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AIR LIQUIDE's SPACE PULSE TUBE CRYOCOOLER SYSTEMS

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ABSTRACT

Thanks to important development efforts completed with ESA funding, Air Liquide Advanced Technology Division (AL/DTA), is now in position to propose two Pulse Tube cooler systems in the 40-80K temperature range for coming Earth Observation missions such as Meteosat Third Generation (MTG), SIFTI, etc…
The Miniature Pulse Tube Cooler (MPTC) is lifting up to 2.47W@80K with 50W compressor input power and 10°C rejection temperature. The weight is 2.8 kg. The Large Pulse Tube Cooler (LPTC) is providing 2.3W@50K for 160W input power and 10°C rejection temperature. This product is weighing 5.1 kg. The two pulse tube coolers thermo-mechanical units are qualified against environmental constraints as per ECSS-E-30.
They are both using dual opposed pistons flexure bearing compressor with moving magnet linear motors in order to ensure very high lifetime.
The associated Cooler Drive Electronics is also an important aspect specifically regarding the active control of the cooler thermo-mechanical unit during the launch phase and the active reduction of the vibrations induced by the compressor (partly supported by the French Agency CNES).
This paper details the presentation of the two Pulse Tube Coolers together with the Cooler Drive Electronics aspects.

1. INTRODUCTION

Following its important cryogenics heritage for the European Space industry for both ARIANE launcher program and Orbital Systems (180K high speed turbo-brayton MELFI on-board the ISS since July 2006, 100mK dilution cooler for PLANCK High Frequency Instrument and HERSCHEL helium tanks and thermal links), AL/DTA is proposing a complete cryocooler system based on a pulse tube cryocoolers range and a dedicated CDE for earth Observations missions.
The cryocoolers are all featuring a splited coaxial pulse tube cold finger connected to a dual opposed pistons flexure bearing compressor with moving magnet type linear motors.

2. MINIATURE PULSE TUBE COOLER - MPTC

The coaxial version of the Miniature Pulse Tube Cooler (Fig. 1) has been developed during the last two years[(1),(2)]. A batch of 3 cold fingers has been manufactured with a high quality level based on Air Liquide Standard Flight Procedures. Today, one MPTC unit is currently running in lifetime test at constant input power since August 2007. The amount of accumulated running hours as per July 2008 is 8050 hours without any degradation of the cold tip temperature. Engineering Model optimization and performance tests have been done to answer request for quote for the ESA Sentinel-3 mission (one of Low Earth Orbiting elements of Global Monitoring for Environment and Security) which responds to the requirements for operational and near-real-time monitoring of ocean, land and ice surfaces over a period of 15 to 20 years.

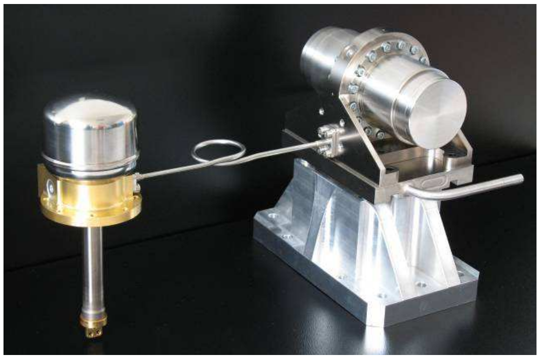

Fig. 1. EQM MPTC cold finger and compressor

This cryocooler has been optimized for 50W input power to the compressor motors. The cryogenic performances of the advanced MPTC are reported bellow:

- Cooling capacity: 2,48W @ 80K (or 1,6W @ 70K)
- Rejection temperature: 288K for both compressor and pulse tube warm end
- Compressor input power: 50 Wrms

The advanced MPTC performance mapping for various input powers and cold tip temperatures for 288K heat sinking conditions is presented in Fig. 2 hereafter. Cooler self-induced vibrations characterization of the MPTC EQM cooler is reported in the Fig. 3. As shown, the cold head self-induced vibrations have been measured bellow 70mN in all axes and in all directions. The RMS value is far bellow 0.1 N all along the bandwidth required in this program (0-300Hz).

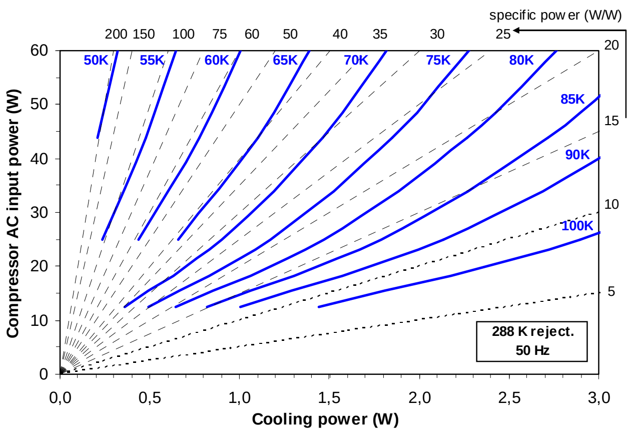

Fig. 2. EQM MPTC cold finger and compressor

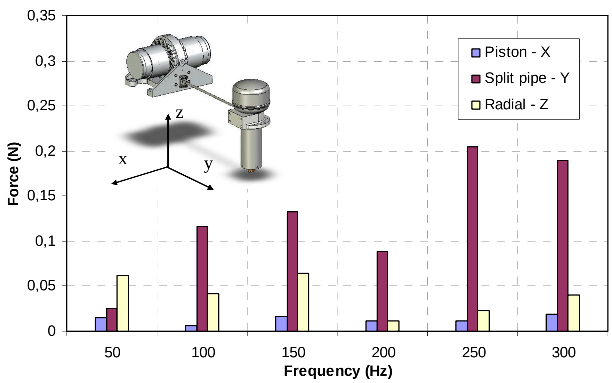

Fig. 3. EQM MPTC self induced forces at compressor interface - 50Wac input - 80K

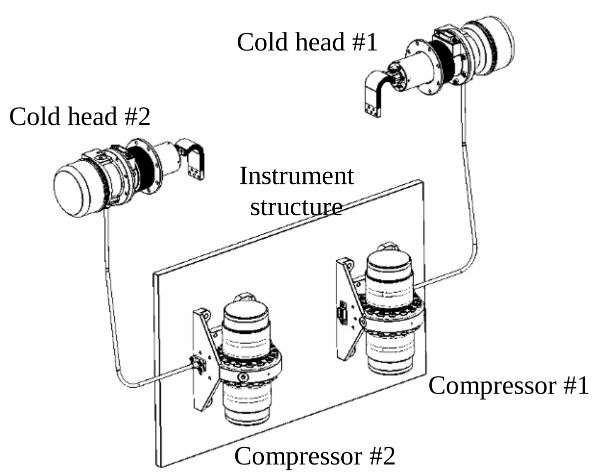

Fig. 4. MPTC redundant architecture integration

An example of two MPTCs thermo-mechanical units in cold redundancy is attached in the Fig. 4, both cold fingers equipped with their thermal flexible link.

3. LARGE PULSE TUBE COOLER - LPTC

The successful development of the Miniature Pulse Tube Cooler MPTC was driven by the need to cool detectors arrays at 80 K. In the meantime, there is a need for Earth Observation to cool Thermal Infrared detectors below 60K. At these temperatures, the cooling power of the MPTC, or the space qualified 50-80K Stirling cooler from EADS-Astrium UK Ltd, is marginal or not sufficient. In order to provide European coolers for the temperature range of 40-60 K, a large heat lift Pulse Tube Cooler LPTC is required in addition to the MPTC.
An Engineering Model (EM) of the LPTC has been designed, manufactured and tested in partnership with AL/DTA, CEA/SBT and THALES Cryogenics BV in the framework of ESA/ESTEC contract 18433/04/NL/AR[3]. The EM (S/N001) performances were 2,3W cooling power lifted at 50K with 160W electrical input power to the compressor and 283K temperature rejection[3]. The EM was successfully tested to thermal and mechanical loads at qualification and duration levels.

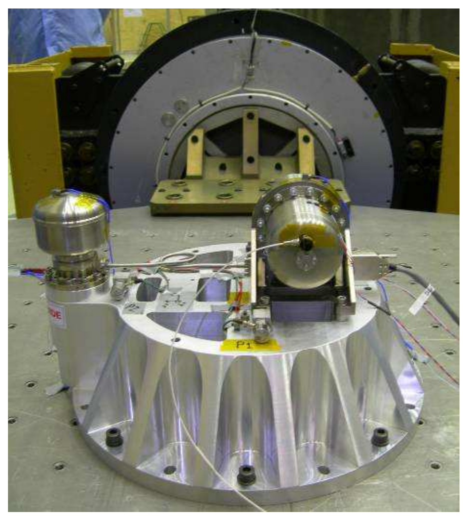

Fig. 5. EM S/N001 installed on the shaker

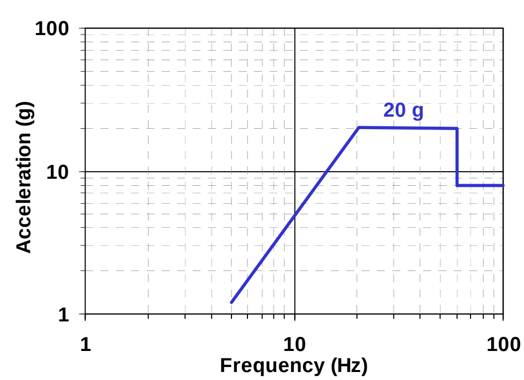

Fig. 6. sinus load qualification profile

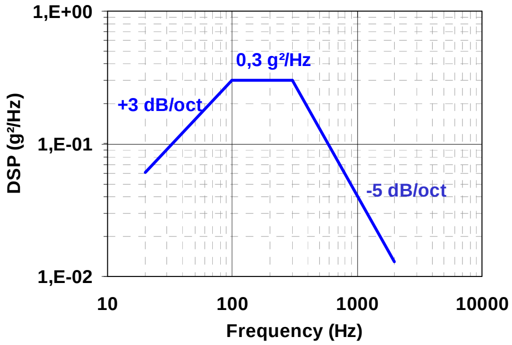

Fig. 7. random load qualification profile

Both LPTC and MPTC products are qualified against mechanical load profiles attached in the Fig. 6 (sinus load) and Fig. 7 (random load) for all axes. Beside that, the LPTC have been also submitted to stringent shock profile as par spectra attached in the Fig. 8 below.

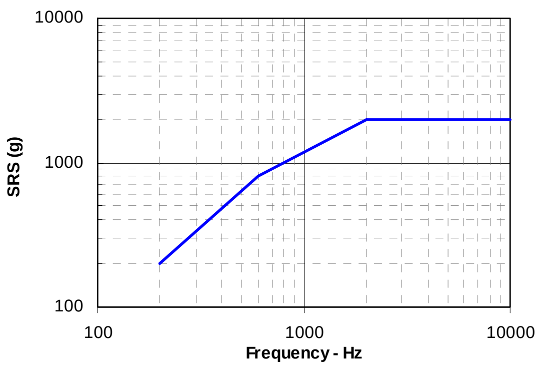

Fig. 8. shock load qualification profile

Fig. 9. LPTC S/N001 during shock test.

Currently, four Engineering Qualification Models (EQM) are under production for various projects and an illustration of the EQM S/N002 is attached in the Fig. 10 together with its integration on a cryostat mock-up at Thales Alenia Space premises (Fig. 11).

Beside cryogenic performance tests, the output forces of the LPTC EQM S/N002 have been measured on a dedicated test bench placed on a seismic block. The output forces at the compressor and cold finger warm end interfaces are measured separately on 3 axis over 1 kHz bandwidth in cryogenic operation and with controlled temperature interfaces (chilled water). The output force profile measured on the compressor piston axis (driving axis) is reported in the Fig. 12 for 80W ac input power applied on each of the compressor coil (160W total compressor).

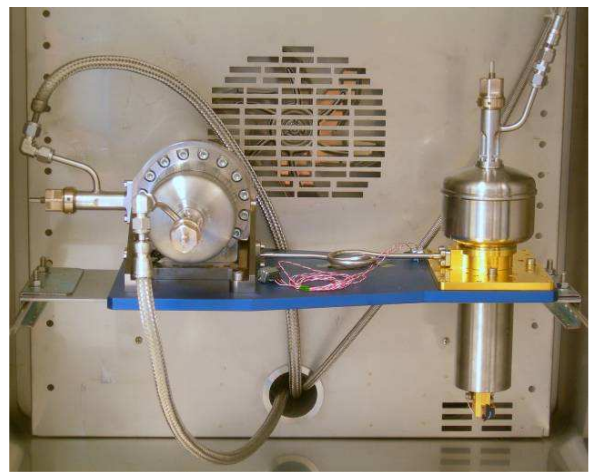

Fig. 10. EQM LPTC S/N002 during curing/filling process

Fig. 11. EQM LPTC S/N002 integrated on a cryostat mock-up (courtesy of ThalesAlenia Space)

At the fundamental driving frequency, the output force is measured at less than 0.6N and all other harmonic levels are measured below 0.25N up to 1 kHz. The Fig. 12 illustrates also the Cooler Drive electronic (CDE) capability to reduce the output force levels once activated. The two coils of the compressor are then supplied separately (Master & Slave) with input voltage controlled over the fundamental and 7 harmonics. As shown, the output force level is drastically reduced over the controlled frequency bandwidth. For the fundamental, the level is reduced down to 25 mN. Notice that for frequency above 400 Hz, the level is not changed with and without active vibration control because the limited frequency harmonics contained in the control signal.

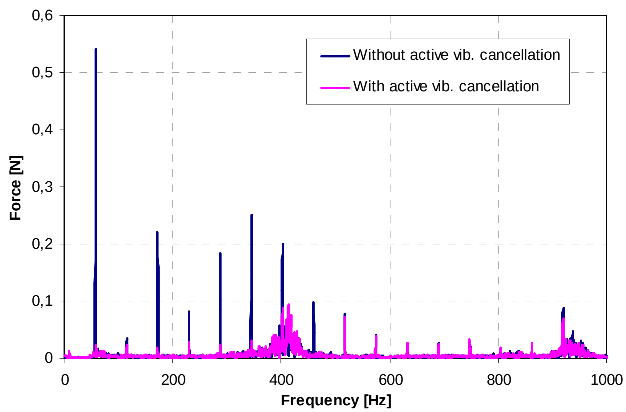

Fig. 12. EQM LPTC S/N002 self induced forces at compressor interface – 160 Wac input – 50K

4. COOLER DRIVE ELECTRONIC - CDE

The architecture of the CDE developed by Air Liquide in partnership with CAEN Aerospace is composed of three separated boards that implement the following functions:

- The DC/DC converter board,
- The power board,
- The control board.

4.1 DC/DC converter board

This board is directly connected to primary power bus and provides DC voltages required by all other blocks inside CDE. It hosts the EMI filter, a Boost pre-regulator and a Push-Pull isolated DC/DC converter. A couple of thermistors, placed at the hottest point of the board, provides temperature telemetry to the satellite, together with power bus supply current and voltage TMs. Analog telemetry proportional to main DC/DC converter output voltage is also provided. CDE primary power bus voltage conditioning is implemented by a DC/DC converter board that houses the following functional blocks.

- EMI input filter to cope with conducted emissions and susceptibility EMC requirements.
- Boost pre-regulator stage. This block acts as an active filter that shall attenuate below specified limits the low frequency sinusoidal current components absorbed by class D amplifiers driving compressor coils.
- Push pull converter. This block is an isolated DC/DC converter that provides all DC voltages to the other blocks inside CDE.
- Two temperature sensors, one to be interfaced with satellite nominal side and one with satellite redundant side, will be used to monitor the temperature in the hottest point of the board (near primary switching MOSFets and PWM controller).
- Power consumption monitor. Two analog telemetries (one for input voltage and one for input current) will be provided in order to monitor CDE power consumption. Since these signals shall be galvanically isolated from power lines, a linear optocoupler will be used to transfer the signal.

Input overcurrent/short-circuit protections are usually provided by instrument via an external 5A Latching Current Limiter.

4.2 power board

This board (Fig. 13) houses two identical and independent Class-D amplifiers that are used to drive respectively Master coil and Slave coil (used for vibration reduction). Two couples of temperature monitors are sent to satellite TM in order to switch off the unit in case of failure that generates an increasing of power dissipation. Each amplifier provides one output voltage monitor that is an attenuated replica of the output voltage and one current monitor providing the replica of the output current. An additional thermistor for each amplifier, together with output voltage and current monitors, are sent to an analog protection circuit that switch-off both amplifiers in case over current, over voltage, over temperature, or output current mismatch between master and slave failure conditions. A flag with the relevant fault condition is sent to the control board in order to communicate the type of failure that has occurred to the instrument.

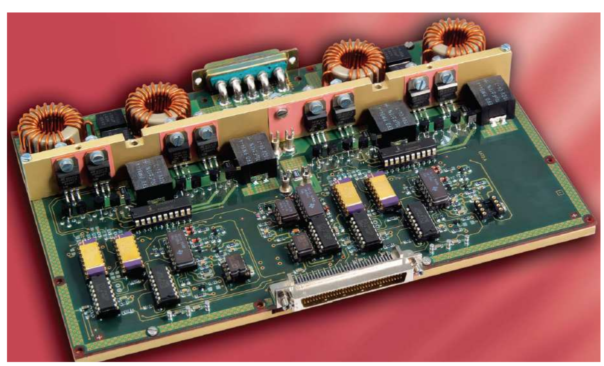

Fig. 13. EM power board of the CDE

4.3 control board

This board contains a FPGA for temperature control, ADCs control and sinusoidal signals generation, ADCs and MUXs (and relative signals conditioning circuits) for external and internal sensors readout and for CDE input and output voltages readout and a RAM for acquired parameters storage. In particular the Processing Unit provides the following features:

- Sinusoidal signals generation for both Master and Slave,
- Acquisition of the force transducer sensors (load washers),
- Acquisition of external thermal sensors,
- Acquisition of output signals voltage and current,
- Cold-tip temperature control loop,
- Vibration Reduction Control,
- Communication to external instrument I/F via RS-422 interface,
- Management of direct digital lines from/to CPE,
- Management of Synchronization signals from instrument,
- Management of EQSOL lines from satellite IF.

The reasons leading to prefer the FPGA solution are summarized below:

- Components number: the large Front End interface for the needed sensors/controls should require the utilization of a companion small FPGA also in case of a micro-programmed solutions (plus an external SRAM to store its run time program and data).
- Effective re-programmability requirements: since the control board is targeted for only a specific application, the complete system re-programmability is not really required.
- Multi treads issues: the problem to be afforded is composed of several tasks to be accomplished in parallel. The single task does not present a large numeric complexity, but the need to keep the synchronism among all of them is the major challenge of this application.

5. CONCLUSIONS

Air Liquide's MPTC and LPTC Pulse Tube Coolers, including their CDE with vibration cancellation, are now available for Earth Observation applications. These two products represent clearly a technology enhancement and integration advantages compared to the former Stirling technology used in the past mainly in Europe.
A third cooler product is under development in partnership with CEA/SBT to provide 15-20 K pulse tube pre-cooling stage in alternative to two stage Stirling coolers.

6. REFERENCES

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