The construction and space qualification of the control electronics for the tracker detector cooling system of the AMS-02 experiment

Mauro Menichelli[1], Lucio Accardo[1], Gabriele Alberti[1], Michiel Bardet[2], Roberto Battiston[1], Sandor Blasko[1], Zhenghui He[3], Vladimir Koutsenko[4], Alexei Lebedev[4], Jiangqun Ni[3], Andrea Papi[1], Aswin Pauw[2] , J. Van Ess[2], Zixin Wang[3], Dong Zhang[3], Teun Zwartbol[2].

[1] INFN Sezione di Perugia Via Pascoli s.n.c. 06100 Perugia, Italy.
[2] NLR National Aerospace Laboratory, NLR, NL-8300 AD Emmeloord, The Netherlands
[3] SYSU Sun Yat-sen University, Guangzhou, 510275, China
[4] MIT Massachusetts Institute of Technology, Cambridge, MA 02139, USA

The tracker cooling system and its EGSE

The AMS-02 Tracker Thermal Control System (TTCS) is a carbon dioxide two-phase cooling system developed by NIKHEF (The Netherlands), Geneva University (Suisse), INFN Perugia (Italy), Sun Yat Sen University Guangzhou (China) and NLR (The Netherlands). Its objective is to provide accurate temperature control of AMS Tracker front-end electronics. The two-phase loop incorporates a long evaporator, picking up the heat from the front end electronics cards in the six silicon planes located inside and just outside the AMS-02 superconducting magnet. The heat is transported to a condenser connected to a heat pipe radiator. The liquid is transported back to the evaporator by means of a mechanical pump. The temperature on the fluid is stabilized by an accumulator. A total of 144 Watt is produced at 192 front-end cards and an additional 6-10 Watt cooling capacity is required for additional electronics.
The thermal design challenges of the TTCS for ASM-02 are:

- Compatibility with the existing Tracker Hardware.
- Limited volume.
- Multiple and widely distributed heat inputs up to 160 W.
- Minimal temperature gradients of less then 1°C
- Low mass budget < 72.9 kg, low power budget < 80 watt.
- High reliability i.e. fully redundant system design.
- Two radiators thermally out of phase.

Those challenges are meet in the design shown schematically in the cooling system general schematics (Fig.1).

The tracker cooling system may be viewed as a set of different sensors and actuators which are necessary for bringing the tracker detector to a uniform temperature at which it can operate properly. The sensors include: Pt1000 thermistors, semiconductor thermal sensors, differential and absolute pressure sensors, and pump rotational speed sensors. The actuators are: resistive heaters, Peltier heat pumps and liquid pumps. In order to test the TTCS control electronics (TTCE) and to emulate the TTCS behavior we developed an Electronic
The EGSE (fig.2 and 3) simulate the behaviour of all sensors and actuators in the TTCS. This means that it must generate the same signals from the electrical point of view but also its global behaviour, namely the response to any internal and external condition change should be the same as the actual tracker cooling system. In order to achieve this performance appropriate software that includes the simulated response of the tracker cooling system have been developed.

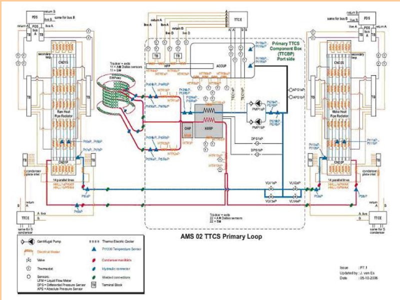


Fig.1 The TTCS


Fig.2 EGSE crate 1


Fig.3 EGSE crate 2

The tracker cooling control electronics

The tracker cooling system described above includes various sensors and actuators. The sensors include: Pt1000 thermistors, semiconductor thermal sensors, differential and absolute pressure sensors, and pump rotational speed sensors. The actuators are: resistive heaters, peltier heat pumps, and liquid pumps. Since the pumps are essential elements of the loops they are dual redundant in each loop.
The electronic control system TTCE (Tracker Thermal Control Electronics) is included in a crate that contains two redundant independent control systems, A and B. Each system is connected to both the primary and secondary loops, so each individual control system can control each loop.
The crate contains 5 boards:
The TTEC A board which contains the interface electronics for the slow control system of the experiment, the thermal sensor readout (both semiconductor sensors and the Pt1000 sensors), the basic logical functions, and the safeguard logic (fig.4).
The TTEC B board (same as A)
The TTEP A board contains circuits for generating local supplies from the primary 28V and the power conversion and switch circuits for the heaters and peltier heat pump (fig.5).
The TTEP B board (same as A)
The TTPP board that includes the pump and pressure sensor interface for subsystems A and B (fig.6)

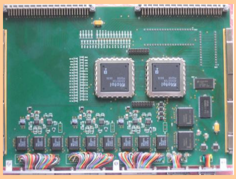


Fig. 4 The TTEC

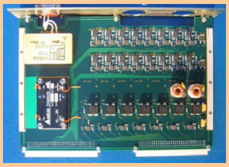


Fig. 5 The TTEP

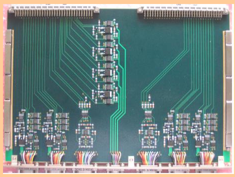


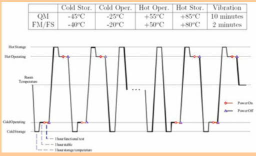
Fig. 6 The TTPP

The Qualification tests

The boards will be produced in three phases:
EM (Engineering Model): will be used for functional tests and preliminary tests of the loop
QM (Qualification Model): will be used for qualification tests, namely Environmental Stress Screening, Thermo-mechanical testing, Thermo-vacuum test and EMI/EMC tests
FM/FS (Flight/Spare Model): will be used for flight after some acceptance test.

In order not to stress the Flight Model Board QM test specifications are more severe and complete compared to the same tests that the FM should undergo. The tests for QM boards are the following:
Board level ESS
Thermo mechanical test
Thermo Vacuum test
EMI/EMC test

For FM we make the first three test (not the EMI/EMC) with reduced stress levels.
Board level ESS is performed cycling boards between –45 °C and 85°C for 10 cycles one hour each temperature at power off(For FM/FS temperatures are: -40 °C, +80 °C).
The thermo mechanical stress it is composed of three phases. The first phase is a thermal cycling test in air with the scheme presented in fig. 7 with 10 intermediate thermal cycles. The second phase includes a vibration test lasting 10 minutes (2 for FM/FS) for each vibration axe the vibration spectrum is shown in fig. 8. The third phase repeats phase one with 5 intermediate cycles.
Thermo vacuum test profile is shown in fig. 9 for QM (For FM/FS temperatures are the same as in the thermo mechanical test)
EMI/EMC tests include conducted susceptibility: CS01, CS02, CS06, conducted emissions: CE01, CE03, Radiated susceptibility: RS02: RS03: and radiated emissions: RE02. Figure 10 shows the outoput of a RE02 test performed using QM.



	Cold Stor.	Cold Oper.	Hot Oper.	Hot Stor.	Vibration
QM	-45°C	-25°C	+55°C	+85°C	10 minutes
FM/FS	-40°C	-20°C	+50°C	+80°C	2 minutes

Fig. 7 Thermal cycling scheme of the ESS the table shows the values both for the QM phase and for the FM/FS acceptance test

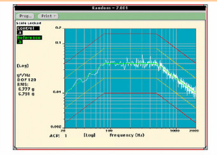


Fig. 8 Random vibration spectrum at which the TTCE crate will be tested

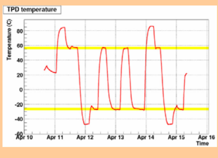


Fig. 9 Thermo-vacuum TEST cycles.

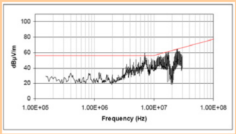


Fig.10 Low frequency RE-02 EMI test