METHOD FOR GLOBAL AND LOCAL LEAK DETECTION APPLICATION FOR HYDRAZINE PROPULSION SYSTEMS

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Abstract. *The China-Brazil Earth Resources Satellite (CBERS-FM2) was designed to be three axes stabilized, in other words, an inertial stabilized satellite. As part of the qualification tests, the spacecraft hydrazine propulsion system had to be completely checked against any possible significant leakage which would dangerously reduce its operational lifetime while in orbit. These tests included the Local Leak Tests, where each part of the propulsion system was individually leak tested using Helium Leak Detectors, and the Global Leak Tests, where the whole spacecraft Service Module (SM) was installed in a Space Simulation Chamber, a large thermal vacuum system, where an external Helium Leak Detector was attached for leakage rate measurements. This paper describes the development of the employed methodologies and does an analysis of the obtained results.*

Keywords*: propulsion system leak tests, helium leak tests, leak detectors.*

1. Introduction

The Integration, Assembly and Environmental Tests campaign of the Flight Model # 2 of the China-Brazil Earth Resources Satellite - CBERS FM2 was performed at the Integration and Tests Laboratory - LIT, INPE, São José dos Campos, SP. Measuring approximately 1.8 x 2.0 x 2.2m, weighting 1.5 ton and carrying three cameras as the main payload, this satellite was launched from the Taiyuan Satellite Launch Center aboard a Long March-4B rocket and it is now orbiting the Earth at approx. 778km as part of its remote sensing mission profile. Considering that this particular spacecraft is stabilized in its three axis using an active attitude control, a fuel storage and firing system based on hydrazine and consisted by four tanks, many valves, directional thrusters and the related pipeline is installed in the spacecraft. As part of the qualification tests, the spacecraft hydrazine propulsion system had to be completely checked against any possible significant leakage in its tanks, valves and titanium pipeline, which would dangerously reduce its operational lifetime while in orbit (Gilmore, 1994).

These tests included the *Local Leak Tests*, where each part of the propulsion system was individually leak tested using Helium Leak Detectors, and the *Global Leak Tests*, where the whole spacecraft Service Module (SM) was installed in a Space Simulation Chamber, a large thermal vacuum system, where an external Helium Leak Detector was attached for leakage rate measurements.

2. The Cbers Fm2 Propulsion System

In order to control and maintain the satellite proper attitude while in orbit, a critical condition for the correct appointment to the ground of the three cameras and the solar panel to the sun, a subsystem composed mainly by four 28-liter fuel tanks, 18 firing thrusters, 12 valves, some filters and the dedicated pipeline is included in the satellite Service Module. Most of these components are made of titanium and stainless steel. In order to feed the thrusters installed at their proper operational locations, the dia. 6mm x 1mm thickness titanium pipeline had to be curved and bent in angles to follow the routing through the spacecraft internal geometry. Inter-connections and valves are also required for the firing procedures. Some pictures of part of the CBERS FM2 propulsion system are shown in fig. 1, 2 and 3.

Figure 1. Titanium pipeline welding process

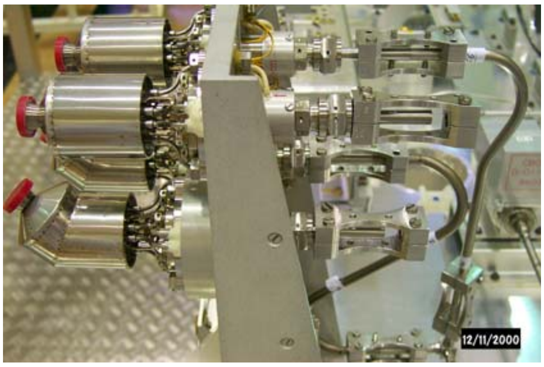

Figure 2. Connection to valves and thrusters

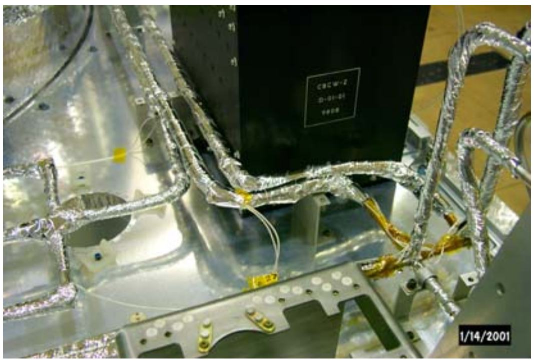

Figure 3. Pipeline covered by Multi Layer Insulation

As the required fuel, a monopropellant-based Hydrazine is used, the most common fuel for satellite applications (Gilmore, 1994). In order to assure the proper flow to the thrusters, some hours before the launching phase the propulsion system is pressurized to 1.6 MPa by using a charge of gaseous nitrogen. Because the satellite operational lifetime is critically dependant on the availability of the fuel, a comprehensive leak tight system is mandatory (MIL-STD-1540B–USAF, 1982), so every significant component of the propulsion system should be adequately tested and, at the end of the spacecraft integration and testing campaign, the whole spacecraft should also be checked for global leakage, as required for CBERS Environmental Specification (Zhixu *et Al*., 1996).

3. Test Specification

According to the China-Brazil cooperation program *Propulsion Subsystem Pipe Leakage Check Requirement*, the Tab. 1 presents the leakage test specification (Almeida, 2002):

Table 1: CBERS leakage test requirements

Test	**Maximum Permissible Leak Rate [Pa.m^3/s]**
Local Leakage Rate, for threads	< 1.0 x 10^{-6}
Local Leakage Rate for welded points	< 1.0 x 10^{-7}
Global Leakage Rate	< 1.0 x 10^{-4}

4. Local Leak Tests

The tubing of the CBERS satellite propulsion system was made of titanium, most of it in 6mm external diameter. Because of the diverse internal geometry of the spacecraft, this pipeline had to be built in several sections that were subsequently welded to obtain the 3-D configuration of the internal routing in the spacecraft. Although this welding process was performed in a specially built and dedicated laboratory with cleanliness of Class 10.000, leaks and other non-conformities could arise during the integration and interconnection procedures, and also from the vibration caused by the transport and acoustic test activities.

To perform the *Local Leak Tests* the spacecraft Service Module was located in a clean room area of the laboratory in Brazil and them its propulsion system, after being evacuated, was pressurized with 99.999% grade Helium to 2.0-2.2 MPa in order to reproduce the flight pressure (1.7 MPa) plus a safety margin of 0.5MPa. In the sequence, after the calibration procedures of the Leak Detector, each significant individual spot of the propulsion system, one by one, was properly checked by the Leak Detector sniffer. Of great concern were the valves, pipeline connections and actuators.

In order to get the most of any possible leak, small plastic bags were placed around each one of the selected spot to be leak tested. These were done to ensure a separate atmosphere from the external environment. At the end of the sniffer probe, a sharp needle could then cut a small hole in the plastic and, for at least 10 seconds, to check for the leak tightness of that particular spot. A picture showing this operation can be seen in Fig. 4.

Figure 4. Local Leak Tests - INPE

For these *Local Leak Tests*, a quantity of 29 individual spots where checked. Some of the local leak rate data are presented in Tab. 3.

Table 3. Some results from the *Local Leak Tests* - INPE

Location	**Leak Rate [Pa.m^3/s]**
Pressure Transducer	1.52×10^{-9}
1N Thruster Assy	4.90×10^{-9}
20N Thruster Assy	4.20×10^{-9}
Fill/Drain Valve	8.20×10^{-10}
Fill/Vent Valve	1.08×10^{-9}

As a result from these tests, it was recorded that all the checked spots, including the ones showed in Table 3, presented leak rate values lower than the specified limit (Garcia, 2001), and in agreement with CBERS Environmental Specification (Zhixu *et Al.*, 1996).

5. Global Leak Tests

Prior to the Global Leak Testing of the CBERS spacecraft propulsion system, a calibration procedure in the empty Thermal Vacuum Chamber (TVC) was performed. This process consisted in installing a standard leak in one side of the Thermal Vacuum Chamber and the Leak Detector at the opposite side. The Chamber was then evacuated to a pressure in the 10^{-4} Pa range, the pumping system valves were closed, and a known calibrated leak was let to flow into the chamber so its value could be measured and checked at the Leak Detector port. These measurements are presented in Tab. 4.

Table 4: *Global Leak Tests* calibration process

Parameter	**Value**
TVC pressure (initial)	10^{-4} Pa range
Standard-Leak value	3.55×10^{-9} Pa.m^3/s
Measure with Standard-Leak installed at Leak Detector port	3.70×10^{-9} Pa.m^3/s
Measure at Leak Detector connected to TVC, without Standard-Leak	2.00×10^{-10} Pa.m^3/s
Measure on Leak Detector, Standard-Leak connected to opposite side of TVC	5.00×10^{-9} Pa.m^3/s

In the sequence, it was performed the *Global Leak Tests* of the CBERS FM2 spacecraft. For this, it was also required its propulsion system to be pressurized with 99.999% high grade Helium to 2MPa. Following the planned sequence, the whole Service Module was installed in LIT 3m dia. x 3m long Space Simulation Chamber. This chamber was built using 304L Stainless Steel and, to get its high vacuum conditioning, it is equipped with two 35" 25,000 l/s (blue painted) cryopumps. A picture of this test set up is presented in Fig. 5. At one of the vacuum ports of this thermal vacuum chamber the Helium Leak Detector was connected, valve closed (see Fig. 6).

Figure 5. Preparation for *Global Leak Tests* - INPE

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The TV Chamber was them evacuated using its primary pumping system consisted by a 96 m^3/h Rotary Vane mechanical pump in series with a 480 m^3/h Roots Blower pump. This pumping system is installed in the basement of the Laboratory in order to minimize any possible oil vapor contamination inside the laboratory Hi Bay. After that the TVC was taken to high vacuum using its cryogenic pumping system and after that the gate valves were closed. The pressure then increased to 1.2 Pa.

Figure 6. Leak Detector connected to TVC port

The Leak Detector to Thermal Vacuum Chamber connection port valve was carefully opened and the rate of leak coming from the entire pressurized spacecraft propulsion system could be measured. A total of five distinct measurements were taken, during an elapsed time of approximately 50 minutes (Garcia, 2001). The results are presented in Tab. 5.

Table 5: CBERS FM2 *Global Leak Tests* results - INPE

Measurement #	**Value [Pa.m^3/s]**
1	1.50×10^{-7}
2	1.60×10^{-7}
3	1.70×10^{-7}
4	1.85×10^{-7}
5	1.82×10^{-7}

After conducting the CBERS FM2 propulsion system leak rate measurements, a calibration double-check was performed. This procedure consisted of re-installing the Standard Leak at the port of the Leak Detector and checking its value, and this was found to be

$q_{Lst} = 3.10 \times 10^{-9}$ Pa.m^3/s

which was considered as close enough to the value obtained just prior to carrying on the spacecraft global leak tests, the results as presented in Tab. 4.

Comparing the results obtained as shown in Tab. 5, it can be seen that these values from the *Global Leak Tests* for the CBERS FM2 are lower than the required upper limits as presented in Tab. 1.

6. Leak Tests Performed In China

After finishing its integration and tests campaign in Brazil, the CBERS FM2 spacecraft was transported to China for the preparation procedures for the launching phase. In the Chinese laboratories, global leak tests were performed again in order to verify the spacecraft integrity after the stress imposed during the transport and the acoustic vibration tests. The procedure adopted in China was, instead the philosophy of using the Vacuum Chamber for better accuracy as performed at LIT, Brazil, to install the CBERS FM2 Service Module inside an atmospheric pressure chamber and the Helium concentration checked for any significant increasing amount after a certain period of time. This is similar to the known *Hood Test* (or *Gas Accumulation Test*) (Leybold-Heraeus, 1986).

The chamber used as the hood had a volume several times larger than the CBERS Service Module. The SM propulsion system was again pressurized with He at 2MPa. In order to analyze the He concentration (partial pressure) inside the Chamber, three sequential steps were performed. The first one was executed in order to get a reading at the time the spacecraft was just installed inside the Chamber and the door closed. The second one followed the same test set-up, but performed at 24 hours later. The third step required an injection of a precise volume of virtually pure Helium (99.999%) at a pre-defined pressure. The results from this sequence were then used to calculate the variation of He concentration inside the Chamber and consequently the global He leakage from the Service Module (Almeida, 2002).

That Chinese rectangular shaped Chamber had metallic door and granite walls. The hinged door was sealed to the Chamber frame by using rubber and foam compression strips. A blower, installed on the left wall of the Chamber, was used to increase the uniformity of the gaseous environment prior to each sample reading. Rubber hoses protruding into the Chamber, also from the left wall and located approx. 1m from the floor, were used to collect and replace the sample to perform the concentration analysis. A Mass Spectrometer, coupled to a HP 34401A Multimeter to get the output readings, was used to measure the mass 4 concentration of the Helium gas. A large control panel, containing valves and analog pressure and flow gauges was used to set and to control the parameters of the flow to the Chamber. A two-way selecting valve was used to alternate from a standard He sample (99.999%) to the flow coming from the Chamber. A small pump was used to produce the gas flow in a close circuit from the Chamber through the Mass Spectrometer analyzer.

The following methodology, given by Eq. (1), was adopted for the calculation of any possible increase of He concentration inside the Test Chamber:

$$q = \frac{(U_2 - U_1) \,.\, P \,.\, V}{(U_3 - U_2) \,.\, \Delta t} \tag{1}$$

where:

q: Helium leak rate [Pa.m^3/s];
U_1: Helium concentration, just after closing chamber door [ppm];
U_2: Helium concentration, after 24 hours [ppm];
U_3: Helium concentration, after forced injection of the Helium sample [ppm];
P: Pressure of injected Helium sample in the circulating system; 0.5 MPa;
V: Volume of injected Helium sample; 10.5 ml;
Δt: Elapsed time; 24 hours.

A picture showing the CBERS FM2 spacecraft installed inside the Chinese atmospheric pressure chamber can be seen in Fig. 7.

Figure 7. CBERS FM2 in Atmospheric Chamber for the *Global Leak Tests* procedures - China

The results from the *Global Leak Tests* performed in China are now presented in Table 6 together with the results obtained at LIT, Brazil, for comparison.

Table 6: Overall results from the Global Leak Tests

Test Site	***Measurement***	***Technique***
China	1.0 x 10^{-5} Pa.m^3/s	Hood Test (Gas Accumulation Test)
INPE Brazil	1.7 x 10^{-7} Pa.m^3/s	Vacuum Test

Table 6 shows that the measurement of the global leaks as performed by CAST presented results showing a significant increase when compared to the values obtained at LIT-INPE, i.e., prior to the *Acoustic Tests* developed at the Chinese laboratories.

It is known from the literature (Varian, 1980) that the Gas Accumulation Test, as performed at the Chinese laboratories, is less accurate than the Vacuum Test, as adopted in Brazil and this makes the comparing analysis of the results as not so straightforward. In this way, considering the very distinct characteristics of the two techniques applied for this measurement, a direct comparison and a precise analysis concerning this difference must be made with some caution and a closer look on the other possible causes of the obtained distinct results is recommended.

7. Concluding Remarks

Although the results from the *Global Leak Tests* performed in China had presented some significant differences when compared with the results from the tests developed at INPE, it must be noted that there is consistency in showing an increase of leak rate values, after the stress caused by the transport to China and subsequent *Acoustic Tests*. Finally, it must be pointed out that, even with the difficulties of a direct comparison of the Chinese-Brazilian results, it was effective and gainful to have the integrity of the CBERS FM2 Service Module checked by two distinct test methods.

A picture of the CBERS FM2 satellite with its folded solar array is shown in Fig. 8. This satellite is now orbiting the Earth, producing clear images from China and Brazil.

Figure 8. CBERS FM2 satellite

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