Progress on 30K-50K Two-Stage EM PT Cold Finger for Space Applications

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ABSTRACT

Within the framework of an ESA Technology and Research Program lead by TCBV, and in collaboration with Absolut System, CEA/SBT has improved the performance and the TRL level of the two-stage coaxial pulse tube developed at CEA/SBT in 2012 under a R&T program co-funded by CNES.

The developments presented in this paper are focused on the thermal performance of the second stage and involve breadboarding of regenerator materials and examining alternateve phase shifting inertance designs and a double inlet (V2) implementation. The EM mechanical developments have been focused on the pulse tube warm flange with electrical feedthrough, an optional double-inlet V2 implementation, and the flange sealing assembly. The TCBV compressor (180 W electrical power) is integrating design improvements from the LPTC cryocooler for which TCBV is currently manufacturing MTG compressor flight models.

Without the double-inlet V2 design, the no-load temperatures of the two-stage pulse tube are expected to be 86 K and 22 K, respectively, at first and second stage. With a load of 3W-1W, temperatures will rise to 111 K and 36.7 K. With the double-inlet V2, the no-load temperature will drop to 81 K and 21 K at first and second stage. With a load of 3W-1W, these expected temperatures will rise to 107 K and 36 K.

After environmental qualification, the cryocooler will be mounted in a breadboard cryostat devoted to infrared Earth observation and developed by Absolut System in the framework of this TRP program. The cryocooler and the cryostat design are made in close collaboration in order to demonstrate interest in such a 2-stage configuration for demanding Earth observation missions.

INTRODUCTION

There has been a trend towards increasing heat loads for cryogenically-cooled Earth Observation instruments in recent years. This is the case at both the current operational temperature levels (~50K), as well as at lower operational temperature levels (30-50K). One solution to meet this trend is to use existing pulse tube technology in a double stage configuration. By doing so, it is possible to intercept parasitic loads at higher temperatures,

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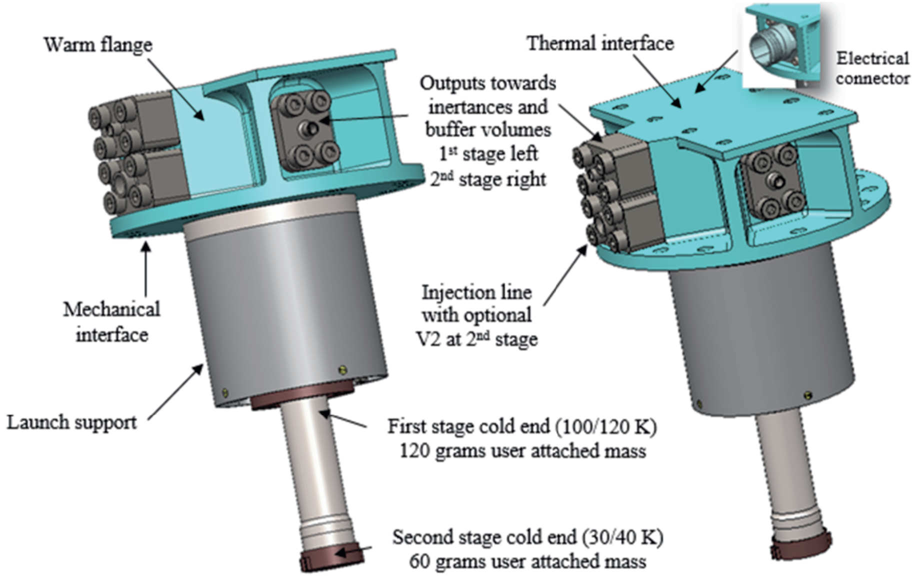

Figure 1. General view of the ESA EM CFA

thereby reducing the thermal load at the lower temperature stage, and making cooling power available at lower temperatures.

The TRP requirements of the 30K-50K pulse tube cooler are given as user loads and include the cold redundant parasitic heat losses. There are two specifications, and both have been updated with CEA parasitics heat losses values. The second specification has been updated to match the thermal budget of the test cryostat built by Absolut System [4]. The two specifications are:

1. The 2-Stage 30-50 K PT cooler shall provide 636 mW at 33 K and 2740 mW at 120 K simultaneously with max 180 W rms input power to the compressor motors and at a rejection temperature of 20°C.
2. The 2-Stage 30-50 K PT cooler shall provide 1080 mW at 42 K and 2730 mW at 126 K simultaneously with max 160 W rms input power to the compressor motors and at a rejection temperature of 20°C.

COLD FINGER ASSEMBLY (CFA) GENERAL OVERVIEW

Mechanical Design

A general view of the coaxial two stage EM cold finger is represented in Figure 1. This design is based on the CNES EM cold finger [1,3]. The warm flange has increased in height to implement an electrical connector, metallic seals, and the optional V2 assembly. The cold tips have been equipped with sensor location areas. The second stage thermo-mechanical interface has been redesigned. The CNES model has mechanical and thermal interfaces made by a disc surface and 4xM2.5 threaded holes. The ESA EM interface is the outer annular surface of the second stage cold tip. This surface is larger than the CNES model, and it enables the use of constriction clamping devices for a strap connection which has been developed by Absolut System [4]. The second stage cold tip still has 2xM2.5 threaded holes which can be used to attach heaters during ground tests. Thermal and mechanical analyses have been done to validate the design, and PA/QA at the ESA EM level has been carried out. The Cold Finger Assembly (CFA) can support 120 grams at the first stage and 60 grams at the second stage under vibration environments of SIN 25g and random 13.1g rms (20-2000 Hz with 0.3 g^2/Hz 100-300 Hz).

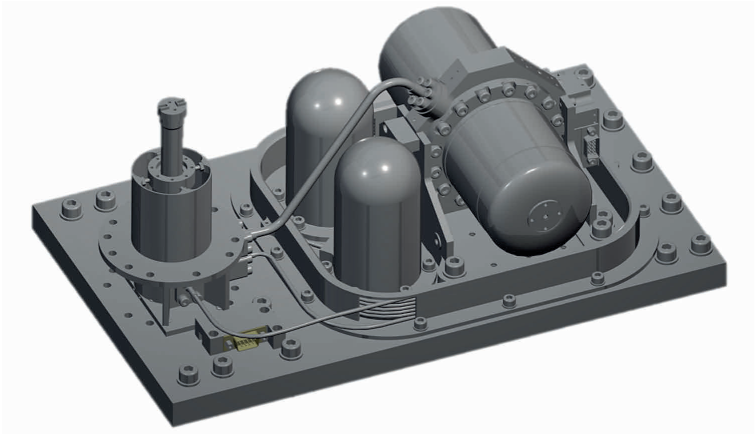

Figure 2. Overview of the complete ESA 30K-50K 2 stage EM pulse tube cryocooler mounted on testing support structure - TCBV design.

2nd Stage Regenerator and Phase Shifting

The second stage regenerator packing material has been optimized during the breadboard phase for operating temperatures of 30K-40K. The phase shifting at the first and second stage is "initially" achieved by inertance and buffer volumes. Along with TCBV, the operating frequency, the filling pressure, and inertance winding shape have been studied and tuned for meeting the best cryogenic performance and EM integration. Figure 2 gives an overview of the complete cryocooler. Inertances are wound into a square shape and placed around the compressor assembly and buffer volumes. An integrated double inlet (V2 assembly) has been designed and will be potentially implemented during the characterization phase in between the split-pipe and second stage inertance. The V2 assembly will be placed on the CFA in the split-pipe / inertance 2nd stage flanges.

Compressor and Supporting Structure

The TCBV compressor assembly (CPA) (180W electrical power) integrates design improvements in the framework of this TRP and has heritage from the LPTC cryocooler, from which TCBV is currently manufacturing the MTG compressor flight models. CEA/TCBV have decided to use a support structure, as shown in Figure 2, to assemble, characterize the cryocooler (to TRL 5) and to make the coupling with the dedicated Absolut System cryostat at a later time. This support structure has been designed by TCBV. The structure has openings to give direct access to the CFA and CPA thermal interfaces for heat rejection. The CFA mechanical supports connecting to the round circular CFA mechanical interface are not shown in Figure 2.

BREADBOARD PHASE ON THE CFA

The improvement of the CFA is a direct result of findings of tests performed on a U-shaped DM pulse tube, a dismountable coaxial pulse tube, and on the CNES EM CFA. The DM coaxial CFA has a dismountable heat exchanger at the second stage cold end. This CFA is identical to the CNES EM except for the dismountable second stage cold heat exchanger, and the fact that the copper heat exchangers were not gold plated. Since MLI is being used on the CFA in place of the gold plating, the measured parasitic heat losses should be equivalent, and we expect reliable results from the ESA EM CFA. To test the two stage cold fingers we measure the temperatures at four thermal-equilibrium points with first/second stage applied powers of 0 W / 0 W, 0 W / 1 W, 3 W / 1 W, 3 W / 0 W. Intermediate performance values are then interpolated in between these points to yield what we call "square measurements."

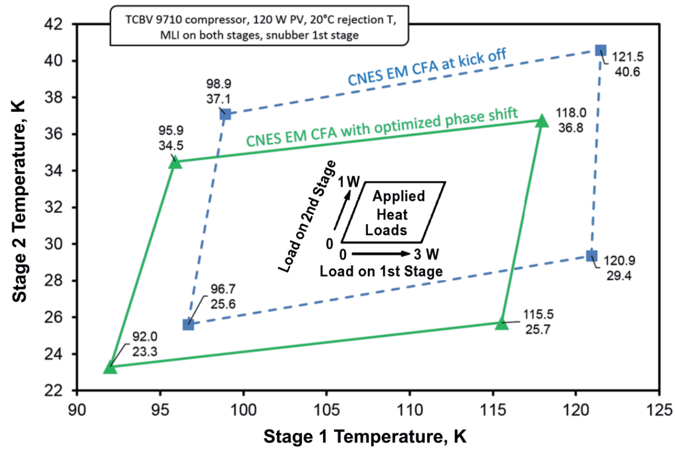

Figure 3. CFA phase shifting optimization (Loading pressure, operating frequency, inertance winding shape).

Phase Shifting

Figure 3 shows the performance obtained with the CNES EM CFA during the TRP program. A significant improvement is seen in the ultimate temperatures and load conditions. The optimization is done by running the cooler at 59.5 Hz and 34 bar (compared to 57.5 Hz and 30 bar for the CNES EM) and also by changing the winding diameter of the inertances.

The phase shifting adjustment on the CFA was optimized further by the use of a double inlet on the second stage pulse tube. This was investigated by using a V2 orifice between the split-pipe inlet and the second stage inertance inlet on the warm flange. The CFA design was made such that the two flanges are on top of each other's. Figure 4 indicates the best results obtained so far with an "EM-like" V2 orifice and operating conditions / inertance shape depicted in the previous paragraph. It is clear from Figure 4 that the second stage V2 orifice improves the first stage significantly by about 5 K at each measurement point. The gain at the second stage is less significant with a decrease of 0.7 K in the cold temperatures, but the inertance length was not optimized for this case. Nevertheless, the measurements were stable over many hours, and the thermal performance using a V2 orifice was reproducible. This clear improvement is why the second stage V2 orifice has been selected as an option on the ESA EM CFA.

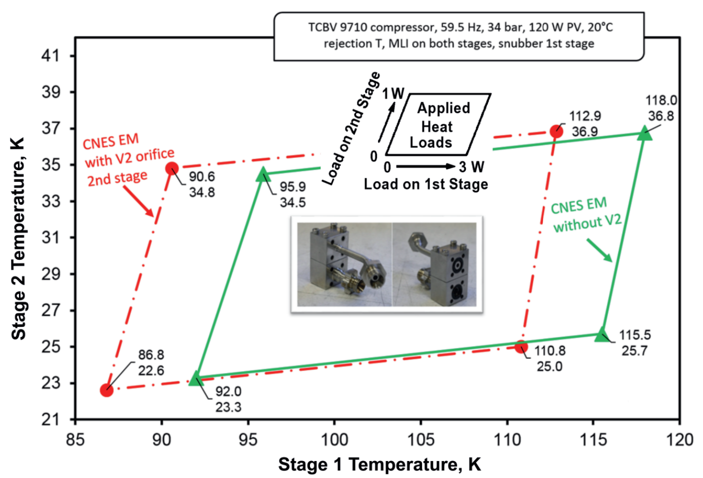

Figure 4. Measured performance gain on CNES EM using a V2 phase shifter.

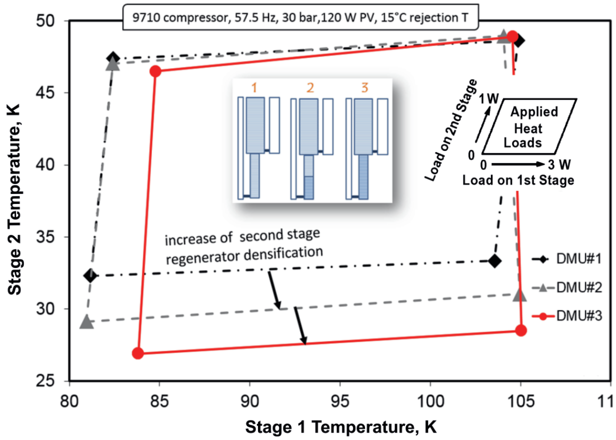

Figure 5. Effect of second stage regenerator densification on a 2 stages coaxial pulse tube

Regenerator Grading

Among the initial requirements of the TRP that have been reworked by Absolut System to fulfill the needs of the associated cryostat under development, the second stage cooling power was identified to be the most critical factor to achieving these updated requirements. Consequently, the regenerator packing study focused on the second stage. Tests were performed on the U-shape CFA first, and the results are presented in Figure 5. Three configurations were tested. Starting (DMU#1) with the same 2nd stage regenerator packing as the CNES EM CFA, the density of the regenerator was increased in its coldest part. It is clear that the U-shape CFA second stage (32 K ultimate) did not perform as well as the CNES EM CFA (25.6 K ultimate) at no load [1]. With that in mind, it was observed that increasing the density of the second stage regenerator lowered the no-load temperature of the second stage by about 5 K. However, it did not increase the cooling capacity at 1 W. Similar tests were then performed with the DM coax CFA and the gain was reduced by 2.5 K. The lower gain was attributed to the lower starting operating temperature of 25 K for this configuration. The impact of increasing the regenerator density on the DM coax CFA was nevertheless the same as on the U-shape CFA.

Assembly Process

The CNES EM regenerator configuration was tested on the DM coax and a drastic difference in the first stage thermal performance was measured. Figure 6 gives the results of the

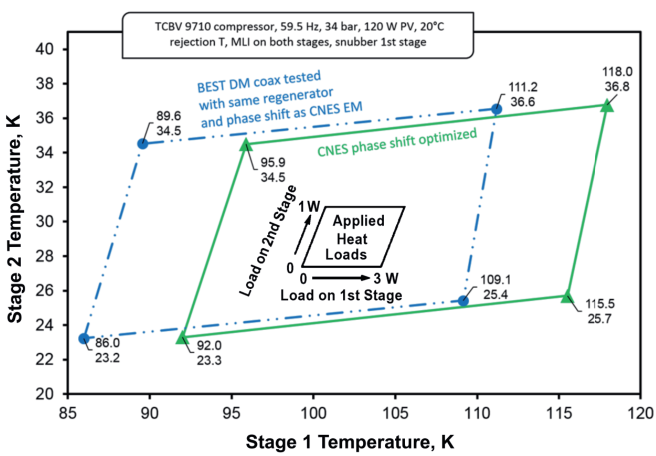

Figure 6. Performance discrepancies between CNES EM and DM coax probably to assembly process.

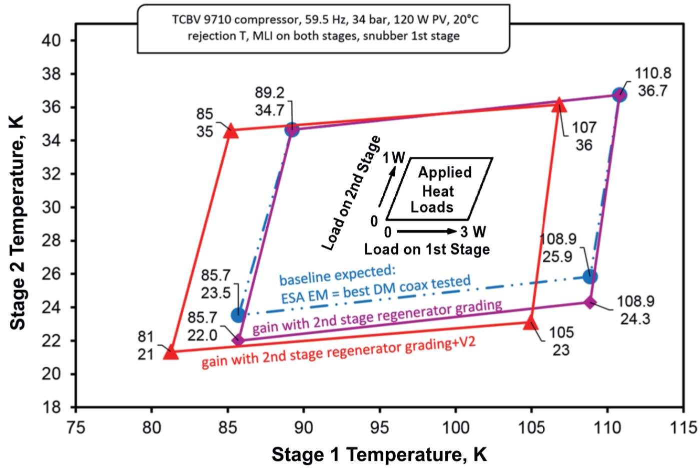

Figure 7. Expected ESA EM CFA performances with optimized phase shift, V2, 2nd stage regenerator grading and DM coax assembly process.

measurements. At the four set points the gain in first stage temperature is about 7 K, and the second stage has an equivalent temperature to the CNES EM. The assembly process of the DM coax was slightly different from the CNES EM. The ESA EM CFA design will have the same assembly process as the DM coax.

EXPECTED PERFORMANCES FOR THE ESA EM CFA

As a result of the improvements made during the breadboard phase activity, some predictions can be made regarding the expected performance of the ESA CFA that is currently being manufactured. Figure 7 gives the detail of the expected cooling capacity of the CFA with the different options that will be implemented in it. The CFA being built is expected to be at least as good as the DM coax version made during the breadboard phase. Then a grading in the regenerator packing at the second stage will be implemented which is expected to lower the ultimate temperature of the second stage as much as was seen on the DM coax, since the CFA has the same range of cold temperature at the second stage. Finally, a double inlet assembly at the second stage will be implemented that is expected to improve the first stage cooling capacity and will continue to lower the ultimate temperature of the second stage close to 20 K.

Parasitic Heat Losses

Parasitic heat losses have been studied in a cold redundant method with the CNES EM CFA and the coax DM CFA. Figure 8 shows the test bed using the coax DM cooler to cool down the OFF CNES EM cooler. The coolers are placed into the test bed cryostat that is used to characterize the cooler. This cryostat has an aluminum warm flange thermalized at 20°C and the coolers are surrounded by a 20°C copper shield thermalized on the vacuum side of the warm flange. The parasitic heat loss values are given for 15 layers of MLI at the first and second stage. The coolers are operating in a vertical (cold tips down) position. In this test configuration the OFF thermal loads of the CFA at 120K/40K are:

- 1.275 W at the first stage heat exchanger
- 0.26 W at the second stage heat exchanger

CONCLUSION

Progress on improving the CFA performance within the framework of this TRP is summarized in Figure 9. Phase shift has been a large focus of this study, since it improves the

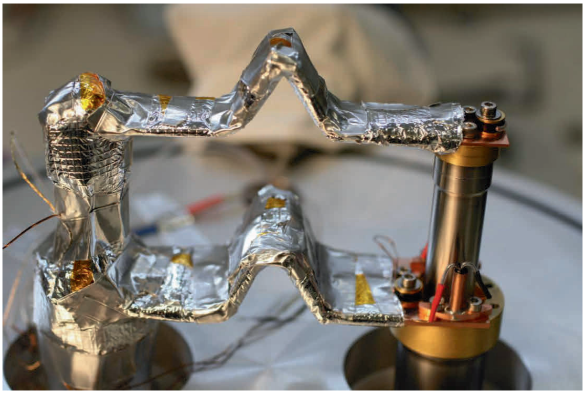

Figure 8. Cold redundant parasitic heat losses test bench. Left: coax DM cooler ON , Right: CNES EM cooler OFF.

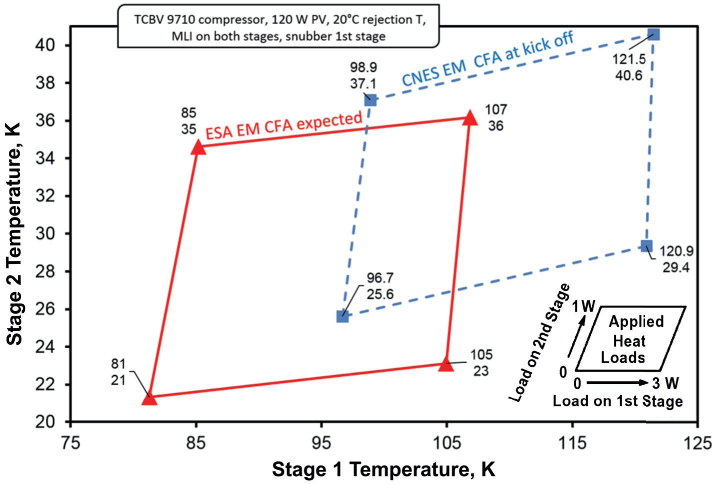

Figure 9. Comparisons between CNES EM and future expected ESA EM CFA.

cooling performances of the CFA at all operating conditions. The double inlet has given good results versus thermal stability and reproducibility. Coupled to that, regenerator optimization has shown the possibility for this CFA to achieve lower temperatures. The regenerator was not optimized further, since the TRP specifications are above 600 mW at the second stage, and the focus was on increased cooling capacity rather than targeting lower temperatures. The 15 K-20 K temperature range should be achievable at the second stage with a passive phase shift and using a specific regenerator packing.

Due to expected TCBV compressor efficiency improvements, we are confident in achieving the TRP requirements presented in the introduction of this paper and are looking forward to demonstrating the feasability of such a cooling solution into the Absolut System flight-like cryostat in the near future.

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