Maturation and Status of the Lockheed Martin Micro1-2 Cryocooler

J.R. Olson[1], E. Roth[1], E.T. Will[1], M. Guzinski[1], A. Ruiz[1], I.M. McKinley[2], D.J. Johnson[2], J.I. Rodriguez[2], K. Frohling[3]

[1]Lockheed Martin Space, Palo Alto, CA 94304
[2]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109
[3]Iris Technology Corporation, Irvine, CA 92614

ABSTRACT

This paper describes the maturation and status of the Lockheed Martin "High Power" Micro1-2 pulse tube cryocooler. This cryocooler, which was qualified to technology readiness level 6 in 2014, is the baseline cooler for the Jet Propulsion Laboratory (JPL) Mapping Imaging Spectrometer for Europa (MISE) instrument aboard the Europa Clipper mission, and the Johns Hopkins University Applied Physics Laboratory (JHU-APL) Gamma Ray and Neutron Spectrometer (GRNS) aboard the planned Psyche asteroid mission.

This paper will describe enhancements to the cryocooler made for the MISE program, specifically modifications to maximize the cooler efficiency at low heat rejection temperature (220 K) and to increase the operating frequency. The paper will also describe minor modifications for the GRNS program, specifically modification of the coldfinger for low thermal emissivity and the addition of a cold tip interface tab. Finally, the paper will describe modifications made for operation with 150 K heat rejection temperature and 35 K cold tip temperature for the Deep Space Cooling System (DSCS) project with Iris Technology.

MICRO1-2 MICROCRYOCOOLER

History

The Micro1-2 cryocooler is a small, robust, 475-gram space-quality pulse tube cryocooler driven by a long-life "Oxford-style" compressor and described in detail in previous publications[1,2] and shown in Figure 1

Following qualification of the Micro1-1 ("standard") Microcryocooler to TRL 6 in 2013[3], Lockheed Martin (LM) identified a need for a microcryocooler with higher cooling capacity and lower cold tip temperature to meet a specific customer need for 2 W cooling at 105 K. Subsequent modifications to the coldhead and compressor to provide greater input power and cooling power. The Micro1-2 coldhead was designed for higher power capacity and included greater heat sink and regenerator volumes while retaining identical assembly techniques. The Micro1-1 and Micro1-2 coldheads are shown in Figure 2. The compressor piston diameter was increased to provide greater swept volume, and the compressor pedestal was

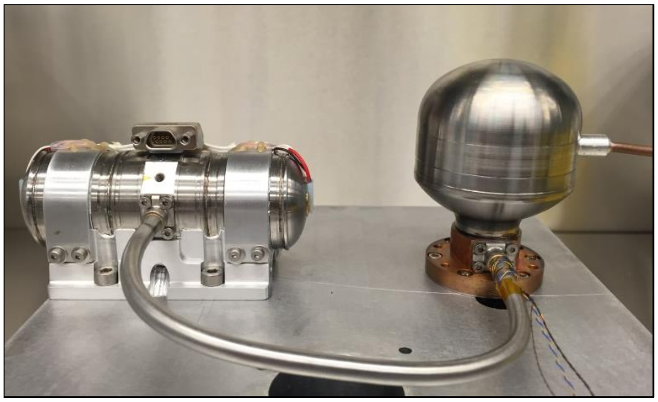

Figure 1. Micro1-2 cryocooler. The compressor is on the left and the warm end of the coldhead is shown on the right. The cold finger is pointing down, and is obscured by the mounting plate in this photo.

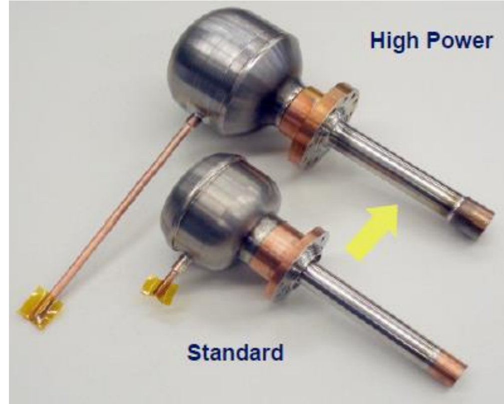

Figure 2. Comparison of the Micro1-1 (Standard) and Micro1-2 (High Power) coldheads. These coldheads use identical manufacturing processes.

enlarged and heat straps were added over the compressor motors to reject compressor heat more effectively. The two different pedestal and heat strap configurations are shown in Figure 3. The Micro1-2 cryocooler was qualified to TRL 6 in 2015 through thermal vacuum / thermal cycling testing, and GEVS-level launch vibration testing which included 50 grams of mass on the coldhead and no launch lock provisions other than shorting the motor coils.

Capabilities

Some unique capabilities of the Micro1-2 cryocooler made it an ideal candidate for several cryogenic instruments which will be described later in this paper. The small size of the compressor and details of its design allow for the compressor not only to survive exposure to cryogenic temperatures, but also to operate at 150 K or colder. This allows the Micro1-2 to be used in planetary missions in extreme environments such as the lunar or Martian surface, where hardware can cool below 200 K when unheated during nighttime, or the outer planets, where utilizing a very low heat rejection temperature can greatly improve cryocooler efficiency or allow operation at colder cold tip temperatures than could otherwise be easily achieved.

Characterization testing of a Micro1-2 cryocooler was previously performed by JPL under extreme conditions relevant to the Jupiter environment[4], including verification of the cryogenic operating capabilities, and the capability to operate with no change in performance after exposure to very high radiation dosage (500 krad of 25 MeV electron beam). This test complimented prior testing of a Micro1-1 cryocooler[5] under harsh environmental conditions.

The all-welded, all-metal coldhead allows the cold tip to be heated to high temperature, in excess of 125 °C. This operation is required for some gamma ray detectors such as the GRNS instrument, which require periodic annealing of the detector's germanium crystal at elevated temperature.

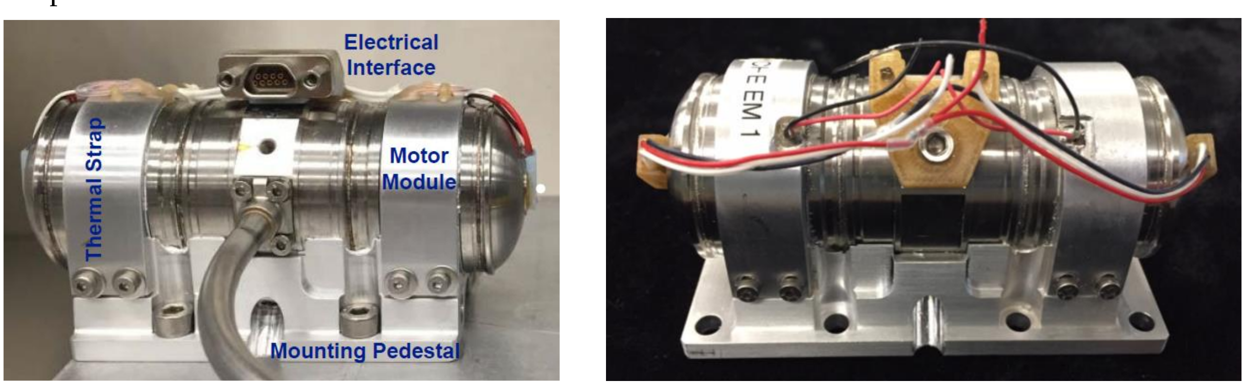

Figure 3. Comparison of the original Micro1-2 compressor mount (left) and modified compressor mount (right). The modified pedestal is slightly wider, with 8 mounting bolts instead of 4, and includes thicker thermal straps for improved heat sinking of the compressor motors.

Past and Future Micro1-2 Cryocooler Deliveries

The first Micro1-2 cryocooler unit was funded by LM IRAD, and following TRL 6 qualification was put on life test, operating for 7700 hours with 60 W compressor ac electrical input power. Following this testing, the cooler was taken off life testing and sent to JPL for testing related to the MISE program. Results of JPL's testing are presented in another paper at this conference[6].

The second Micro1-2 cryocooler was built for JHU-APL, funded by NASA's Maturation of Instruments for Solar System Exploration program (MatISSE), to mature JHU-APL's GRNS instrument. Following the successful MatISSE program, this instrument was selected for the planned Psyche asteroid mission. LM will deliver two engineering model cryocoolers to JHU-APL in 2018 for GRNS instrument qualification and mission-specific life-testing.

The third and fourth Micro1-2 cryocoolers were built for JPL to support the MISE instrument, part of the Europa Clipper mission. LM expects to deliver flight and flight spare Micro1-2 cryocoolers to JPL for use in the MISE instrument in 2019.

LM is currently building a Micro1-2 cryocooler for team partner Iris Technology for a NASA Phase II SBIR for science topic S1.09. This cryocooler is called the Deep Space Cooling System, and designed to provide 0.3 W cooling at 35 K while rejecting heat at 150 K. This cooler will be delivered to Iris Technology in late 2018, for integration and testing with the newly-developed µLCCE electronic controller, and delivery to NASA in 2019. Results of Iris Technology's electronic controller development are presented in another paper at this conference[7].

PROGRAM-SPECIFIC REQUIREMENTS

Mapping Instrument Spectrometer for Europa (MISE)

The MISE instrument, being built by the Jet Propulsion Laboratory (JPL) is one of the instruments selected for the Europa Clipper mission. The MISE instrument cooling requirement is 0.75 W at 80 K with a nominal heat rejection temperature of 220 K. Because of the nature of the Europa Clipper mission, with periodic flybys of the Jovian moon, there are dozens of cycles where the cooler will be powered off, and temperatures will soak to below 150 K. In order to facilitate cooler stability prior to a flyby, it is required that the cooler can power on at temperatures below 150 K. Thermal cycling related to these flybys is currently being tested at JPL.

Electrical power is scarce at the Jovian orbit, so cryocooler efficiency is critically important. Consequently, several modifications were made to the cryocooler to improve efficiency. The cryocooler regenerator packing and inertance tube configuration were optimized for the low heat rejection temperature. The regenerator tube material was also changed from Inconel 718 to Ti6Al4V to reduce parasitic conduction and improve efficiency. The compressor pedestal was lengthened and the bolt interface changed from four to eight bolts to reduce interface resistance, and the thermal straps on the compressor motors were thickened and changed to 1100 series aluminum to reduce temperature gradients in the compressor.

JPL also requested that the MISE cryocoolers be optimized for operation at 135 Hz or higher, in order to more easily reduce exported vibration through passive damping. Although the MISE instrument is not especially sensitive to vibration, the possible impact of the MISE instrument on other instruments aboard the Europa Clipper requires a reduction in exported vibration. A comparison of the cryocooler specific power and motor efficiency for the LM life test cooler and the MISE demo coolers is shown in Figure 4. This figure clearly shows the successful re-optimization for higher frequency. The MISE demo coolers have been extensively tested at JPL[6], and a photo of one of those coolers under test is shown in Figure 5.

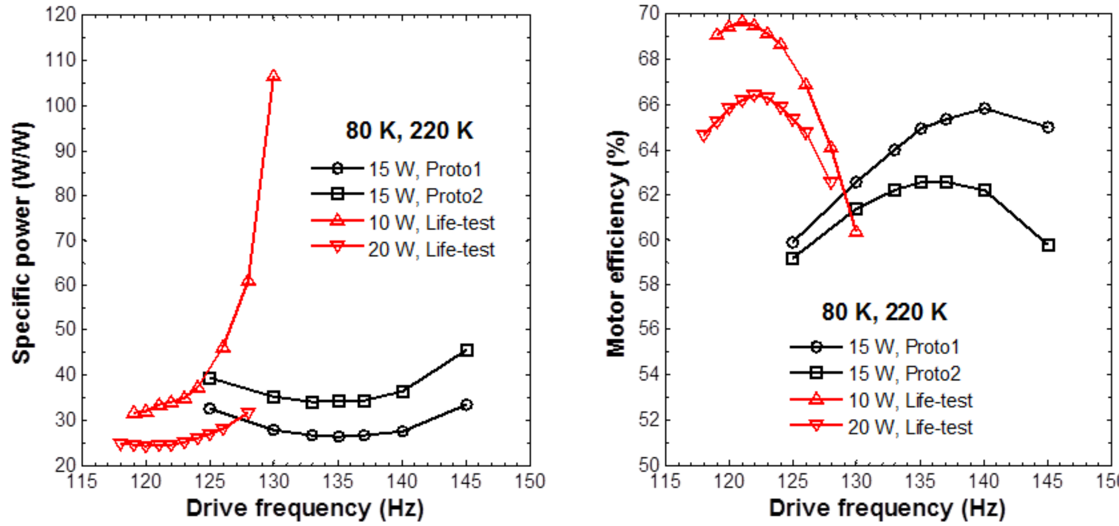

Figure 4. Comparison of the cryocooler specific power (left) and motor efficiency (right) as functions of drive frequency, for the LM IRAD-funded life-test cooler (red), and the MISE demo (prototype) coolers (black). The MISE coolers were optimized for maximum performance at 135 Hz.

Gamma Ray and Neutron Spectrometer (GRNS)

The GRNS instrument, being built by Johns Hopkins University Applied Physics Laboratory (JHU-APL) will fly on the Psyche asteroid mission. The GRNS instrument cooling requirement is 1 W cooling at 85 K with a nominal heat rejection temperature of 270 K, and the regenerator packing and inertance tube were optimized for these conditions. An interface tab, shown in Figure 6, was added to the cold tip to facilitate integration with the detector's germanium crystal.

The nature of the GRNS instrument precludes the use of multi-later insulation on the coldfinger, and so thermal conductance testing was conducted on a gold-plated regenerator tube and an unplated tube, to assess whether the low-emissivity gold plating reduces radiative parasitic heat loads. The conducted heat load of the two tubes was identical, and a difference in radiated heat load of less than 10 mW was measured between the two tubes, so the decision was made to abandon the idea to gold plate the regenerator and cold tip.

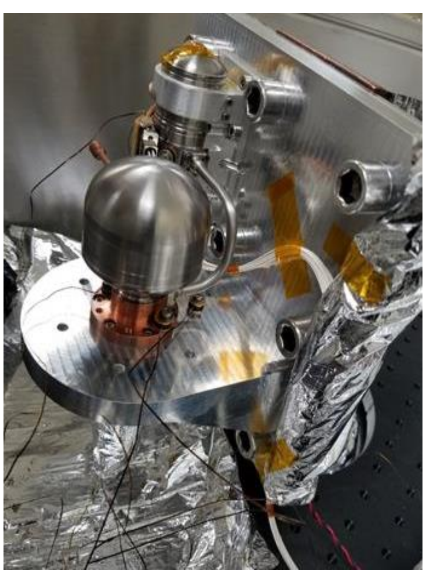

Figure 5. One of the two MISE demo cryocoolers under test at JPL.

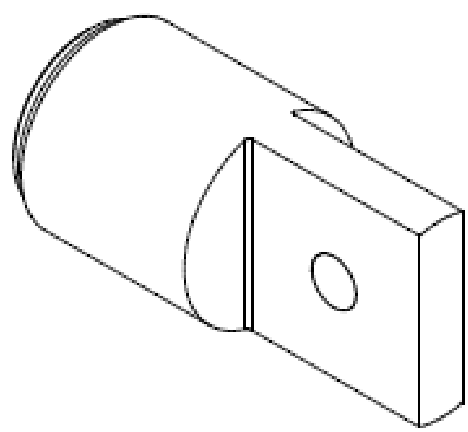

Figure 6. Coldtip configuration implemented for Psyche, which includes a tab with a mounting hole for ease of integration with the thermal strap for the GRNS germanium crystal.

Deep Space Cooling System (DSCS)

The DSCS program is a NASA Phase II Small Business Innovative Research (SBIR) project, for science topic S1.09. This project is funding the development of a cryocooler designed to provide 0.3 W of cooling at 35 K while rejecting heat at 150 K. Results from a modeling trade study conducted in Phase I are shown in Figure 7. That trade study compared the cooling performance of the Micro1-1 and Micro1-2 coldheads (with optimized regenerator packing and inertance tubes), as well as a reoptimized coldhead, with 35 K cold tip and 150 K heat rejection temperature. The Phase I study showed that the Micro1-2 coldhead was already well-optimized for these conditions.

As part of this SBIR, Iris Technology is reducing the mass and volume of the cryocooler control electronics. That work is described elsewhere in this conference proceedings[7].

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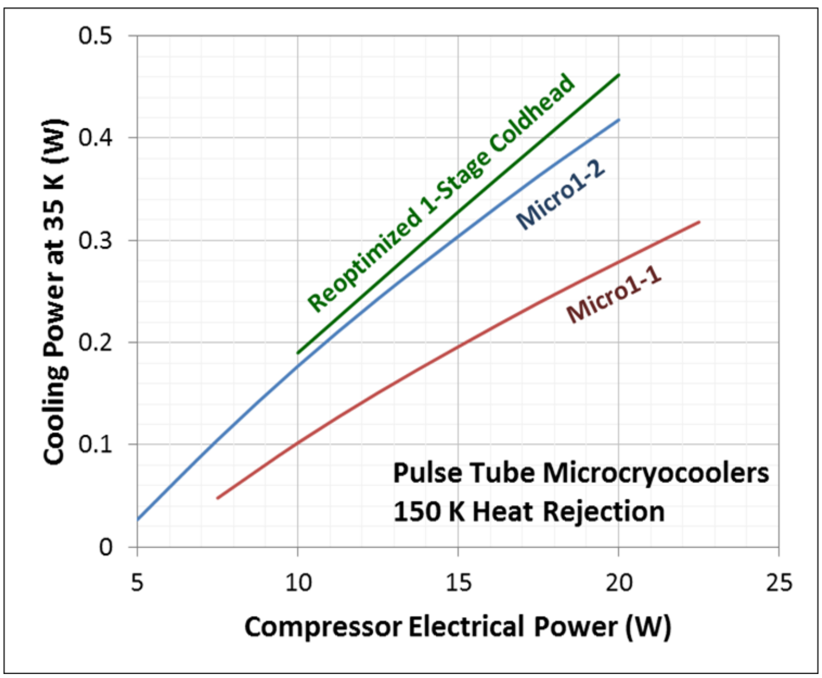

Figure 7. Trade study from the DSCS Phase I SBIR program, which compared the predicted performance of the Micro1-1 and Micro1-2 coldheads, along with a reoptimized single-stage coldhead. These optimizations assumed 35 K cold tip temperature and 150 K heat rejection temperature. The Micro1-2 coldhead is already nearly optimum for these environmental conditions and was selected for assembly during Phase II.

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