Stirling Cryocooler for 3rd-Generation IR Platforms

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ABSTRACT

This paper describes the development and performance of a new tactical Stirling cryocooler developed by Carleton Life Support Systems, Inc. (CLSS) of Davenport, Iowa. The new cryocooler aims to fulfill the requirements of new Forward Looking Infrared (FLIR) systems. The new cryocooler has a cooling capacity of a 1.5 W tactical cooler in a smaller package. It uses a modified 1.75 inch diameter compressor from the CLSS LC1062 cryocooler with an entirely new coldfinger and expander. The cryocooler design benefits from system and component level simulations using commercially available software, such as Sage and ANSYS. The cryocooler can hold a 1.5 W heat load at less than 77 K with less than 50 W electrical input power at an ambient heat rejection temperature of 23°C. Cool down time from 300 K to 77 K with a 19 g copper mass is 6.3 minutes. At an elevated temperature of 71°C, the cooler can hold a 1 W load at 77 K with 53 W electrical input power, and will cool a 19 g copper mass to 77 K in 7.2 minutes.

INTRODUCTION

Third generation Forward Looking Infrared (FLIR) systems improve on the first and second generation systems through the use of multispectral scanning and improved imaging.[1] As IR technology progresses, so too does the demand for smaller, lighter, and more powerful cryocoolers to cool the IR focal plane arrays. The LC1065 linear cryocooler is the latest cooler from Carleton Life Support Systems (CLSS) of Davenport, Iowa. The LC1065 has been optimized to provide the cooling capacity of a 1.5 W cooler in a package only slighter larger than a 1/3 W cooler.

The principal design goals for the LC1065 are to be capable of lifting 1.5 W from 77 K at 23°C ambient with no more than 50 Wdc input power to the controller, and 1 W at 71°C with no more than 75 Wdc to the controller. These challenging goals were tackled by years of accumulated experience in the cryocooler industry together with system and component level simulation in Sage[2] and ANSYS.

The cooler is powered using the ADRS232 digital controller, which is a temperature compensated digital controller recently made available by CLSS. This programmable controller is capable of sourcing up to 100 Wac and weighs in at less than 3 ounces. The controller also has a host of internal checks and diagnostics, and will record historical performance data of the cooler. Figure 1 is a photograph of the cooler and controller.

DEVELOPMENT

The LC1065 was built on the platform of the LC1062 1/3 W linear cryocooler. It shares the same compressor dimensions (1.75 inch diameter, 4.67 inch length) with a larger expander and longer coldfinger. A listing of key dimensions and physical attributes can be found in Table 1.

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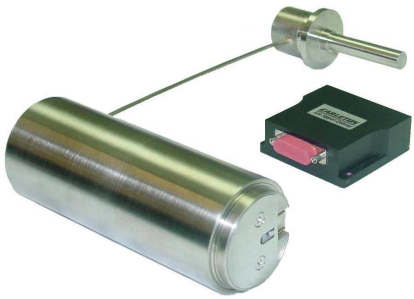

Figure 1. LC1065 cryocooler with ADRS232 digital controller.

Table 1. Geometric Parameters

Mass	1.1 kg
Compressor diameter	1.75 inches
Coldfinger diameter	0.373 inches
Coldfinger length	1.985 inches
Expander length	3.096 inches
Expander diameter	1.0 inches

The cooler was designed using Sage: a step that reduced the development time substantially. A system level model was built in Sage that allowed key parameters such as regenerator length and mass, spring rates, gas volumes, and regenerator matrix properties to be chosen appropriately. The modeling was successful, as the first prototype operated very close to the target performance.

In addition to the system level modeling in Sage, component level modeling of heat and stress was performed using ANSYS. The heat analysis was completed to ensure that heat flows from the expander would be sufficient, and the stress analysis was completed to check the integrity of the displacer spring.

PERFORMANCE

The LC1065 linear cryocooler meets the target of holding a 1.5 W load at 77 K and 23°C with less than 50 Wdc, and also easily meets the target to hold a 1 W load at 77 K and 71°C with less than 75 Wdc. At an ambient temperature of 23°C, the cooler requires 45 Wdc to hold 1.5 W, well within the target of 50 Wdc. At 71°C, the cooler requires 53 Wdc to hold 1 W, easily meeting the goal of 75 Wdc or less. At -40°C, the cooler requires 33 WDC to hold 1.5 W, and will hold more than 2 W when powered at 50 Wdc.

Cool down time to 77 K for a 19 g copper mass is 6.3 minutes from 23°C and 7.2 minutes from 71°C. The cooling power peaks at 59 Wdc from 23°C and at 72 Wdc from 71°C. A summary of basic performance data is found in Table 2.

Performance graphs for the LC1065 are found in Figures 2–4. Figure 2 shows the cryocooler performance over a range of tip temperatures assuming constant 50 Wdc to the controller at ambi-

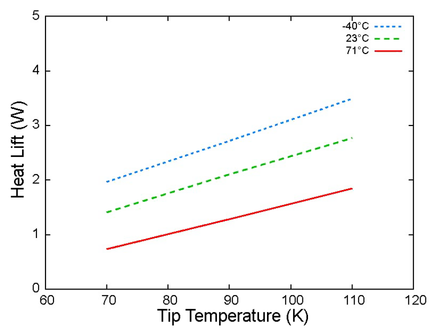

Figure 2. Heat lift at 50 Wdc for various tip temperatures.

Table 2. Performance at 77 K

Typical lift at 23°C (50 WDC)	>1.5 W
Typical lift at 71°C (50 WDC)	~1.0 W
Typical lift at -40°C (50 WDC)	>2.0 W
Cooldown time (300-77 K) for 19 g cu mass	6.3 minutes
Cooldown time (344-77 K) for 19 g cu mass	7.2 minutes
Operating frequency	60 Hz.

ent temperatures of -40°C, 23°C, and 71°C. Figure 3 is the power required to hold a heat load at 77 K.

Figure 4 is a plot of the estimated cool down time required for equivalent copper masses up to 20 g at ambient temperatures of -40°C, 23°C, and 71°C. Cool down time is less than 9 minutes for all cases.

The equivalent copper mass of an arbitrary combination of materials can be found in Eqn. 1.

$$m_{\mathrm{cu}} = \frac{\sum_{1}^{N} m_n \int_{T_\mathrm{C}}^{T_\mathrm{H}} c_n(T)\mathrm{d}T}{\int_{T_\mathrm{C}}^{T_\mathrm{H}} c_{\mathrm{cu}}(T)\mathrm{d}T} \tag{1}$$

where n is the nth material in the set of materials N, c_n(T) is the temperature dependent specific heat of material n, m_n is the mass of material n, and T_C and T_H are the cold and hot temperatures, respectively.

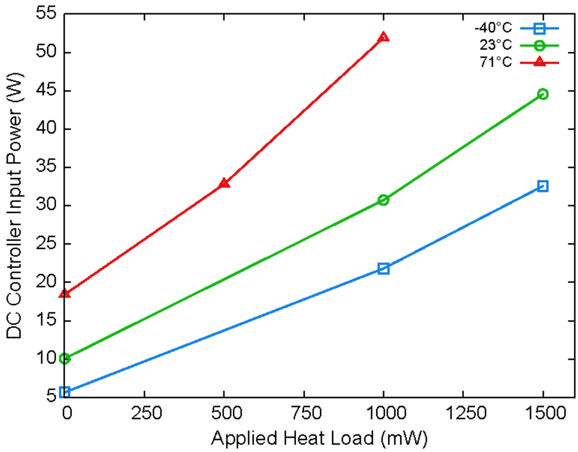

Figure 3. DC power required for applied heatloads at 77 K.

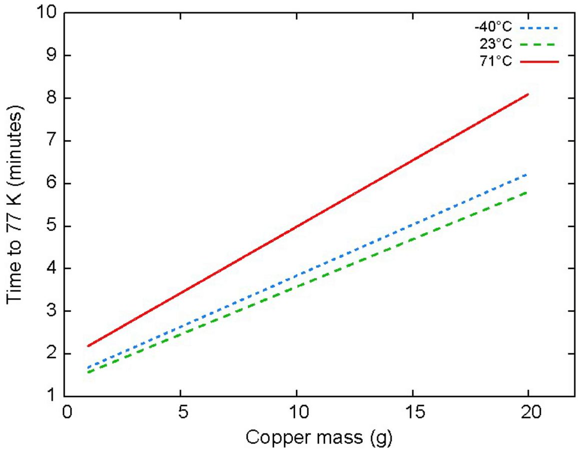

Figure 4. Estimated cooldown time to 77 K for various equivalent copper masses.

SUMMARY

Advances in IR focal plane technology require commensurate advances in cryocooler technology. The LC1065 cryocooler from Carleton Life Support Systems advances the state of the art by providing the cooling power of a 1.5 W cryocooler in a package that is only slightly larger than a 1/3 W cryocooler.

The cryocooler meets the target of 1.5 W at 77 K at 23°C with less than 50 Wdc, and also meets the target of 1 W at 77 K at 71°C with less than 75 Wdc.

First article environmental and reliability testing have begun, results will be presented at a future conference.

REFERENCES

1. Rogalski, A., "Competitive technologies of third generation infrared photon detectors," *Opto Electronics Review*, Volume 14, Number 1, Versita (2006), pp. 84–98.

2. Gedeon, D., *Sage User's Guide, v4 Edition*, Gedeon Associates, Athens, OH (2006).