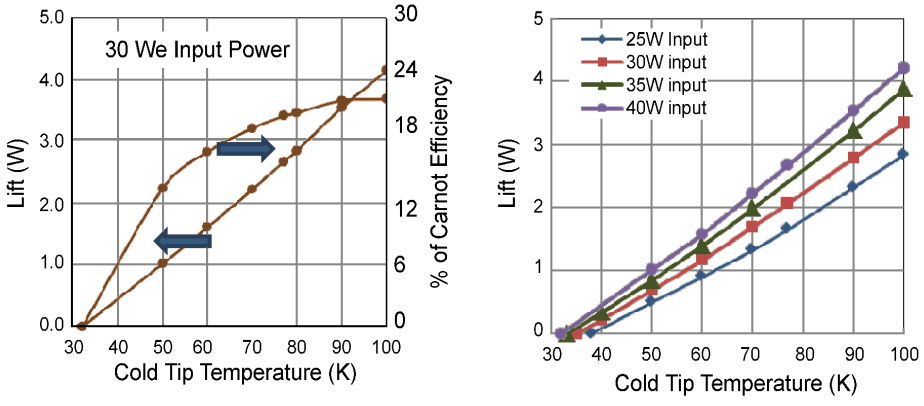

Figure 5. CryoTel® DT60 Performance Test Data

CONCLUSION

Sunpower has successfully developed the CryoTel® DT, a small split-type Stirling cryocooler driven by a dual-opposed pressure wave generator. The vibration of the cold head was dramatically lowered while maintaining the unrivaled performance. The pre-production units have passed the qualification tests of a certain customer and the new products will be available in 2013.

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