LPT6510 Test Results up to TRL6

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ABSTRACT

The LPT6510 is a compact integral pulse-tube cryocooler for 50-120 K space applications, with a design derived from the Thales Cryogenics MPTC compressor developed under ESA TRP and the Absolut System SSC80 pulse-tube. Results of the test campaign on a flight-representative Engineering Model are presented, demonstrating Technology Readiness Level 6 for the product. Detailed cryogenic performance and environmental test campaign results are shown over the cooler's entire operational envelope, and specific aspects, such as off-state parasitic losses and induced vibrations, are discussed.

INTRODUCTION

The need for a compact, efficient pulse-tube cooler for earth observation applications has been recognized, with several developments towards such a product, dating back as far as the Thales MPTC compressor, developed under ESA contract [1]. However, to date, the MPTC cryocooler has not been developed up to a maturity where it could be considered for flight programs. In order to address requirements for this class of cryocooler, Absolut System and Thales Cryogenics have partnered, each allocating internal funding to develop what is now named the LPT6510 cryocooler.

The LPT6510 was initially built as a breadboard demonstrator, using a modified Thales MPTC compressor and a modified Absolut System SSC80 pulse-tube cold finger. The results obtained with this demonstrator model were previously presented [2] and based on these results, the actual product design was made [3]. While a detailed examination of design is not the focus of this paper, key changes are highlighted in Figure 1, with the as-built cooler shown in Figure 2.

Key development goals included high efficiency at 100 K, low vibrations, compliance to all relevant environmental requirements, simplified mechanical and thermal interfaces, and a reduced complexity of overall MAIT.

Figure 1. Change to all-welded compressor (left) and all-welded cold finger (right).

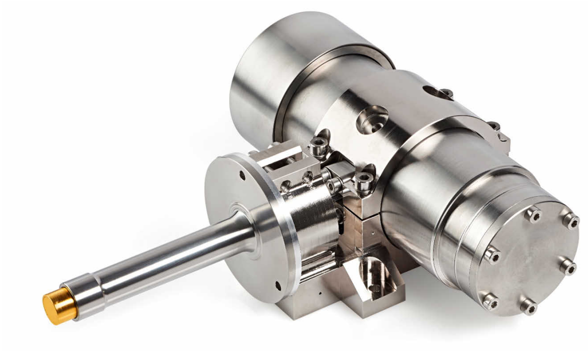


Figure 2. LPT6510 EM01.

Table 1. Test overview

Parameter	Specification	Test performed
Off-state parasitics	2 mW/K	Multi-slope warm-up calorimetry
Pressure load	Proof 1.5X MDP	Leak-Proof-Leak
Induced Vibrations	< 2 N RMS	Kistler dynamometer table measurement
Thermal vacuum	-40 °C to +60 °C (qual, op), 8 cycles	Thermal Vacuum Cycle Test performed at Absolut System
Random vibration Sine vibration Shock	15.5 Grms 25g 1000 g 0.5 ms	Random vibration test 3 axes Sine test 3 axes Shock 3 axes
Thermal performance	3.2 W @ 100 K @ 23 C	Full characterization Twarm=[-30...60] C, Tcold = [50...150] K, PAC=[0...max]

The EM01 cooler was subjected to a comprehensive test campaign, including performance characterization, measurements of induced vibrations, thermal vacuum cycling, and mechanical testing (shock & vibration). The test definitions are detailed in Table 1. The test campaign was successfully concluded in May 2020. Details of individual tests are given in subsequent paragraphs.

THERMAL PERFORMANCE TESTING

Test Conditions

The EM01 cooler was subjected to a comprehensive test campaign, including performance characterization, measurements of induced vibrations, thermal vacuum cycling, and mechanical testing (shock & vibration). Unless stated otherwise, all thermal performance tests were done with radiative insulation around the cold finger and with the cold tip pointing in the gravity down direction (tip-down). See also Figure 3.

Figure 3. Wiring and instrumentation (left), radiation insulation (middle) and mounting inside climate chamber (right).

All reported measurement values were corrected only for the conductive load through the wires to the heater resistor – 4 copper AWG30 wires with a conduction length of 159 mm, resulting in a calculated conductive load of 0.407 mW/K.

Off-state Parasitic Load

For many typical flight configurations, a cold redundant configuration is used in which one cryocooler is operated and the other cryocooler is present but unpowered, to be used in the event of failure of the first cryocooler. However, as both the operational and the non-operational cryocoolers are thermally coupled to the cooled load, the non-operational cryocooler will introduce an additional thermal path (additional heat load). This off-state parasitic load therefore needs to be known in order to take it into account in system design.

During design of the cold finger, this heat load was calculated by Absolut System to be better than 2 mW/K. During the test campaign, this value was verified by performing a multi-slope warmup measurement.

This measurement is achieved by performing a cooldown, and then switching off the power to the cryocooler and recording the warmup curve – cold tip temperature as a function of time. The time derivative of this curve, dT/dt, is a measure of the total heat flux to the cold tip. However, this time derivative dT/dt is dependent on the heat flux as well as the thermal mass of the cold finger. To eliminate this thermal mass, the measurement is performed multiple times, each time with a different constant dissipative load added to the cold tip.

By keeping the warm side temperature constant, this allows conversion of dT/dt to a load in mW for each temperature. By correcting for the heater wire parasitic heat load as indicated in previous paragraph, an off-state parasitic load of 1.98 mW/K was determined.

Thermal Performance

A full characterization of the cooler thermal performance has been performed. The cooler performance has been measured for the warm side temperature range from -30°C to +60°C. The results from these tests are shown in Figure 4.

It can be seen that the LTP6510 cooler achieves its thermal performance specification at its nominal operating point with a 24% margin on cooling power. At low ambient temperatures the cooler input power is limited to 50W in order to not exceed the nominal piston stroke in the compressor.

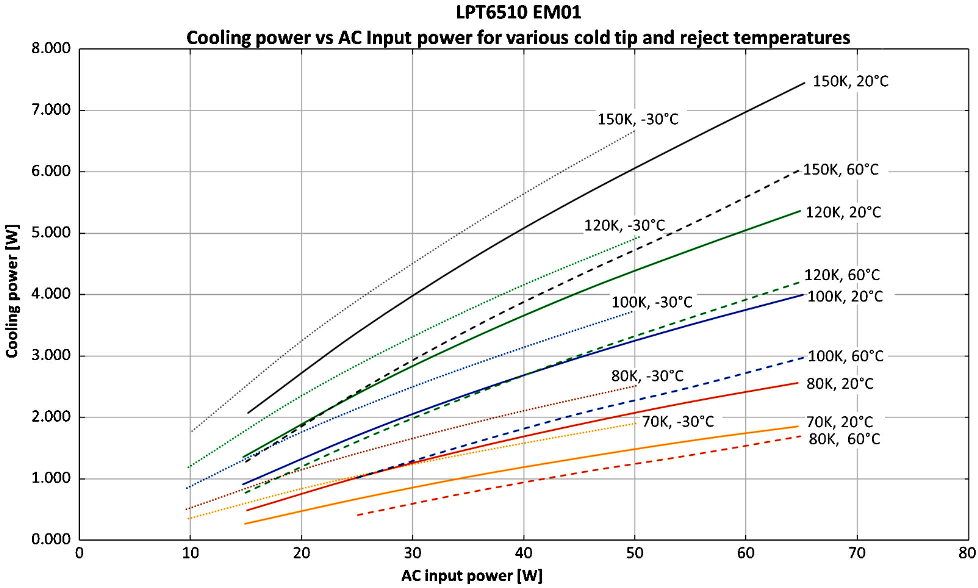


Figure 4. Heat-lift performance characterization results

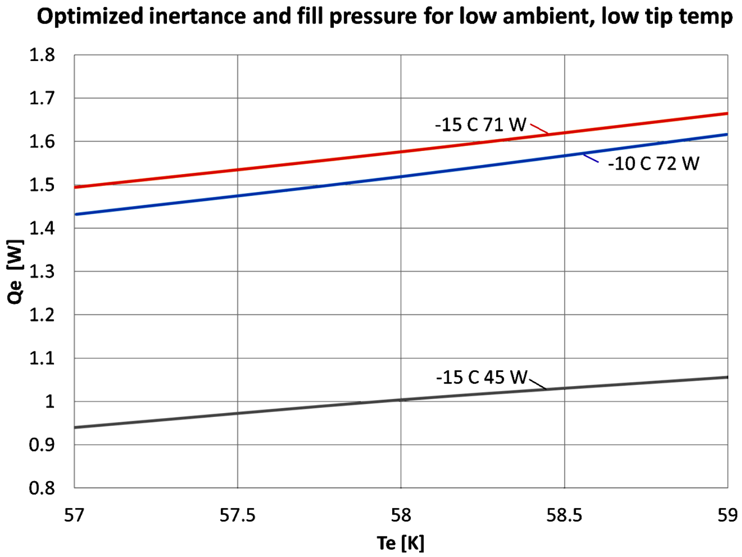


Figure 5. Optimization for low tip & skin temperature

As for specific applications use of the cooler below 60 K is foreseen, an optimization was performed for operation of the cooler at -15 °C baseplate temperature to allow larger input powers while maintaining efficiency. The phase shifter was re-optimized specifically, and fill pressure together with the driving frequency were increased. Test results can be seen in Figure 5.

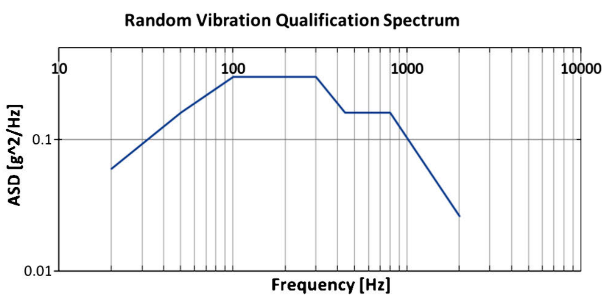
MECHANICAL LOADS

The cooler was subjected to a full mechanical test campaign in Thales Cryogenics environmental test laboratory (ETL). A random vibration spectrum was used that covers both the typical spectrum requested in ESA programs as well as the NASA GEVS qualification levels. For shock testing, a half-sine profile was used that approximates SRS levels required for previous flight programs Thales was involved in.

Static acceleration loads were not tested as these loads are fully covered by the sine vibration loads tested.

The following tests were performed:

- Random vibrations (see Figure 6), 3 minutes/axis, 15.5. Grms
- Half-sine shock of 1000g, 0.5 ms – one shock per axis
- Sine vibration, +/- 10 mm for 5-25 Hz, 25 g for 25-100 Hz, 2 octaves/minute



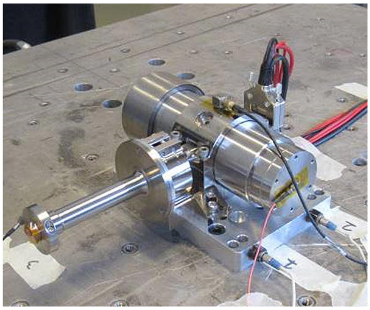


Figure 6. Applied random vibration spectrum (left) and shaker mount (right).

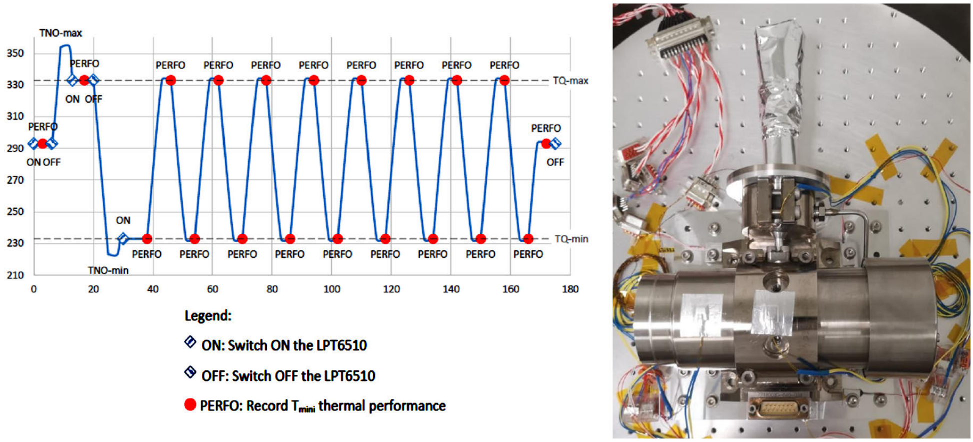


Figure 7. Applied thermal cycle (left) and vacuum chamber mounting (right).

All axes were tested, with the following notes:

- A 50-gram mass was mounted on the cold tip to represent the mass contribution of a thermal strap.
- No launch support used on the cold finger.
- The compressor motors were shorted during piston axis vibration to prevent the pistons hitting the end stops.
- All tests were performed with cooler non-operational (unpowered).

During initial random vibration testing, notching was applied to prevent damage. The full qualification levels without notch will be tested on the second engineering model cooler (EM02) that is currently being built. Low-level sine sweeps (signature runs) were performed before and after testing. Tests were completed successfully.

THERMAL VACUUM CYCLING

The cryocooler was subjected to thermal cycling at Absolut System as shown in Fig. 7. Due to space constraints inside the vacuum chamber used for testing, all tests were performed with the cold finger horizontal. A total of eight operating cycles were performed, with temperatures logged at several points on the cooler skin.

INDUCED VIBRATIONS

The induced vibrations generated by the cryocooler during operation have been analyzed. The exported vibrations have been measured using the in-house available dynamometer type Kistler 9255CQ, see Figure 8. In nominal operating conditions the exported vibrations did not exceed 0.53Nrms on the first

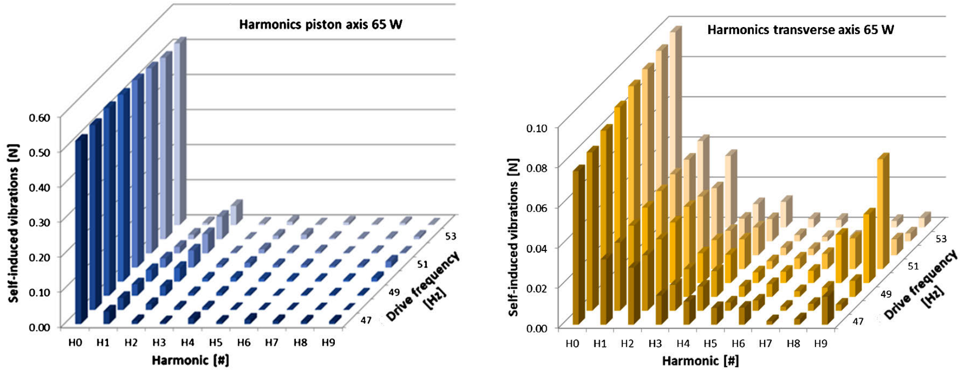


Figure 8. Exported vibration piston axis (middle), exported vibrations transverse axis (right).

harmonic in the compressor motion axis. Contributions of higher harmonics were not significant. Exported vibrations in transverse direction to compressor motion axis remained below 0.1Nrms. These results were obtained without the implementation of active vibration reduction control.

CONCLUSIONS AND FUTURE WORK

The LPT6510 test campaign has been completed successfully, and work is currently underway to perform a delta qualification for the low temperature working point shown in Figure 5, as this is needed for the first contract that has been awarded for the delivery of LPT6510 flight coolers and drive electronics. A second Engineering Model cooler (EM02) is currently being built using internal funds from Thales and Absolut System to support the delta qualification tests. The EM02 cooler will be placed in life time testing at Thales afterwards.

Steel Electronique (France) is currently developing space-qualified drive electronics specifically for use with the LPT6510 cryocooler, with a full qualification campaign on an EQM planned for 2021.

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