TIRS Cryocooler Integration and Test at the Instrument Level

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ABSTRACT

The Thermal InfraRed Sensor (TIRS) is an instrument on the Landsat Data Continuity Mission (LDCM) currently scheduled for launch in January 2013. The TIRS data in the thermal infrared band will provide land-use information, volcanic and fire monitoring, and water resource management. Cryogenic cooling for the instrument is provided by a two-stage Ball Aerospace cryocooler. The cooler was delivered to GSFC in April 2011 and immediately integrated into the TIRS instrument. Since that integration, the TIRS instrument has undergone complete environmental testing including random vibration, launch loads and thermal vacuum, with delivery to the spacecraft in February 2012. This paper discusses this integration as well as the cooler performance during subsequent testing.

INTRODUCTION

LDCM, a collaboration between NASA and the U.S. Geological Survey, will provide moderate-resolution measurements of the Earth's terrestrial and polar regions in the visible, near-infrared, short wave infrared, and thermal infrared. The LDCM spacecraft (Figure 1) is intended to provide continuity with the 40-year long Landsat land imaging data set. Launch of LDCM, currently scheduled for January 2013, is intended to take place while Landsat 7, the youngest of the series currently on-orbit, is still at least partly functional.

TIRS was included in the LDCM payload to provide thermal imaging and to support emerging applications in water management. TIRS has been built by NASA GSFC and it has a three-year design life. The TIRS instrument requires cryogenic cooling for three Quantum Well Infrared Photodetectors (QWIP) arrays and a thermal shield[1]. The QWIPs will be operated at 36-38 K, while the shield temperature will be maintained around 100 K.

The TIRS flight cryocooler system consists of a thermo-mechanical unit (TMU) and the cryocooler control electronics (CCE)[2]. The cryocooler system was built and qualified by Ball Aerospace and delivered to the instrument in April 2011. It has since been integrated into the sensor unit, tested at the instrument level, and installed with the instrument on to the spacecraft.

The cryocooler was characterized at higher power than was actually required by the instrument, and the cooler was damaged, probably at the time of shipping. These two issues led to a great deal of additional work for the cryocooler and instrument teams.

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Figure 1. TIRS and the Operational Land Imager (OLI) can be seen in their payload positions on the LDCM spacecraft at the facility where the spacecraft integration is ongoing. In this view, the left side of the spacecraft is in the nadir direction on orbit.

CRYOCOOLER INTEGRATION

Coldfinger Integration and Stiction Test Results

After delivery to instrument Integration and Test (I&T) at GSFC in April 2011, the cryocooler was checked out and then integrated into the instrument. The Stirling coldfinger of the TIRS TMU contains a displacer with tight clearance seals. Side loads on the coldfinger can cause contact between moving components in the coldfinger, possibly causing permanent damage to the machine. To desensitize the coldfinger to movement of the rest of the instrument, both the warm stage and cold stage of the TMU are coupled to the sensor unit by flexible thermal straps. The TIRS cooler has position sensors on each of its pistons, and can thus be tested for touch contact with a "stiction test." In this test, each piston is slowly swept between its end stops while monitoring current in the motor coil. The piston sweeps a characteristic path of motor current versus displacement, with a slight amount of hysteresis caused by gas forces and friction in the system (Figure 2). Stiction data from before and after instrument integration show very similar characteristics.

The TMU is integrated to the FPA without a vacuum housing, so the only ambient testing that may be performed is a short-duration checkout at low stroke, allowing some measure of the CCE and TMU functionality. Full-power operation is only possible when the instrument is in a vacuum chamber.

INSTRUMENT OPERATING CONDITIONS

Coldfinger Loads

The cooler was sized for a conservative estimate of the loading on the FPA and thermal shield, as much as 2 W on the cold stage and up to 10 W on the warm stage. During thermal/vacuum testing in August 2011, the instrument was tested over a wide range of heat rejection temperatures. Input power at the instrument bus was between 90-120 W, lower than the cooler had been characterized (Figure 3). Extrapolating from the characterization data of the cooler, the loading on the cold stage seems to be around 600 mW, and on the warm stage 5-6 W,

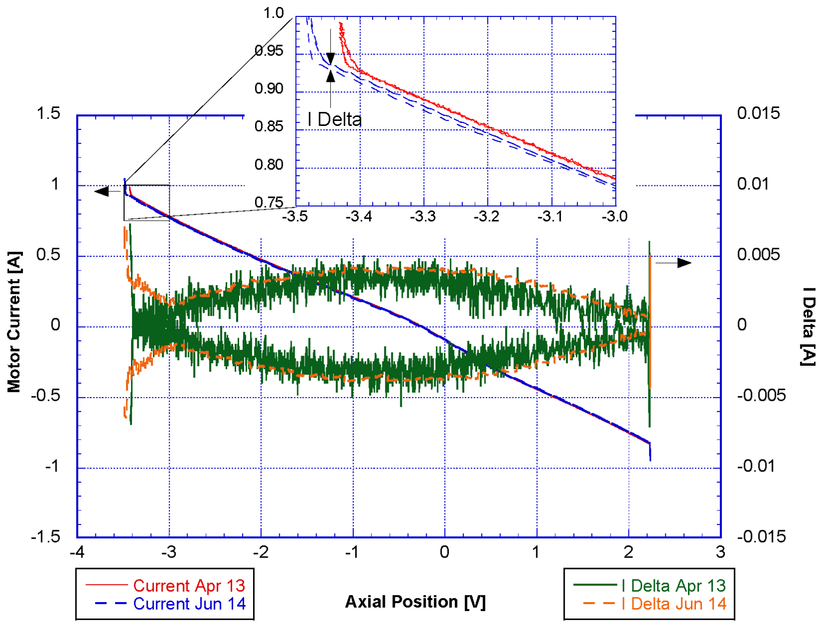

Figure 2. Stiction test data at time of receipt (Apr 13) and after instrument integration (Jun 14). Hysteresis of the piston current is an indirect measure of piston friction, and I Delta is a measure of the openness of the hysteresis loop.

depending on the instrument operating temperature. The cryocooler is well behaved at these conditions, but the operating power had implications for other thermal control systems.

Operating Power

Both the TMU and CCE have dedicated radiator areas for heat rejection on orbit, designed for approximately 180 W and 50 W, respectively. The TMU radiator has survival heaters, with thermostat set points between -40 to -45°C. The TMU has been qualified to operate at this temperature, and would potentially come to operate there if loads were low enough and the spacecraft was at its coldest operating condition. Thermostat cycling on the radiator would perturb the coldfinger operating point, so the operating point of the TMU is targeted to around 0°C. With a TMU dissipation of only 55-75 W, the TMU radiator is large enough to fall well below -50°C during cold operational conditions. Therefore, it was necessary to blanket part of the TMU radiator, eventually covering about 50% of the area with MLI.

The CCE dissipation was slightly higher than anticipated, running to as high as 65 W for 180 W of TMU power. To limit the CCE dissipation to less than 50 W, TMU motor power is now limited by procedure to less than 120 W.

SPACECRAFT INTEGRATION

Shipping Damage and Diagnosis

The instrument was shipped to the spacecraft integration facility in Gilbert, AZ in February 2012. An initial stiction test didn't reveal any obvious problem with the cryocooler, but an ambient checkout on the instrument showed that the cryocooler was drawing higher power than usual and seemed to be cooling at a much lower rate than expected. The initial understanding of the team was that there was a problem with the CCE, but an experiment with a similar non-flight cooler in early March strongly suggested that the TMU had lost its helium charge. A "sniff" test

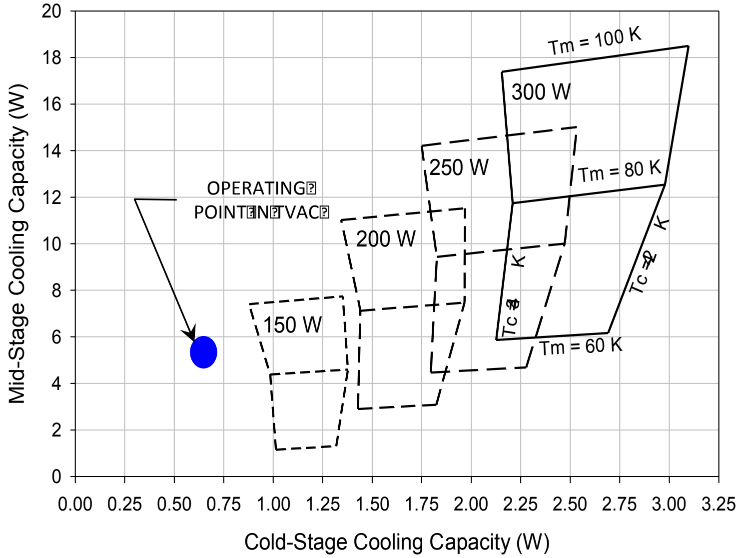

Figure 3 The cryocooler system was characterized over a wide range of operating points, all at higher power than were actually encountered during thermal vacuum testing of the instrument.

of the TMU showed a strong indication at the tip of the fill tube, a pinch-off design that seemed to have opened up.

A test of the TIRS cooler in March looked at the resonant characteristic of the TMU, and confirmed that the behavior at low stroke was very like a machine at low pressure (Figure 4).

Fill Tube Repair

With the cooler still mounted in the TIRS instrument, the fill tube pinch-off was removed. X-ray imaging showed that the delicate pinch had been cracked open, probably by incidental contact during instrument shipping. The pinch was replaced by a valve assembly (Figure 5), and the TMU refilled to 135 psia. Full-power operation will not be possible until thermal/vacuum

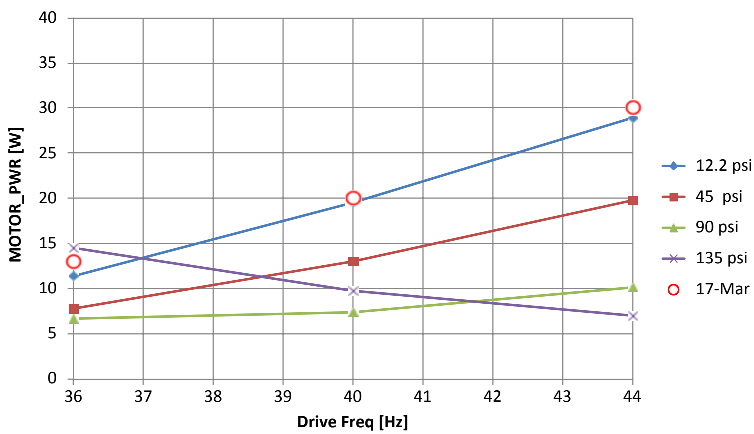

Figure 4 A similar cooler was characterized at low stroke over a range of charge pressure at different operating frequencies (solid lines). The TIRS TMU, which had originally been charged to 135 psia, was found in March to have the characteristics of a machine near 1 atm.

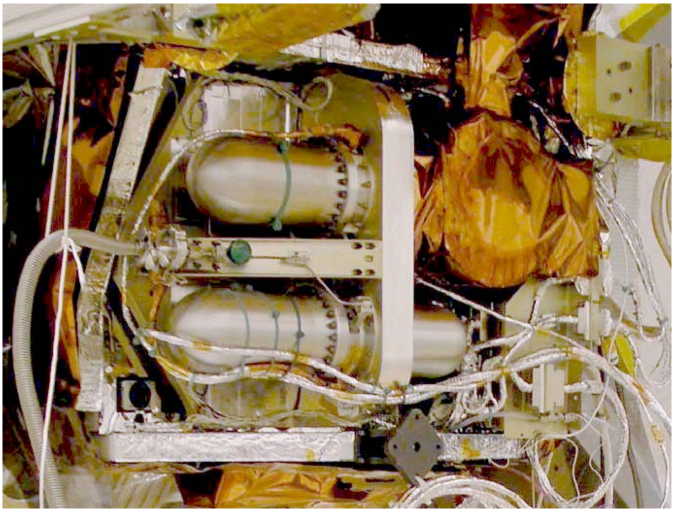

Figure 5. A small bellows-sealed valve was used to retro-fit the TMU fill line.

testing later in 2012, but low-power ambient performance has returned to normal.

During the time before launch of LDCM, the team will monitor the cryocooler for any signs of further leaks. During the fill process, the performance of the cryocooler was recorded over the first 3 K of cooldown. Cooldown rates mapped very cleanly to charge pressure, providing enough resolution to identify leaks large enough to jeopardize the mission. (Figure 6)

CONCLUSION

The TIRS cryocooler has been successfully integrated in the TIRS instrument and all instrument level qualification testing has been completed. The GSFC/Ball team has successfully worked through issues encountered during testing, and the cryogenic system and overall

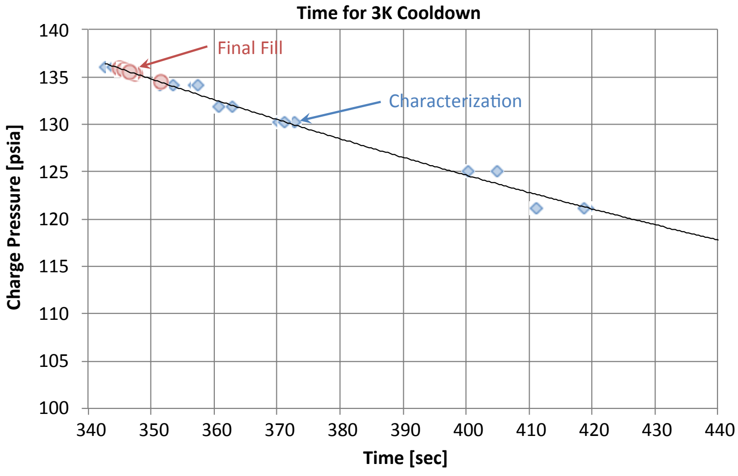

Figure 6 Characterization of the cooler during the fill process will allow visibility into the charge pressure without requiring the addition of a pressure gauge.

instrument are now ready for observatory level testing. LDCM observatory testing will be completed in 2012 with anticipated launch in January 2013.

ACKNOWLEDGMENT

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