MatISSE Microcryocooler

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Abstract. Lockheed Martin Space Systems Company has built and delivered an engineering model microcryocooler to the Jet Propulsion Laboratory for use with instruments for deep space and earth science missions. Funding for this cryocooler was through JPL’s Maturation of Instruments for Solar System Exploration (MatISSE). This cooler is nearly identical to the compact coaxial microcryocooler presented at the 2014 International Cryocooler Conference. The cryocooler mass is just 345 grams for the entire thermal mechanical unit, and is compact enough to be packaged in a CubeSat. This paper describes the measured performance of the MatISSE cryocooler, including the performance at cold heat rejection temperatures.

1. Introduction and background

The Jet Propulsion Laboratory (JPL) was awarded funding for an IR Spectrometer under NASA’s Maturation of Instruments for Solar System Exploration (MatISSE) program. JPL funded Lockheed Martin Space Systems Company (LMSSC) to build and deliver a prototype microcryocooler for integration with their instrument. The cryocooler was to be a nearly build-to-print copy of the microcryocooler which was matured to TRL 6 in late 2013[1-3].

Science instruments designed for solar system exploration must be small and lightweight, because of the high cost of launching into deep space, and because of the small size of many deep space probes, especially landers. Reliability is also extremely important, because the instrument must sometimes survive for many years in a cold non-operating state, followed by years of operation. Power efficiency is also important, because the mass of the electrical power system must also be minimized. Low exported vibration is desirable, as is the capability of the hardware to survive cryogenic temperatures during non-operation.

1.1 Microcryocooler heritage

Lockheed Martin qualified the microcryocooler to TRL 6 in 2013 [2]. This cryocooler’s low mass (320 grams), small size (small enough to fit in ½ of a CubeSat U) and high predicted reliability made it a good candidate for JPL’s IR spectrometer. Furthermore, the microcryocooler can survive thermal cycling to 150K ambient temperature, and was able to operate at cryogenic temperatures as well.

2. Design Specifications of the MatISSE Microcryocooler

The MatISSE microcryocooler was to be a nearly build-to-print copy of the microcryocooler previously qualified to TRL 6. There were only two modifications made to that design. First, the transfer line connecting the compressor and pulse tube coldhead was made shorter, and the coldhead was aligned parallel to the compressor, for compact packaging within JPL’s IR spectrometer. A
photograph of the MatISSE cryocooler is shown in figure 1, with the cold tip oriented toward the bottom, near the subject’s thumb.

![Photograph of MatISSE microcryocooler](image)

**Figure 1.** Photograph of MatISSE microcryocooler, which was delivered to JPL in June, 2015

The cryocooler compressor, on the left in figure 1, was modified to improve the efficiency compared with earlier versions of the compressor. Low-cost 1018 low carbon steel iron pieces were replaced with higher cost, but higher performance Vanadium Permendur. This modification to the compressor resulted in a higher motor force constant and lower motor electrical coil \(i^2R\) losses, highly desirable to JPL, and led to cryocooler efficiency nearly 20% higher, as will be seen below.

### 3. Measured Performance of the MatISSE Microcryocooler

Cryocooler performance characterization testing was conducted in a thermal vacuum chamber, with the entire cryocooler in vacuum and surrounded by a shell conductively cooled and controlled at the desired ambient temperature. The coldfinger was instrumented with a diode thermometer and heater, and the cryocooler electrical power was supplied by a two-channel linear amplifier, driven by a sinusoidal waveform at the desired drive frequency. This testing did not use the compact transfer line configuration shown in figure 1, because we did not have enough time to build special heat sink mounting. Instead, we used a traditional transfer line of the earlier TRL 6 configuration [2, 3].

Three different heat rejection temperatures were tested: 300K, 280K, and 260K. These temperatures were defined as the temperature on the pulse tube coldhead warm flange, on the
cryocooler side of the thermal interface. This thermometer can be seen in figure 1, bonded to the warm flange with “blue death” epoxy. During testing, the aluminum plate to which the cooler was mounted was about 2-4K colder than this temperature. At each reject temperature, a frequency scan was obtained with a constant 10W compressor electrical input power. The results of these frequency scans are shown in figure 2.

Figure 2. Frequency scans with constant 10W compressor electrical input power. The peak of the cooling power (left side) is at 94 Hz, very close to the peak motor efficiency of 92-94 Hz (right side), indicating a good match between the cryocooler thermodynamic peak and the compressor resonance.

The results in figure 2 show that the peak cooling power on the left side plot is at 94 Hz, very close to the peak in the motor efficiency on the right side plot, which indicates that the peak thermodynamic frequency of the coldhead is well matched to the compressor resonant frequency. The insensitivity of the peak operating frequency to the heat rejection temperature indicates that complex frequency optimization during operation is not required, even over a fairly broad range of heat rejection temperature.

Cooling load lines are shown in figure 3. These load lines are shown with three different heat rejection temperatures in the three figures, and with different amounts of electrical input power within each figure. With 300K heat rejection temperature and 10W compressor electrical power, the cooling power at 150K (the nominal design point of the microcryocooler) is 0.825W, almost 20% higher than the measured cooling power of 0.69W for the TRL 6 microcryocooler. This improvement is due to the improved motor efficiency caused by the Vanadium Permendur motor iron parts.

The load lines with 10W compressor electrical power are all shown together in figure 4. The left side simply plots again three of the 10W load lines from figure 3 together on the same plot. The right side shows the specific power, which is the compressor electrical power divided by the cooling power. At the nominal design point (300K heat rejection, 150K cold tip temperature), the specific power is 12 W/W.
Figure 3. Load lines for three different heat rejection temperatures: 300K (top figure), 280K (middle figure) and 260K (bottom figure).

A summary of the performance parameters of the MatISSE cryocooler is given in table 1. With the exception of the specific power, these values are identical to those for the TRL 6 microcryocooler.
Figure 4. Right side figure: load lines with 10W compressor electrical input power, at three different rejection temperatures. Left side figure: specific power, defined as compressor electrical power divided by cooling power. At the nominal design point (300K reject, 150K cold tip), the specific power is 12 W/W.

| Cryocooler Parameter       | Nominal Performance                                      |
|----------------------------|----------------------------------------------------------|
| Net Cooling Power          | >1W net cooling at 150 K                                  |
| Specific Power             | 12 W/W at 150 K, with 10W input power                    |
| Compressor Mass            | 200 grams                                                |
| Compressor Length          | 90 mm length                                             |
| Compressor Configuration   | Back-to-back vibrationally-balanced pistons              |
| Cryocooler Lifetime        | 10 year on-orbit lifetime                                |
| Coldfinger Configuration   | Compact coaxial coldfinger                               |
| Cryocooler Configuration   | Split cryocooler configuration                           |

4. Summary
A microcryocooler was successfully built, tested and delivered to the Jet Propulsion Laboratory for integration with a ground demo IR spectrometer. This ground demo will allow JPL to test their entire instrument, to demonstrate maturity in anticipation of winning future science missions. Some of these missions include a Discovery class mission to Phobos, a New Frontiers lunar science mission, Earth science missions such as weather and atmospheric analysis, and airborne missions.

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References

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