A 30-50 K Dual-Stage Pulse Tube Space Cooler

P. Bruins, T. Prouvé[1], I. Charles[1], T.Trollier[2], J. Tanchon[2],
J.Mullié, T. Benschop.

Thales Cryogenics BV, 5626 DC, Eindhoven, NL
[1]Univ. Grenoble Alpes, CEA INAC-SBT, 38000 Grenoble, France
[2]Absolut System SAS, 38240 Meylan, France

ABSTRACT

A Technical Research Program (TRP) has been granted to the TCBV/CEA/AS consortium for the development, optimization and testing of a cryostat actively cooled by a 2-stage, high reliability pulse tube cryocooler. The interest in this concept is to allow the operation of detectors — for example QWIP or MCT infrared detectors — at lower temperatures (in the range of 35-40K) for an overall input power similar to that required by current Earth Observation programs.

The primary objective of the activity is to develop and manufacture a two-stage pulse tube cooler that is able to provide 350mW at 33K and 1200mW at 120K with 180W input, or 800mW at 40K and 1500mW at 130K with 160W input plus the load of one off cooler (redundant configuration). This cooler will make use of compressors previously developed for space applications by Thales Cryogenics.

The secondary objective of the TRP program is to perform a test of this cryocooler mounted into a breadboard 2-Stage cryostat in order to verify the ability to integrate such a system and to test 'in-situ' the cooling capabilities of the 2-Stage cryocooler.

The cryostat will be designed to provide adequate mechanical, thermal and electrical interfaces between the 2-stage cryocooler, the detector assembly, and the external structure. The key requirements that are likely to critically impact the assembly, integration and testability of the cryostat equipped with the cryocooler are discussed in this paper

INTRODUCTION

European developments in recent years have yielded coolers that meet Earth Observation requirements, and which are capable of providing more than ~3 W of cooling power at an operational temperature around 50 K [1]. Those single stage Stirling or pulse tube coolers have a no-load temperature around 30 K, with very limited cooling power available at 40 K, given reasonable rejection temperatures.

On the other hand, the trend of focal plane cooling requirements of Earth Observation is to aim either at higher cooling power at current temperature levels (around 50 K) due to the use of larger detector matrices, or to lower ultimate temperatures to limit dark current or to support the use of new types of detectors (e.g. QWIP, which needs to operate around 35-45K). This trend is not reasonably attainable with the currently available coolers developed for Earth Observation.

Cryocoolers 18, edited by S.D. Miller and R.G. Ross, Jr.
©International Cryocooler Conference, Inc., Boulder, CO, 2014

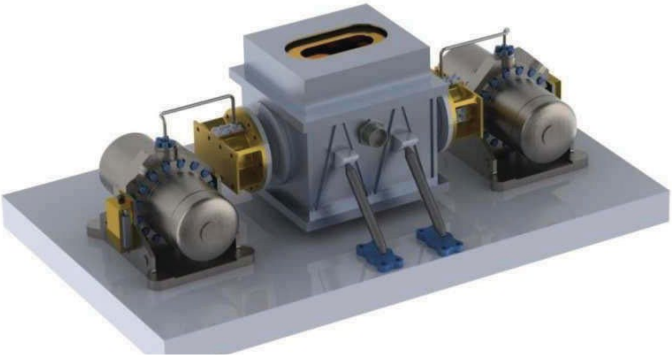

Figure 1. Conceptual design using 2 redundant 2-stage coaxial pulse tube coolers

To satisfy the trend, the proposed solution consists in using the current pulse tube and compressor technologies in a dual stage configuration. This solution makes the most use of existing technology building blocks (e.g. compressor), but requires mastering the design, manufacturing, and integration constraints linked to the use of dual stage cryocoolers used in cryostats.

Furthermore, the concept of the dual stage pulse tube enables optimization of the overall efficiency by making optimal use of the multistage cooling system. The higher temperature first stage can be used for shield cooling, or as an intercept for parasitic loads at a higher temperature, thus making more useful cooling power available at the low temperature.

CONCEPTUAL DESIGN

The program concerns the development, optimization, and testing of a cryostat actively cooled by a 2-Stage high reliability pulse tube cryocooler. The interest of this concept is to allow the operation of the detectors — for example QWIP or MCT infrared detectors — at lower temperatures, in the range of 35-40 K, for an overall input power similar to the one required by current Earth Observation programs. The cryostat will be designed to provide adequate mechanical, thermal and electrical interfaces between the 2-stage cryocooler, a redundant (off) cooler, the detector assembly and the external structure. The pulse tube cryocooler offers a 2-stage cold head configuration with a coaxial cold head, to facilitate a high level of integration. This is not currently the case for most 2-stage cold fingers, which commonly use a “U shape” geometry for the cold head. The target performance for the coaxial pulse tube cooler is 350mW at 33K and 1200mW at 120K (180W input) or 800mW at 40K and 1500mW at 130K (160W input) ; this level of performance corresponds to the performance of a cooler coupled with a second OFF cooler (cold redundancy).

Preliminary calculations show that a carefully designed cryostat with a cold shield at 100-130 K, should be able to use the available cooling power to cool the detectors down to 30-40K, and in parallel, cool the parasitic losses of the wiring, support structure, and redundant cooler.

CONSORTIUM

As the introduction describes, the development of the complete system requires close feedback between development of the 2-stage cryostat (which has its impact on the heat loads at the two stages), the pulse tube (which has its impact on the temperatures and heat loads and on

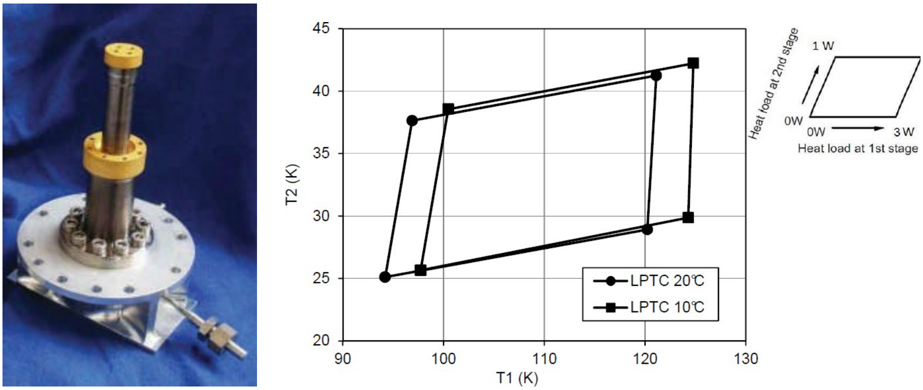

Figure 2. Baseline pulse tube configuration and available pulse tube performance.

the compressor resonance conditions), and the compressor (which has its impact on the overall efficiency). Furthermore, practical limitations have to be taken into account when manufacturing and integration aspects are considered.

Furthermore, the Earth Observation and Instrumentation groups in ESA see a possible need for the developed hardware in the near future. Even though the present program is a TRP program, there is a clear goal to develop a product with a high TRL level, with an inherit possibility of quickly qualifying the solution for an actual mission. The development should therefore be based on building blocks that already possess a high level of maturity.

ESA has therefore selected a consortium that has a proven track record in collaboration on cooler development and cryostat optimization. CEA/SBT are widely known for their involvement in cryocoolers and space cryogenics, and a number of these projects have been in collaboration with Thales Cryogenics BV (TCBV) and the engineers of Absolut System. Furthermore, industrialization of CEA/SBT designs has been performed for a number of TCBV commercial pulse tube coolers. Absolut System's engineers and experts have considerable experience in both cooler development, system engineering, and design of cryogenic thermal link systems for ESA and CNES research programs, as well as for other primes in the space business. For the present contract, the overlap of knowledge is used to create a strong peer review loop within the project team. Based on earlier experience, it is believed that the project will lead to an EM cooler which is quite close to a standard that can be qualified for later flight use.

Specific requirements for existing detectors and typical integration aspects will be discussed throughout the program with a number of selected primes to ensure that the resulting product will indeed meet the typical requirements of flight programs.

HERITAGE AND DEVELOPMENT APPROACH

Pulse Tube

As a starting point for the pulse tube development, a 2-stage pulse tube cold finger developed at CEA under R&T CNES contract N° 9382 will be used. Used in combination with the LPTC compressor, this 2-stage pulse tube has already demonstrated performance close to the requirement (Figure 2). Preliminary experiments are ongoing [4] to quantify the possible improvements on the first stage cooling power (heat intercept) and second stage temperature. In a double-stage pulse tube, there is always interaction between the two stages, since the gas flow follows the path of least resistance. A carefully planned breadboarding campaign is therefore foreseen to enable optimization of the pulse tube in a number of steps, and to allow mapping the effect on each of the two stages. Performing this mapping (including the possible reduction of the parasitic losses in off-state) in parallel with the cryostat optimization enables a trade-off that

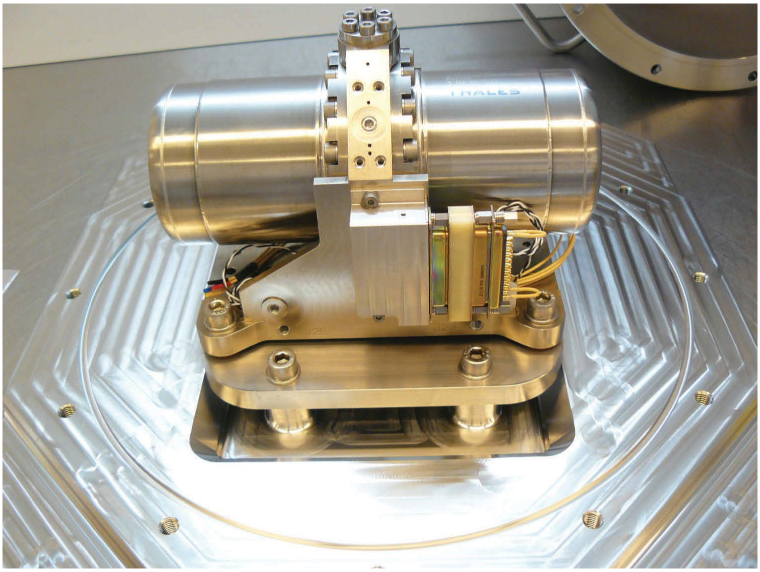

Figure 3. LPTC compressor.

will ultimately give the optimum overall cryogenic performance. In parallel with this, the pulse tube development will be done with a close look at the compressor resonance conditions as described in the next section.

Compressor

Thales Cryogenics BV (TCBV) have a range of space-qualified compressors. Based on the experience gained in the ESA Cryosystem program [2], a medium size MPTC and a large size LPTC compressor have been developed [1]. Presently, TCBV is working on the development of an even larger compressor in the frame of the ESA 15K TRP [3]. The MPTC and LPTC compressors have been qualified against the thermal and mechanical environment of ECSS-E-10-03A, and LPTC flight models are actually being built. The '15K' compressor is designed for a similar environment; its environmental test campaign is foreseen for Q1 2015.

Based on lifetime tests and extensive fatigue testing on the compressor flexures, analysis shows that the lifetime requirement of > 80.000 hrs with a reliability > 0.997 is met for these compressor types.

It is apparent from the various articles referenced here [1, 2, 3, 4], that the TCBV space compressors are the 'workhorses' for most of the European space cryogenics programs. One of the main reasons for their popularity is their modular design, which enables the compressors to be optimized to the requirements of the associated cold finger. The modular design enables limited optimization of the resonance conditions without invalidating heritage qualification results.

The selected baseline compressor for the 30-50K program is the LPTC compressor. The maximum swept volume is 7.5cc, and the compressor can deliver 110W of PV power to the pulse tube. Consistent with the requirement to retain qualification status where possible, the motor design, pressure containment characteristics (e.g. weld characteristics) and magnetic circuit are expected to stay the same. This leaves room for optimization of the piston diameter (and associated swept volume), moving mass, and filling pressure (albeit limited because of the qualification limits of the pressure vessel).

During pulse tube breadboard testing, a standard TCBV LPT9710 compressor will be used. This large compressor originates from a commercial pulse tube cooler (15 W at 80 K), and has a swept volume of 11.5 cc per piston. It is able to deliver up to 240 W of PV power, and it enables measurement of the piston stroke by means of an LVDT displacement transducer connected to a special port.

Because of the limits imposed by the LPTC compressor design, the pulse tube development should take the resonance conditions of the compressor into close consideration. The approach is to measure for each pulse tube breadboard configuration the performance at different drive frequencies and filling pressures. The results of these tests will be input for the compressor design. Since that design has the mentioned constraints, an analysis of the overall cooler analysis is required to be able to determine which of the breadboard concepts will be used as a basis for the detailed design phase.

Cryostat

The cryostat foreseen for this application shall converge most of the constraints surrounding the cryocooler integration. The critical points identified in this activity are mainly:

- Minimization of parasitic heat losses while offering a mechanical structure that is robust against launch loads. Extensive trade-offs will be performed in order to accommodate the two stage cooler cryogenic performance. The design studies will include the optimization of the structural characteristics of the cryostat housing, thermal shield, cold box, and struts for a given thermal budget considering the structural contribution of the cold fingers and redundant off cold finger parasitic heat losses. Coatings will be studied also to reduce the radiative thermal losses, and the thermal conductance will be optimized.
- Management of the residual induced vibrations from the cooler towards the cold box equipped with detectors. Dedicated thermal links will be studied taking into account the conductance, structural (mass, stiffness, etc..), induced vibration, assembly and integration constraints.
- Accessibility for assembly, integration and tests tasks taking into account the cleanliness constraints.
- Management of the thermo-mechanical aspects. These aspects are critical for optical performances. The position stability of the detector assembly will be analyzed and quantified during the thermal and mechanical design of the cryostat.
- Thermal control of the detector's interfaces. Besides the fact the cryostat to be developed will be equipped with dummy detectors, temperature stability of the detector's interface will be experienced during the thermal test campaign of the cryostat.

ACKNOWLEDGMENT

The work described here will be performed under a program of and funded by the European Space Agency. It should be noted that the views expressed in this article can in no way be taken to reflect the official opinion of the European Space Agency.

REFERENCES

1. Trollier T., Tanchon J., Buquet J., Ravex A.T. "Status of Air Liquide Space Pulse Tube Cryocoolers," *Cryocoolers 15*, ICC Press, Boulder, CO (2009), pp. 115-123.
2. Trollier T., Ravex A., Crespi P., Mullié J., Bruins P., Benschop T., "High capacity flexure bearing stirling cryocooler on-board the ISS," *Cryocoolers 12*, Kluwer Academic/Plenum Publishers, New York (2003), pp. 31-35.
3. Duval J.M., Charles, I., Butterworth J., Mullié J., Linder M., "7K-15K Pulse tube cooler for space," *Cryocoolers 17*, ICC Press, Boulder, CO (2012), pp. 17-23.
4. Charles I., Prouvé T., Ercolani E., Daniel C., "Thermal testing of an EM two stage coaxial pulse tube for Earth observation missions," *Cryocoolers 18*, ICC Press, Boulder, CO (2014), (this proceedings).