LPT6510 Pulse-tube Cooler for 60-150 K applications

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ABSTRACT

For a number of future instruments, such as the OCO-3 instrument, there is an anticipated need for a high-efficiency, small-scale pulse-tube cryocooler for the 60-150 K operating regime.

The LPT6510 cryocooler, based on the Thales Cryogenics MPTC compressor originally developed under ESA TRP and the Absolut System SSC80 pulse-tube cold finger, was designed to fill this niche in an elegant manner. In this paper, an update is given regarding the ongoing development on this cryocooler.

Key performance data as well as an overview of the MAIT processes as compared to the LPTC compressor heritage is shown. A novel new design for the buffer-inertance assembly will be presented. The presentation will conclude with a discussion on various integration aspects. This will include the heat sink and mounting design as well as the induced vibration characteristics of this cooler when operated with and without active vibration control

INTRODUCTION

The need for a compact pulse-tube cryocooler for 60-150 K space applications has long been anticipated, which resulted in the Thales MPTC compressor being developed under ESA funding [1]. Whereas the MPTC cooler developed under this ESA contract has to date not been used in satellite programs, a commercial spin-off has been produced as the Thales LPT9510 [2]. This cooler has subsequently been series-produced and is even regarded as a viable option for low-cost flight missions, such as [3]. This has resulted in attention from various parties interested in using the LPT9510 for low-cost flight programs [4, 5, 7].

However, when examining the performances of the LPT9510 it becomes apparent that the cooler was developed as a compromise between cost and efficiency. For space applications where power budgets are tight, a more efficient alternative is preferred.

Therefore Thales Cryogenics B.V. has partnered with Absolut System SAS to develop a designed-for-space, high efficiency pulse-tube cooler, based on the MPTC compressor developed under ESA funding (Figure 1), and the SSC80 pulse-tube developed originally for a high-efficiency terrestrial astronomy application (Figure 2).

Figure 1. MPTC compressor

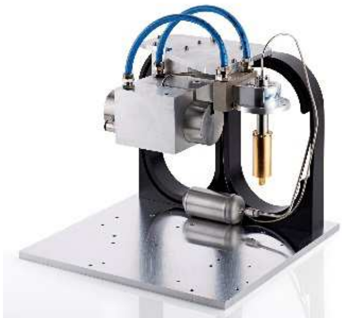

Figure 2. SSC80 pulse-tube for IPAG

DESIGN OUTLINE

Early on in the development a working point was defined for the cryocooler. As the development was not performed against a specific requirement, a generalized requirement was formulated. A working point of 100-110 K was initially targeted for optimization of efficiency, with a maximum heat lift of 3 W and a system mass below 3 kg. Exported vibrations should be in the 100 mN range for most satellite applications, with the use of active vibration reduction.

In order to determine design parameters various trade-off studies were performed. For the cryocooler compressor this resulted largely in the same choices as those initially made for the MPTC compressor: an aluminum center part, with Titanium alloy motor shells.

Another aspect of the trade-off was the position of the inertance tube and buffer volume of the pulse-tube cold finger. This resulted in a design where the inertance and buffer volume were integrated onto the compressor.

Finally, the choice was made to mount the cold finger directly onto the compressor, rather than using a transfer line in between. This has the advantage of eliminating an interface, as mechanical mounting and heat sinking can all be done through the aluminum center part of the compressor. Furthermore, removing the transfer line has an advantage on cryogenic performance.

For applications where positioning freedom of cold head with respect to compressor is required, a specific version with a transfer line can be produced. This is not needed in many space applications, as a thermal strap is typically used to connect the tip of the cold finger to the object to be cooled, providing freedom in positioning and mechanical isolation.

An artist impression of the proposed design can be seen in **Error! Reference source not found.**.

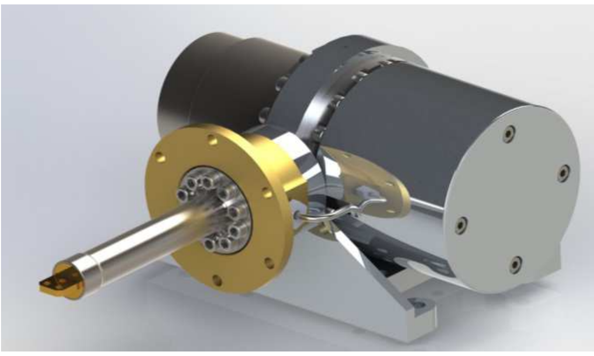

Figure 3. Artist impression of final system.

Figure 4. Demonstrator model.

BREADBOARD DEMONSTRATOR

In order to validate the design concept, a breadboard demonstrator model was built based on existing building blocks with minimal modifications. A photograph of this demonstrator can be seen in **Error! Reference source not found.**.

A test campaign was conducted to provide preliminary validation of all key performances. First of all, the heat lift and efficiency were tested. All performances obtained were measured with multi-layer insulation around the pulse-tube and heat sinking through the compressor baseplate. Results can be seen in Figure 5 and Figure 6.

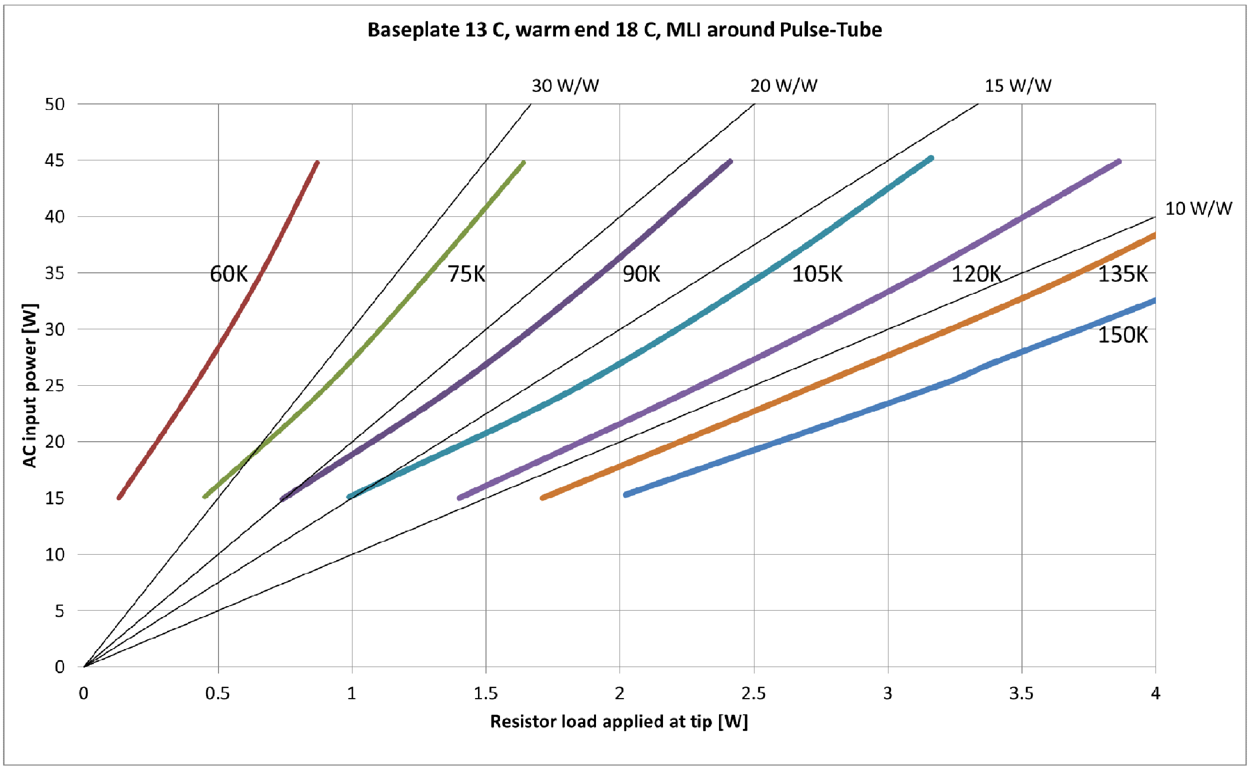

Figure 5: Heat lift at 13 C base plate temperature.

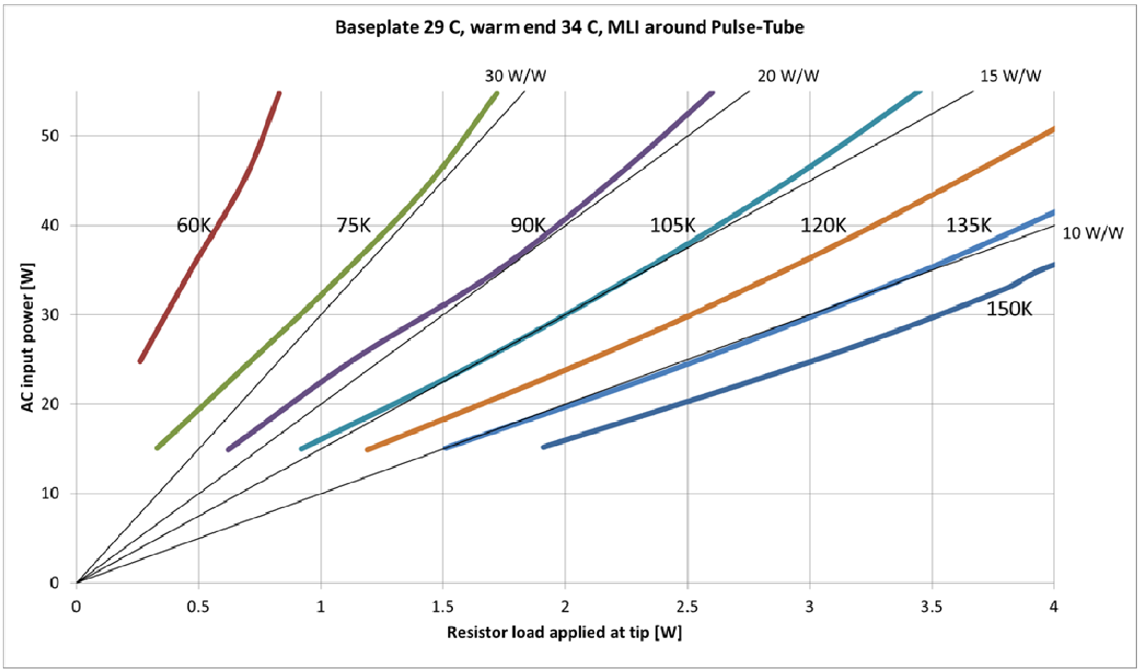

Figure 6: Heat lift at 29 C base plate temperature.

A well-known effect in pulse-tube coolers is the sensitivity of performance to the warm side temperature of the cold finger. As the heat sinking concept was changed compared to a standard split pulse-tube cooler, the temperature difference between compressor base plate and the pulse-tube warm side was measured. The test was done in a climate chamber at normal atmosphere, with the entire cooler wrapped in multi-layer insulation to ensure heat rejection through the base plate. The result can be seen in Figure 7. It can be seen that, even with a breadboard setup based on modified existing hardware, the thermal contact from cold head to compressor center part is sufficient to ensure a ΔT of 5 K at 45 W input to the cooler. In the final design it is expected that this still can be improved.

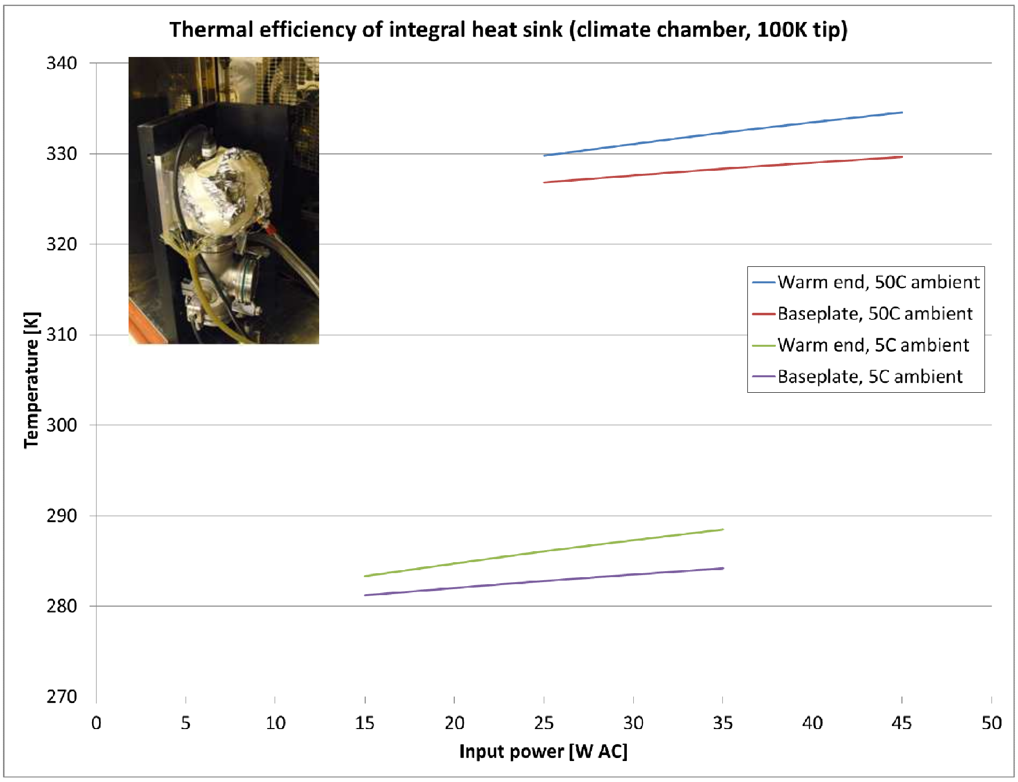

Figure 7. Efficiency of heat sinking through base plate

The final key requirement for any designed-for-space cryocooler is the exported vibration. As an initial characterization of the exported vibrations signature, the breadboard cooler was mounted in suspensions (springs) and fitted with a three-axis accelerometer. The vibration signature of the cooler was measured with a standard drive signal and with active vibration cancellation, in both cases using the Thales CDE7232 bench-top drive electronics. The measurement data can be seen in Figure 8 and Figure 9. It can be seen that using active vibration cancellation, the exported vibrations could be reduced well below 100 mN in the compressor piston axis. The vibrations exported in off-axis directions were in the 100 mN range.

As neither partner in the development of the LPT6510 currently has radiation-hardened space qualified drive electronics available, the compatibility of the LPT6510 breadboard with off-the-shelf radiation-hardened cooler drive electronics was assessed, by performing a functional test of the cooler when driven with the Iris HP-LCCE drive electronics [6]. The LPT6510 was successfully driven with both sets of electronics, the Thales bench-top CDE7232 and the Iris HP-LCCE brassboard model, with no special effort required to operate the cooler with the HP-LCCE.

As several minor changes are still planned for the final design, no environmental tests have yet been performed. However, the breadboard model is fully representative of the cryogenic performance of the final design.

CONCLUSION AND OUTLOOK

A number of minor design changes (parts and materials) are still required in order to bring the LPT6510 to true flight standard, but the base design as tested in the breadboard demonstrator shows good efficiency, low vibrations and a compact design convenient for system integrators.

Custom variants based on the base design as well as specific product qualification tests can be performed for specific requirements. Thales and Absolut invite feedback on the presented performances from all interested parties.

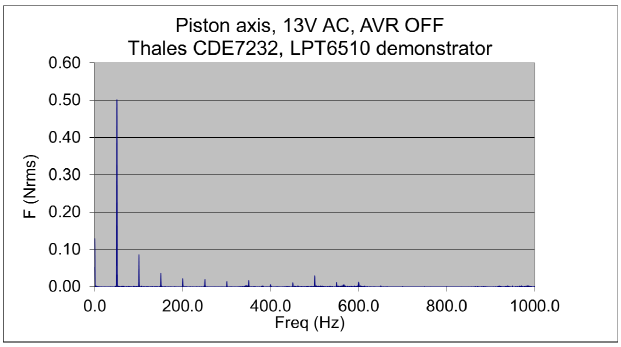

Figure 8. Exported vibrations (compressor axis), AVR OFF.

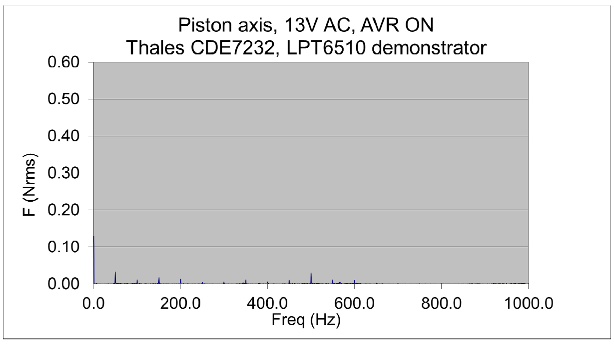

Figure 9. Exported vibrations (compressor axis), AVR ON.

ACKNOWLEDGEMENTS

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