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The S.E.R.M.S. laboratory

a research and test facility for space payloads and instrumentation

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Abstract. The SERMS laboratory is a joint facility of the Perugia University and the Italian Institute for Nuclear Physics (INFN) established in 1995 to provide engineering support in the design and test of scientific instruments for space. Located in the Engineering Faculty of the Perugia University premises in Terni, SERMS takes advantage of a lively research environment hosting graduate and PhD students within academical training programs. In the following we will give a general overview of the SERMS facility and briefly review past experiences in the field of mechanical and thermal design and test.

Key words. Instrumentation for Space, Environmental testing

1. Introduction

Space is a harsh environment where systems are subject to accelerated ageing due to the large variety of mechanical and thermal stresses experienced in the launch phase and in orbit, as well as to the continuous irradiation by ionizing cosmic particles. At the same time, any human intervention to repair system failures is hardly ever possible: full reliability is therefore a mandatory requirement for any instrument to be operated in space.

Careful design and a detailed thermal and mechanical stress analysis of a device are among the key points to reach its full reliability. Extensive experimental campaigns are also usually applied to test the system functionality in the expected environmental conditions and to verify the mechanical/thermal behavior of the instrument.

Quite a large experience in the design and the qualification tests of space instruments has been gained at SERMS during the last ten years while providing a constant support to scientific payloads for space as GLAST (2008), LAZIO-SIRAD (2008) and AMS (2008). All activities are managed according to ISO-9001:2000 standard rules, SERMS being a certified laboratory since 2006.

In the following, after a general overview of the SERMS facility, we will present some examples of the qualification campaign carried at SERMS in the last three years on different sub-systems of the AMS experiment.

2. The laboratory

A panoramic view of the SERMS main building interiors is shown in Fig.1. The central part of the ∼ 500 m^2 hangar surface is occupied by the vibration laboratory. An electrodynamic

Fig. 1. The SERMS laboratory overview

shaker connected to a $2 \times 2\, m^2$ slipping table allows to perform dynamical tests within a frequency range between 5 Hz and 3000 Hz for a maximum applied force of 80 KN. Up to 100 accelerometers and 128 strain gauges can be used to monitor in real time and to record for further analysis the response of the device under test. The area in front of the vibration laboratory is free of permanent structures to allow the handling of cumbersome objects to be tested: a 12.5 tons crane allows their moving from the hangar entrance to the vibration area. Ground floor offices and the clean area for thermal tests are located on opposite sides with respect to the vibration table, respectively on the right and on the left of Fig.1.

Two interconnected clean rooms insure the proper handling of electronics and instrumentation undergoing to thermal tests in vacuum. A space simulator suitable for the test of small size satellites and instruments to be qualified in absence of atmosphere is located in the first clean room (class M6.5, $4 \times 5 \times 3.5$ m^3). As shown in Fig.2, the space simulator consists in a thermo-vacuum cylindrical chamber, 2100 mm length and 2100 mm inner diameter, where a pressure of 10^{-7} mbar can be reached in empty chamber conditions. Temperature is controlled in the range [-70°C, +125°C] and monitored within the chamber volume with PT100 thermal sensors. Using conductive and/or radiative coupling, it is possible to cycle the item under test within a temperature range comparable to that expected for the instrument during its operating life. Up to 64 PT100 and 128 strain gages can be used to continuously record temperature and mechanical stresses on the devices under test.

Thermal tests at ambient pressure can be carried in three thermal chambers located either in front of the clean area or in the second clean room (class M5.5, $4 \times 4 \times 3.5$ m^3) if needed. Thermal gradients of $1.5, 2, 15$°C/min can be applied in the different chambers within volumes of 1-2 m^3 along a temperature range of $-70, +180$°C. The thermal chambers are also used for thermal tests in vacuum of small sized objects, as electronic boards: the device under test is put in a pressure tight container inside the chamber and an external turbomolecular vacuum pump is used to reach the desired vacuum level.

Fig. 2. The Space Simulator

3. AMS-02 qualification at SERMS

The AMS-02 instrument is a magnetic spectrometer conceived to search for the faint traces of primordial anti-matter and dark matter within the cosmic ray flux. It has been designed to be operated in space for a minimum of three years on the International Space Station, with a 51,7° inclined orbit at a 400 km altitude. A schematic view of the Alpha Magnetic Spectrometer (AMS-02) is presented in Fig.3. A superconducting magnet embed-

Table 1. Summary of Qualification Test on AMS-02 instrument performed at SERMS. Numbers reported in parenthesis represent the number of Qualification (QM) or Flight (FM) model tested units.

AMS Component		Vibration	Thermal	Thermo-vacuum
Subdetectors:	L-TOF / U-TOF	Y	-	Y
	ECAL	Y	-	Y
	Magnet VC	Y	-	-
Electronics :	Tracker (× 9 QM + 9 FM)	-	-	Y
	TTCE 1 QM + 1 FM	Y	Y	Y
	TOF 5 QM + 5 FM	-	-	Y
	ECAL 1 QM + 9 FM	Y	-	Y
	TRD 2 QM	Y	Y	Y
	TRD-GAS system 2 QM + 2 FM	Y	Y	Y

ding a high resolution tracker made of ~ $6.4m^2$ of silicon microstrip sensors is the core of the instrument. Four approximately circular planes of plastic scintillator paddles with a sensitive area of 1.2 m^2 each are placed in pairs above (U-TOF) and below (L-TOF) the tracking core. They constitute the Time of Flight system, performing the velocity measurement and triggering on charged particle traversing the apparatus. A redundant and more accurate measurement of particle velocity is performed by a Ring Imaging CHerenkov detector (RICH). A Transition Radiation Detector (TRD) and a 3-D imaging electromagnetic calorimeter (ECAL) allow discrimination between the electromagnetic (e^+/e^-) and hadronic ($p, \bar{p}$) components of cosmic rays. Nearly 200.000 electronic channels are needed to readout the detector signals: the control and readout electronics is organized in ~ 60 crates placed on radiator panels on the external parts of the apparatus in order to dissipate in deep space ~ 2kW of power. With an acceptance of ~ 0.5 m^2 sr and a magnetic field of 0.8 T the AMS instrument is the largest and most complex spectrometer ever built to be operated in space.

A full qualification campaign has been carried out on each subsystem in order to verify its functionality under the foreseen operational conditions as well as to validate the mechanical/thermal design. The AMS-02 integration is currently on going in a clean room at the CERN laboratory (2008) and a thermal-vacuum test of the full operating detector in the ESTEC ESA facility at Norwijk will finally conclude the qualification of the instrument. The SERMS facility has played a key role in the process, being the laboratory where most of the subdetectors, the mechanical support of the magnet and all the electronic crates have undergone to mechanical and/or thermal tests. SERMS engineers, in collaboration with Carlo Gavazzi Space (CGS), are studying the conditions and preparing the procedures for the ESTEC test and are in charge for the test data analysis and the AMS thermal model update.

In table 1 the test activities carried on at SERMS on the AMS instrument subsystems are summarized: in the following just few examples of the performed tests will be given.

3.1. The AMS-02 magnet vibration test

The AMS magnet system, schematically represented in Fig.4 (left), is shaped as a short cylinder (inner diameter 1.1 m, external diameter 2.7 m, total weight ~ 2300 Kg) with the useful field generated perpendicular to the axis Blau et al. (2002). A pair of large racetrack coils will provide ~ 70% of the dipole field

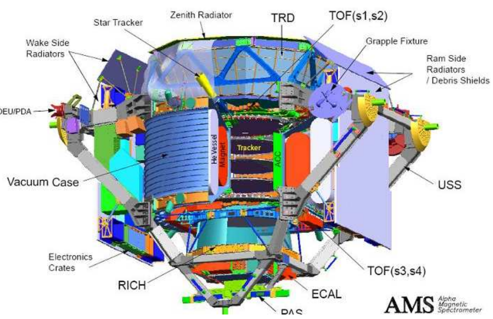

Fig. 3. Schematic view of the AMS experiment

Fig. 4. Left: Schematic drawing of the AMS Magnet. Center: The Stress Test Article mounted on the SERMS slip table. Right: Registered force on one strap as a function of time during the x-axis vibration test.

in the bore, whereas two series of six smaller racetrack coils contribute the rest of the field reducing the stray field outside the system. All superconducting coils are situated inside a vacuum tank and operated at 1.8K with superfluid helium contained in a 2500 l storage vessel. Magnetic and inertial loads were carefully taken into account in the design of the system structure. The coil structure forms a circular ring with all the magnetic loads reacted internally, whereas inertial loads on ground and in the launch phase are taken from four points on the coil structures via 16 tension ties (straps) to the vacuum tank. The strap design is fairly complicated to minimize the heat conduction between the ambient temperature vacuum vessel and the magnet at 1.8K: the final validation of the strap design has been performed at SERMS with a dedicated test to measure their characteristic response to mechanical vibrations when mounted in a truthful replica of the AMS system, the Stress Test Article (STA).

Test design and procedures were under NASA responsibility in cooperation with Jacobs Sverdrup, Scientific Magnetics and SERMS with a three years period elapsed from the first facility survey to the successful accomplishment of the test in February 2007. The setup and test operations at SERMS were lasting nearly four months.

The STA, assembled in the Space Magnetics Oxford laboratories, consisted in a mass load, equivalent to the magnet coils, located inside the flight spare model of the vacuum tank and connected to the vacuum tank via 16 straps as in the final magnet system configuration. Strain gauges and accelerometers were located along the straps before sealing the system. After shipping to SERMS, the STA was fitted into a mechanical fixture expressly designed for the test. The STA inserted in the test fixture (the grey aluminium frame) is shown in Fig.4 (center) after positioning on the slip table before vibration in the horizontal x-axis. Connection to the shaker head is achieved by means of the blue transition frame via a spherical joint.

Purpose of the test was to measure the non linear response of the support strap to a known applied force in order to verify the FEM analysis at the basis of the system design. Vibration runs at frequencies [5-20] Hz with acceleration levels spanning from 0.05 up to 0.16 g were performed along the three orthogonal directions (z along the cylinder axis, x-y in the horizontal plane). The full time history of the induced accelerations and stresses on straps and on $\sim$ 80 measuring channels disposed on the straps, the fixture frame and vacuum tank exterior was recorded. In Fig.4 (right) an example of the recorded force as a function of time, i.e. at increasing frequency value, on strap # 5 is shown during the 0.16 g test along the x-axis.

3.2. The AMS-02 Time of Flight TVT

The L-TOF/U-TOF thermal control concept is based upon passive rejection of heat. The scintillator paddles, readout at both ends by Hamamatsu R5946 Photo Multipliers Tubes, are enclosed within a carbon fiber box. The heat is generated inside the PMTs electron-

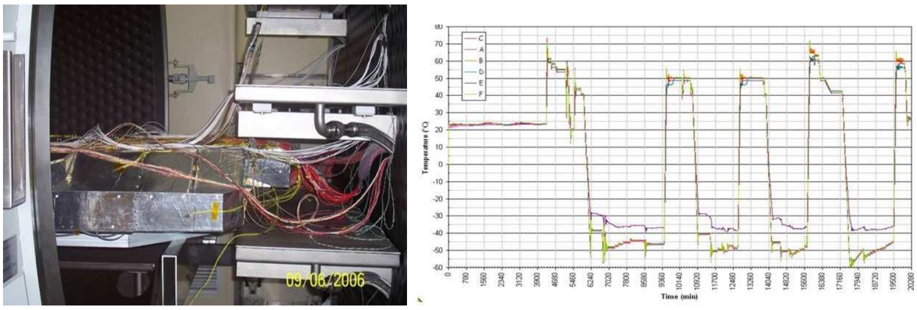

Fig. 5. Left: The L-TOF detectors positioned in the space simulator. Right: The measured temperature profile by the chamber sensors along the L-TOF test

ics, conducted and radiated to the carbon fiber box and in turn radiated to the external environment. 120 VDC heaters and thermostats are needed for the L-TOF to keep electronics above the minimum non-operative temperature when TOF is switched off and/or bring electronics to the minimum switch-on temperature during coldest environmental temperature. Four thermo-vacuum cycles have been performed on the L-TOF/U-TOF systems in order to verify the internal thermal design (conductive and radiative links within the flight unit) in hot and cold conditions. At the same time the heater power budget, the thermostats performances and the functionality of the detector at the extreme temperatures were tested. The L-TOF has been thermally coupled to the shroud of the TVC only by radiation, as this will be the typical heat transfer during flight conditions. This was achieved by supporting the detector inside the TVC by means of 4 insulating feet put on the chamber rails, as can be appreciated from the photo of the L-TOF inside the TVC shown in Fig.5 (left). During the test, temperatures close to the PMT shields have been monitored both by the 16 Dallas Sensors which will be used during the flight and by 14 PT100 sensors to verify the correct calibration of the flight sensors. Monitoring of the thermal conditions during the test was completed by 44 and 13 PT100 sensors placed respectively on the exterior of the detector and on the TVC surfaces. As an example the temperature readout in different TVC locations is shown as a function of time in Fig.5 (right).

4. Conclusions

The SERMS facility is a good example of a laboratory where design and theoretical analysis of structures can be validated with experimental measurements and qualification tests. The close contacts of the laboratory with major industrial and research institutions during the AMS qualification process has allowed a professional training of the personnel in a collaborative effort towards a major scientific objective. In this contribution we could only briefly review some of the SERMS past activities, we would then conclude by inviting the readers to directly experience our facility (2008).

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