Qualification of Lockheed Martin Micro Pulse Tube Cryocooler to TRL6

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ABSTRACT

Lockheed Martin has developed a micro pulse tube cryocooler for Avionics and space applications. This thermal mechanical unit (TMU) is very light weight and compact with high reliability. The technology is an extension of our space systems and has predicted lifetimes of 10 years or more. System weight is 328 grams, including the 210 gram compressor. The system utilizes the classic flexure bearing/clearance seal technology with a coaxial pulse tube cold head.

This unit recently underwent qualification to a technology readiness level (TRL) of 6, which included launch vibration and temperature cycling for the range of operating and standby conditions. Load lines were obtained over a range of powers and cold tip temperatures.

In addition the entire TMU unit was operated down to temperatures as low as 132 K for potential use on hostile planetary environments.

This paper summarizes the operating characteristics over a range of cooling loads and temperature conditions and the response to random launch vibration levels.

INTRODUCTION

This paper describes the system along with the qualification testing it has undergone for space operation. Although we foresee numerous space applications for this system, the primary focus for this testing was in support of the JPL Ultra Compact Imaging Spectrometer (UCIS), which is a precursor to a potential MARS lander, in which it would be utilized in the arm of the rover. As such, part of the qualification testing is to expose the cryocooler to the low temperatures encountered during MARS night (as low as 153 K) to demonstrate survivability without a heater, and also to operate at low powers at this survival temperature to accelerate the warm up for MARS daytime use. This system is being developed for both Avionics and space applications.

A thermal vacuum cycle test was performed to raise the Micro Split Coax Cryocooler (TMU) Technology Readiness Level to a value of six (TRL 6). This test was performed after the TMU was subjected to random vibration and initial thermal performance characterization.

SYSTEM DESCRIPTION

The TMU is shown in Fig. 1 and consists of the Cold Head Assembly, the Compressor, and the connecting transfer line. This unit employed a 7 mm diameter piston and dual flexures at each end of the motor assembly. Two back to back motor modules are employed for vibration

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Figure 1. Micro Coax Cryocooler Thermal Mechanical Unit

reduction. The TMU is charged with gaseous helium and proof pressure tested to 1.5 times the maximum expected operating pressure of 519 psia at the maximum non-operational temperature. Laboratory control electronics are used to operate the TMU.

A 15 gram copper cold block that includes the heater and temperature sensors is attached to the cold tip (not shown). This mass also represents the attached sensor hardware of the instrument (primarily thermal links).

The system that was developed consists of four modules—the two motor modules, the cold head assembly, and the hub. These modules are assembled into the cryocooler system by electron beam welding and C-seals for the transfer line connections. The compressor assembly with the motor modules and integrating hub is shown in Fig. 2. The total weight of the assembly is 210 grams including mounting provisions.

The compressor envelope dimensions (mm) are shown in Fig. 3. One of several possible mounting schemes is shown.

Two of the cold head assemblies, which have a weight of 118 grams, are shown in Fig. 4. The integrated unit includes the plenum volume and internal inertance tube, with an overall volume envelope of 111 mm L x 42 mm as shown in Fig. 5.

Figure 2. Compressor assembly weight is 210 grams

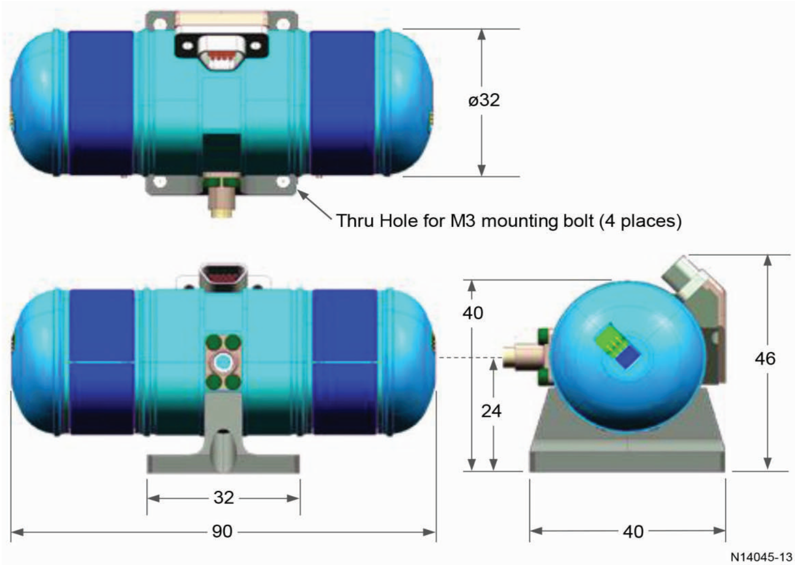

Figure 3. Compressor Envelope is 90 mm L x 32 mm D

TESTING

Initial testing was performed to measure the load lines at various powers and subject the system to random vibration loads. After this, the thermal vacuum tests were conducted. Table 1 identifies the specified interface temperatures for both operational and non-operating conditions used during the test. The test demonstrated the capability of a start and operation at each of the operating temperature extremes. A second series of tests was conducted to demonstrate survival and operation at 132 K.

Periodically the TMU was subjected to a baseline load line performance test. These data were used to assure there was no change in cooling performance during the qualification program. This test was performed at three cold tip temperatures with the TMU input power and interface temperature as specified in Table 2. The heat lift capability of the TMU was recorded to assure no degradation resulted.

Figure 4. Cold head assemblies

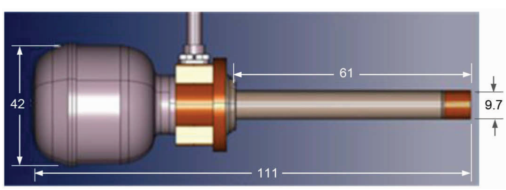

Figure 5. Cold head assembly dimensions

Table 1. Interface temperatures

Item	Temperature
Operational	-15 to +55°C
Non-Operational	-30 to +65°C

Table 2. Baseline performance parameters

Input Power (W)	10
Cold tip Temperature (K)	125, 180 220, and no load
Interface Temperature (K)	**293**

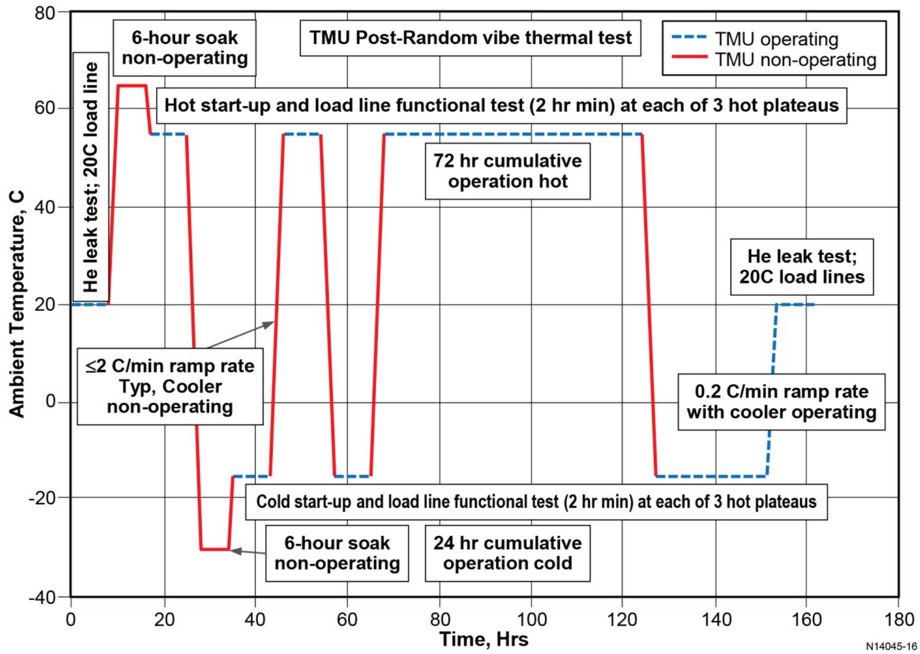

Figure 6. Thermal vacuum cycle

The desired vacuum thermal cycle test, which was supplied by JPL, is shown in Fig. 6. Each cycle starts at +20°C, goes hot then cold and returns to + 20°C. The test consists of one non-operating cycle and two operational cycles in a vacuum environment. The TMU was turned OFF during interface temperature transitions except as specified for part of the third cycle.

Prior to launch vibration and thermal vacuum testing, the pre-test cooling performance was established to allow assessment of any change in cooling capability after the qualification testing.

Then launch vibration tests were conducted with the loads summarized in Table 3 and Fig. 7.

The cooler assembly mounted to the shake fixture is shown in Fig. 8. The cold head was pointed down and utilized an accelerometer in addition to the simulated mass of the flex braids to be utilized for the connection to the instrument. The total weight supported at the cold tip was 15 grams.

Table 3. Summary of random launch loads

Frequency (Hz)	PSD (G^2/Hz)	Slope (dB/Oct)
20	0.02	--
40	0.08	+6
450	0.08	0
2000	0.0045	-6
7.9 G_{rms} Overall		

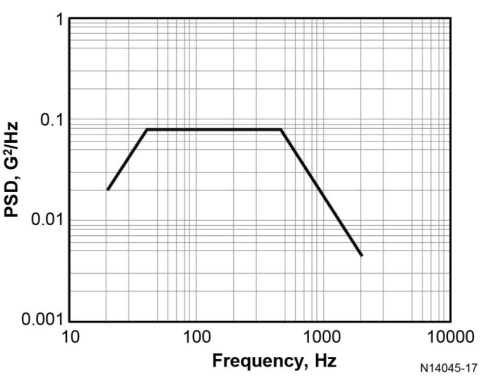

Figure 7. Random vibration spectrum

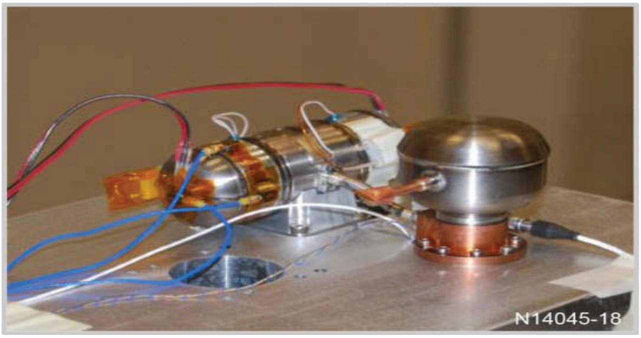

Figure 8. Cryocooler mounted to the shake fixture.

After the random vibration testing was completed the cooler was subjected to a range of load lines along with the specified temperature cycling. The results of these tests are summarized in Figs. 9 and 10 for both the cooling load lines and the specific power at various rejection temperatures.

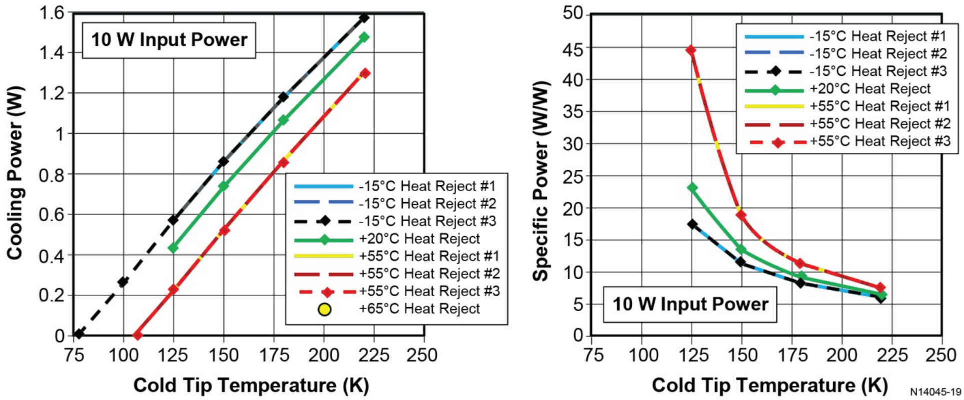

Figure 9. Cooling load lines at various rejection temperatures

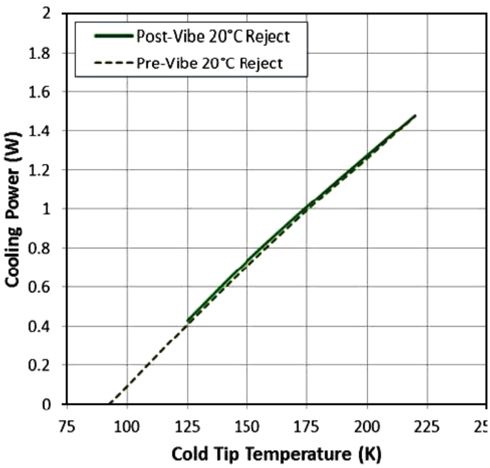

Figure 10. Repeatability of load line prior to and after vibration and thermal vacuum cycling

SUMMARY

A micro cryocooler system weighing 328 gams (without electronics) has been developed from scaling from our previous space flight cryocoolers experience. The system is compact and can provide cooling loads of 0.85 W at 150 K with 10 W of power input.

The thermal mechanical unit (TMU) was successfully subjected to qualification levels to TRL6, which included thermal performance testing, random launch vibration and thermal vacuum testing environments supplied by JPL in support of their Ultra Compact Imaging Spectrometer instrument. All testing was successfully completed with no degradation in performance. A motor module has undergone continuous life testing and has now accumulated in excess of 7000 hours. Future work planned for 2014 includes additional life testing on a complete compressor, measurements of induced vibration, and operation with candidate electronic drivers.

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