CHEOPS SOLAR CELL ASSEMBLIES LIFE TEST

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ABSTRACT

Life tests are performed to determine the stability of solar cell assemblies under worst case operation conditions for long duration. This test is part of the qualification programme to which solar cell assemblies are submitted according to ECSS standards. This paper presents the test set-up configuration (recently implemented in the European Space Power Laboratory), test conditions and test results obtained of the solar cell assembly life test performed under the ESA CHEOPS satellite programme.

1. INTRODUCTION

1.1 The CHEOPS Mission

The CHEOPS (CHAracterizing ExoPlanet Satellite) mission is dedicated to searching for planet transits by means of ultrahigh precision photometry on bright stars already known to host planets. The mission was selected by the Science Programme Committee in November 2012 as the first small mission in the ESA Science Programme. The project passed the system CDR in May 2016 and is targeting a shared launch opportunity in 2018.

To cope with the very challenging schedule and budget, the design and implementation of CHEOPS is articulated around the re-use of an existing, “off-the-shelf” platform, the AS250 product line from Airbus DS with some minor adaptations. The aim of the modifications is to meet the power requirements of the mission (battery and solar array resizing) and to provide a cost efficient solution where a downsizing of elements is possible while satisfying the performances. The manufacture of the platform and the integration & testing of the satellite (including the integration of the scientific instrumentation) is carried out by AIRBUS DS Spain.

The satellite (Fig. 1) is composed of a prismatic body platform, an optical instrument (a photometer developed by a consortium led by the University of Berne) mounted on top of the platform, and three body-

mounted solar array panels. The three body-mounted solar array panels have a 67 degree deviation between them, in order to achieve the best illumination in any mission attitude. See [1] for more information about CHEOPS mission.

Figure 1. CHEOPS Satellite.

To account for the specific requirements of the CHEOPS mission in terms of sky visibility and stray-light rejection (e.g. minimizing Earth stray light) and the mission constraints (e.g. shared launch scenario), a dawn-dusk circular SSO (LTAN 6 a.m. or 6 p.m., and altitude from 650 to 800 km) was selected as the nominal orbit. Due to the attitude range and characteristics (e.g. roll around the line-of-sight to maintain the instrument's radiators pointed to cold space), the solar cells are subject to a large number of thermal cycles and elevated cell temperatures, specifically for the central panel, which has resulted in the need for delta-qualification tests of the solar cell assemblies.

1.2 Delta-Qualification Tests

The solar cell assembly delta-Qualification test for CHEOPS mission consisted of the performance of a life test in accordance with ECSS [2] and the specific mission requirements.

2. LIFE TEST DEFINITION

The solar cell assembly life test is specified to be performed in a vacuum (less than 2×10^{-5} mBar) and under 1 solar constant AM0 illuminated simulated conditions.

The duration of the life test is calculated to be considerably less than the real duration of the mission and follows the Arrhenius law, taking into account the total duration of the CHEOPS mission (3.5 years), solar cell activation energy (0.7eV, being a rather conservative value and in accordance with [2]) and the worst case solar array operational temperature during the mission (i.e. in the range between 120°C and 130°C). Therefore, CHEOPS mission conditions require a life test exposure much larger than for GEO and LEO missions and it has been calculated to be 6990 hours at 160°C.

The life test is split in 3 phases, where the solar cells are exposed at three different temperatures. Therefore, the duration of each phase is calculated to be 2000 hours at 140°C, 2000 hours at 160°C and 2078 hours at 175°C. The solar cells are loaded close to the maximum power point for 93% of the time of each phase. During the remaining 7%, the solar cells are biased in reverse voltage to simulate the worst case condition of solar cells current matching in the string with a 0.05V margin.

3. CHEOPS LIFE TEST SAMPLE

Leonardo-Finmeccanica provided the test sample plate (see Fig.2) consisting of 12 flight representative solar cell assemblies, that were previously qualified for GEO missions under ESA's MTG programme.

The substrate is an stainless steel plate of 300 x 300 mm². The use of stainless steel material helps to avoid cell cracking during vacuum and temperature exposure and provides a reasonable thermal conductivity.

The Solar cell assembly is comprised of 12 AzurSpace 3G30 Triple Junction solar cells with CMG 100 µm coverglass with AR coating and Ag plated Invar interconnectors. These are high grade solar cells. The solar cell shunt diode is an AzurSpace SIBD type, but they are not connected in parallel to the cell.

The bus bars are InvarAg single strips and the solar cell laydown adhesive and bus bar potting is RTV-S691.

Figure 2. CHEOPS life test sample.

The bus bar bonding patterns and adhesive is CV-2-1142 and the wire type is 3901-020 ESCC specification.

The plate is equipped with 6 thermocouples of type T bonded below 6 different solar cells.

The 4xPolymide heaters for active thermal control and attached with RTV-S691 used for the MTG life test, were removed for the CHEOPS life test.

4. ESTEC LIFE TEST FACILITY

The test facility is located in the Solar Generator Laboratory of the Power Systems Division (TEC-EP) at ESTEC and is comprised of:

4.1 Thermal vacuum facility

The Vacuum Solar Cell Illumination Facility (VSCIF) is equipped with a quartz glass window that allows AM0 illumination of the solar cells samples. The VSCIF facility is equipped with a XDS10 scroll pump and a BOC Edwards STP-301/451 Series turbomolecular pump and the vacuum level is typically lower than 10^{-6} mbar. The VSCIF facility is equipped with a hot plate that uses flat Mica based heaters and allows exposure at constant temperature of the solar cell samples between 120°C and 400°C. No cold trap is used for the CHEOPS life test as the VSCIF facility walls are at much lower temperature (40-60°C) than the solar cells.

Calcium fluoride windows, placed in the chamber cold locations and in close proximity to the test samples, are used to monitor the deposition on these surfaces of organic contamination during the test.

4.2 Solar Simulator

The solar simulator (SESO SSMD 1x2,5-0-3,5) is a single source system with a Xenon arc lamp of 2500 W. The light beam is composed by reflection on 8 internally mounted mirrors. The SESO solar simulator is placed outside the vacuum facility. The vertical light beam illuminates the solar cell sample through the VSCIF facility window. The illuminated plane has a diameter of 350mm at a distance of 650mm from the exit window of the simulator.

The solar simulator performance is as follows:

- Intensity: 0.7 solar constant (SC) to 1.7 SC.
- Uniformity: 2.0% at 1 SC in the 350mm beam target diameter.
- Spectrum: AM0 at 1 SC, Class A [2].
- Long term stability: 0.2% over 24 h at 1 solar constant (SC).

4.3 Solar cells biasing electrical device

Solar cells under test are electrically connected to an electric switch box to allow operation in loaded mode and in reverse mode. Each cell is looped with two other solar cells of the same row by means of the open positive terminal. Two groups of 6 cells in parallel are connected to two different power supplies for working in reverse mode. Each solar cells are loaded with a resistor (2Ω) when working in loaded mode.

4.4 Data Acquisition Unit

The current equivalent and voltage are measured for each solar cell independently during the complete test. The DACQ also records the solar cell temperatures and the equivalent current of two silicon solar cells (one filtered to be sensitive to UV spectral range) in order to control the solar simulator light intensity that degrades due to lamp ageing.

5. TEST SET-UP VERIFICATION

5.1. Test set-up spike verification

The solar cell electrical circuit was verified to be free of electrical transients for planned (transitions between safe mode and forward/reverse modes) and unexpected events that may occur during the life test execution. A dummy cell was used to verify the transients in the electrical circuit. The dummy cell terminals were directly connected to the measurement oscilloscope. The verification helped to refine the test operational procedure and to prevent transients during nominal test operations. Furthermore an oscilloscope has been connected to one of the cells, in order to monitor unexpected transients, during the complete life test.

5.2. Solar Simulator Calibration

The uniformity was measured with the CHEOPS test solar cells that were previously electrically characterized with a calibrated pulsed solar simulator. The overall uniformity is verified to be in the range of $\pm 2.0\%$.

The solar simulator intensity at the solar cell sample test plane is measured with a set of representative component solar cells in the centre of the beam and in the same plane of the CHEOPS test solar cells. In order to characterize the lamp spectral ageing, the light beam intensity is measured at the beginning and at the end of each phase or lamp change. The nominal solar simulator lamp life is around 2000 hours.

6. LIFE TEST EXECUTION

The following figures show the temperature, current and voltage of the solar cells monitored during part of phase 2, as an example of the execution of the CHEOPS life test.

Fig. 3 shows the solar cells temperature in loaded mode and in reverse mode. The temperature increase corresponds to the reverse mode step.

Figure 3. Solar cells temperatures.

Fig. 4 shows the solar cells currents in loaded mode and for a short period in reverse mode. The solar simulator light intensity was increased at 600h to compensate for the aging of the lamp.

Figure 4. Solar cells currents.

Fig. 5 shows the solar cells voltage in loaded mode and few hours in reverse mode.

Figure 5. Solar cells voltages.

7. LIFE TEST RESULTS

The solar cells are inspected and electrically characterised before the exposure test starts and at the end of each phase. The electrical performance of the solar cell assemblies is measured, at 1 solar constant conditions and at 25°C. Visual inspection, including electroluminescence inspection of the solar cells, is also carried out. The contamination content of the calcium fluoride windows is measured using IR spectrometry analysis.

After the completion of phases 1 and 2 and more than 1800 hours of exposure at 175°C, no degradation of solar cell assembly's electrical performance has been recorded and no defects have been identified. The test is planned to be completed towards the end of September 2016.

8. LESSONS LEARNED

The Solar simulator optics are sensitive to contamination that becomes fixed to their surfaces as a result of the exposure time, this is particularly due to Ultra Violet (UV) radiation. This contamination decreases the performance of the solar simulator in the UV region and requires the cleaning of the optic surfaces in order to restore it. The cleaning is performed with solvent agents that do not damage the optic coatings.

The process to set-up the reverse bias condition on the solar cells is time consuming because of inter-cell interaction due to the electric switch box design. The solution to implement individual power supplies to bias each solar cell, is seen as a much efficient, even if more expensive.

The solar simulators lamp life may be linked to specific lamp manufacturing batches. Therefore, the implementation of an individual lamp life control has been established.

The use of reference component solar cells and monitor, silicon and silicon VI & IR filtered, solar cells to calibrate and monitor the solar simulator intensity, helped to verify the CHEOPS solar cells performance, together with their measured current at test temperature, after unforeseen test interruptions.

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10. REFERENCES

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