

Performance of Aerospazio Lifetest Facilities and Diagnostic Tools for the HEMPT Qualification Programme

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In the framework of the HEMP-TIS Project (HEMP-Thruster In orbit verification on SGEO) of German Space Agency DLR, the Business Unit Electron Devices of Thales Deutschland is qualifying the HEMP-T propulsion system with two HTM qualification models, HTM-QM1 and HTM-QM2, and with one PSCU engineering-qualification model, PSCU-EQM. A major step in the qualification campaign is the HEMPT Lifetime Test. The Lifetime Test started at the end of May 2015 in the Large Vacuum Test Facility (LVTF-1) at AEROSPAZIO Tecnologie S.r.l. and it is still in progress (currently 77% of planned thruster firing hours have been completed, the qualification factor QF=1.0 achieved). In order to fit the stringent requirements of the HEMP-TIS Project, the LVTF-1 facility was modified and refurbished. In particular, specially designed aluminum shielding consisting of conical blades and cylindrical parts were installed. Also the beam target was modified by installing aluminum blades. The test facility was equipped with a plasma diagnostics system so as to characterize the plume of the thruster during the lifetest. The plasma diagnostics is hosted in a special closed box while at rest during the testing, so as to maximise the possibility of survival for the probes subjected to aluminum backspattering. A review of the performance achieved so far by the lifetest facility and the plasma diagnostics will be presented in this paper; up to now the LVTF-1 vacuum facility is demonstrating a remarkable reliability greater than 90% (full pumping hours/overall test duration ratio).

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Nomenclature

<i>EQM</i>	= Engineering Qualification Model
<i>FP</i>	= Faraday Probe
<i>GN2</i>	= Gas Nitrogen
<i>HD</i>	= High Definition
<i>HEMPT</i>	= High Efficiency Multistage Plasma Thruster
<i>HEMP-TIS</i>	= HEMP – Thruster In-orbit-verification on SmallGEO
<i>HTA</i>	= HEMP Thruster Assembly
<i>HTM</i>	= HEMP Thruster Module
<i>LN2</i>	= Liquid Nitrogen
<i>PSCU</i>	= Power Supply and Control Unit
<i>QM</i>	= Qualification Model
<i>QMS</i>	= Quadrupole Mass Spectrometer
<i>RPA</i>	= Retarding Potential Analyzer
<i>SGEO</i>	= Small GEOstationary satellite
<i>TES</i>	= THALES Electronic Systems
<i>UPS</i>	= Uninterruptible Power Source

I. Introduction

AEROSPAZIO Tecnologie S.r.l. is collaborating as qualified and expertise Electric Propulsion test center together with THALES Electronic Systems GmbH on the HEMP-TIS Lifetime Test.

The Business Unit Electron Devices of THALES Deutschland has designed and developed an ion propulsion system based on the High Efficiency Multistage Plasma Thruster (HEMPT) technology for the SGEO/H2Sat satellites developed by OHB-System AG. The HEMP Thruster Assembly (HTA) consists of a Power Supply and Control Unit (PSCU) and four HEMPT Modules (HTMs). A major step in the HEMP-TIS qualification campaign is the HTA Lifetime Test; the main goal of this test is to verify the SGEO and H2Sat lifetime and operational cycling requirements including >10000 operational cycles and >8500 firing hours.

The Lifetime qualification test on HTM and HTA level, started at the end of May 2015, is still in progress in the LVFT-1 vacuum test facility at Aerospazio Tecnologie, Rapolano Terme, Siena, Italy; at present currently 77% of planned thruster firing hours have been completed, the qualification factor QF=1.0 achieved.

The facility allows for a 3D ion beam characterization (Faraday Probes). An advanced inspection system with 2 HD cameras, developed in collaboration with Thales, is present in vacuum to observe the state of the thrusters. Thales diagnostic tools (thrust balance and RPA) have been integrated inside the LVTF-1. The facility provides a LN2 feed control system to the thermal shrouds simulating the cold environment around the two HTMs. An auxiliary small chamber (0.5m diameter, 0.7m length), placed next to the LVTF-1, hosts the PSCU-EQM.



Figure 1. The LVTF-1 facility at AEROSPAZIO.

II. Lifetest facilities

A. LVTF-1 Vacuum Test Facility

The LVTF-1 (Large Vacuum Test Facility) was built up in earlier 2000s to host electric propulsion test activities. It provides an excellent long-term vacuum stability and a unique 3D beam current diagnostics; all this makes the LVTF-1 suitable for lifetime test of HEMP thrusters.

The LVTF-1 consists of a diamagnetic horizontal stainless steel cylinder with two full-diameter end caps, which can be removed to allow the introduction of large test articles. The chamber is 11.5 m long and has a diameter of 3.8 m for a total volume of ~120 m³ (Fig. 1). On the side of the chamber there is a number of flanges (up to three 900mm diameter large flanges) which allow connecting additional service chambers.

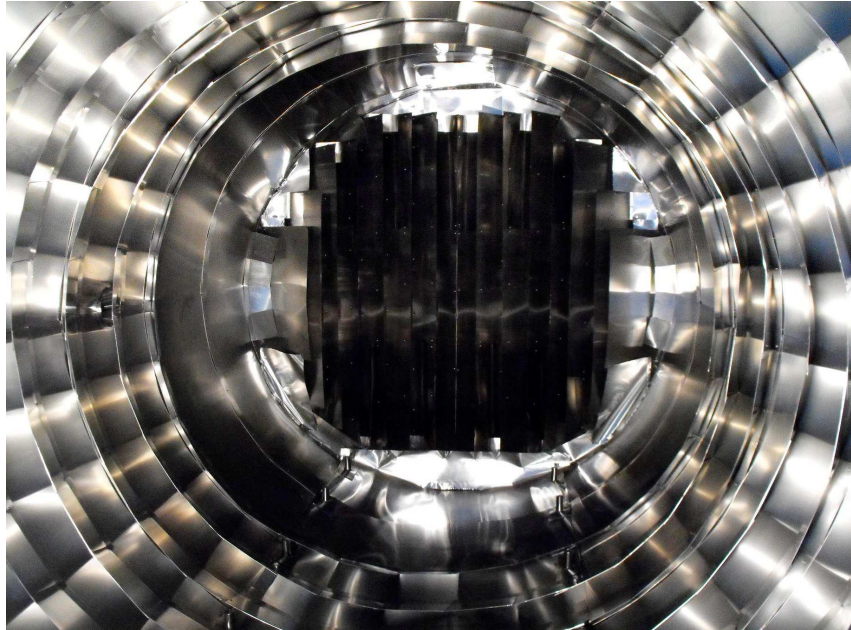


Figure 2. Aluminum shielding inside LVTF-1.

The pumping system includes:

- 1st stage consisting of rotary pumps operated in parallel during the first phase of the pump-down (1Bar ÷ 10mbar);
- 2nd stage consisting of one large roots pump backed by a rotary pump (10mbar ÷ E-02mbar);
- 3rd stage consisting of turbo molecular pumps backed by rotary pumps (E-02mbar ÷ E-05mbar);
- 4th stage consisting of a large commercial cryogenic pump;
- 5th stage consisting of a special system of panels cryogenically cooled by cold heads and surrounded by liquid nitrogen baffles, specifically designed to pump Xenon (pumping speed >170.000 l/s).

The minimum attainable basis pressure is in the order of 2E-08 mbar, typical Xe pressure during HTM testing is 2.2E-06 mbar. The vacuum level is monitored with the help of 3 full-range Leybold Ionivac ITR90 gauges that are mounted behind manual gate valve in order to allow their replacement for calibration-maintenance without breaking vacuum operations. The vacuum quality (residual gas analysis) is monitored with a Quadrupole Mass Spectrometer QMS (200 a.m.u.).

In the frame of the HEMP-TIS lifetime test, a special internal configuration has been developed under Thales supervision and according the accurate design performed by the Max-Planck-Institut für Plasmaphysik, Greifswald - Germany. All the graphite protections used in the past have been fully removed from any part of the facility and new Aluminium panels have been installed in a concentric-cylindrical chevron shape (Fig. 2) in order to reduce the contamination of the thruster channel with the backspattered wall material.

For HEMP testing, the usable test volume consists of a cylinder of about 3.7m diameter (with aluminum protective shields installed) and ~7 m length. A GN2-cooled chevron beam target is mounted at the chamber end opposite to the cryogenic system. The LVTF-1 is equipped with a heating system, placed inside the vacuum chamber, in order to accelerate the outgasing of the inner surfaces during the pump-down phase and to achieve better vacuum conditions. The atmospheric pressure is recovered after the testing by venting the chamber with dry nitrogen to keep water vapor adsorption to the walls as low as possible.

All instruments and equipment related to the proper operation of the LVTF-1 are connected under UPS, which provides instantaneous protection from input power interruptions and also correct voltage spikes, sustained overvoltages, noise and oscillations. In case of critical long blackouts, the vacuum level inside LVTF-1 can be

maintained for many hours by means of an auxiliary standby generator so as to allow time for cooling of the thruster and preserve the test article from possible risks or damages.

B. PSCU vacuum chamber

An auxiliary small vacuum chamber, placed close the LVFT-1, hosts the PSCU-EQM unit (Fig. 3). The PSCU chamber consists of a stainless steel cylinder DN500 standard with 700mm length. It provides several flanges equipped with vacuum feedthroughs for the PSCU connections to HTM-QM1 as well as to connect the pumping system and the vacuum diagnostics. The PSCU is mounted on a testing adapter placed on a bracket.

The pumping system consists of a double redundant turbomolecular pumping system backed by dry primary pumps. The vacuum diagnostics consist of two calibrated Ionivac gauges and one quadrupole mass spectrometer 100 a.m.u.. A heating system is available for the preliminary vacuum conditioning of the chamber.

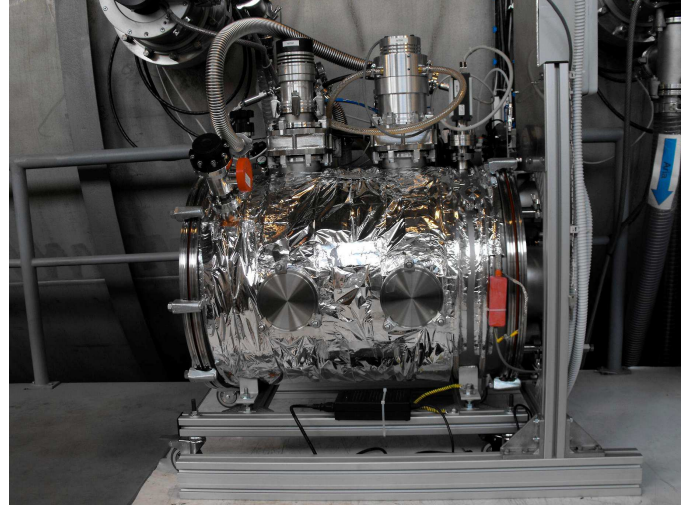


Figure 3. The PSCU small vacuum chamber.

III. In-vacuum test set-up and diagnostic tools

The internal set-up in the LVTF-1 features the presence of two HTMs. The HTM-QM1 is installed on a thrust balance supplied by Thales. The balance is aligned along the symmetry axis of the chamber, the HTM-QM2 is mounted on a side of the HTM-QM1 (Fig. 4). Each HTM is supplied with a thermal shroud without direct mechanical contact with HTMs in order to simulate the extreme in-flight background temperatures and perform the thermal vacuum characterization. The thermal shrouds are feed by liquid nitrogen flowing through a dedicated line.

Aerospazio has developed the LN2 control system for the shrouds equipped with redundant cryogenic on-off valves. The system allows to keep the shrouds temperature at the required range of $-170 \pm 10^\circ\text{C}$. The mounting bracket for HTM-QM2 and the support structures for thermal shrouds have been designed and manufactured in such a way to avoid thermal distortion caused by vicinity of the LVTF-1 main shroud operating at -180°C .

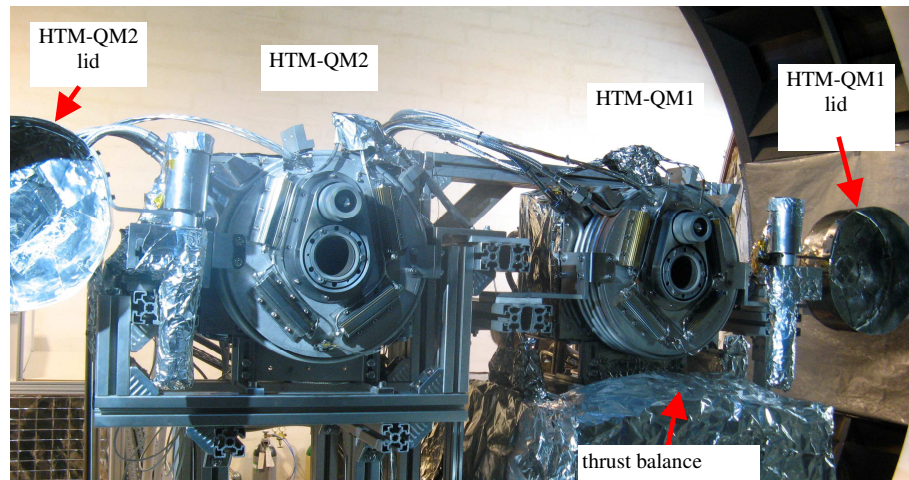


Figure 4. HTM-QM1 and HTM-QM2 inside the LVTF-1 vacuum chamber (courtesy of DLR).

The ion beam diagnostics set is mounted on a rotating semicircular arm inside the chamber and includes:

- 32 Faraday Probes (FP) placed at different angular positions on the arm, are used to determine the 3D ion current distribution in the plume and provide an assessment of the thrust vector direction;
- 2 Retarding Potential Analyzer (RPA) provided by Thales, are used for ion energy characterization.

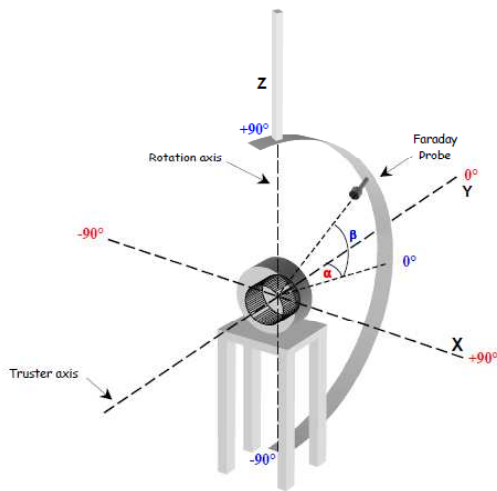


Figure 5. Definition of generalized coordinates for the thruster diagnostics reference system.

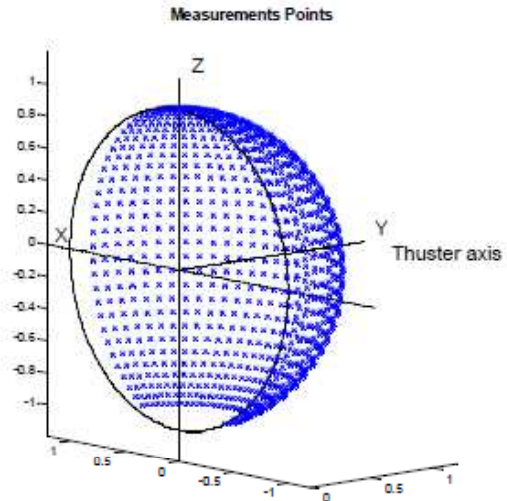


Figure 6. Points of measurements mapping.

The probes arm is positioned such that the centre of the thruster exit section corresponds to the centre of the semicircular arm and the arm rotation axis coincides to the vertical axis crossing the centre of the thruster exit section. Each probe is mounted on the arm so that the collector faces the centre of thruster exit section at a distance of 1 m. The position of a probe w.r.t. the centre of the thruster is determined by α and β angles, where α is the angular position of the arm w.r.t. thruster axis and β is the angular position of the probe on the arm, as shown in Fig. 5. This configuration enables complete 1m-radius hemispherical profiles of the exhaust plume to be obtained (Fig. 6). The arm is moved by a stepper motor and can perform a 180 deg rotation (-90 deg to +90 deg off axis).

The stepper motor is controlled by a PXI based system and equipped with an absolute encoder. The ion beam diagnostic system is operated by AEROSPAZIO personnel. The data reduction and analysis of the Faraday probes measurements are also performed by Aerospazio personnel. In order to avoid the risk of contamination of the diagnostics caused by the aluminium sputtering a closed shape box has been manufactured as housing for the beam diagnostics arm during rest periods (Fig. 7). The probes positions and the thruster position and orientation are determined in a reference system defined by several points, used as references, chosen on the chamber walls. Because of symmetry issue beam diagnostics can be performed on HTM-QM1 only. On the beam diagnostic an advanced thruster inspection system is also installed; this is constituted by two commercial digital cameras customized for the in-vacuum operation and oriented towards the HMT-QM1 face in order to visually inspect the thruster in-situ without breaking the vacuum (Fig. 8). The development of the thruster inspection system is based on a cooperation between Aerospazio and Thales.

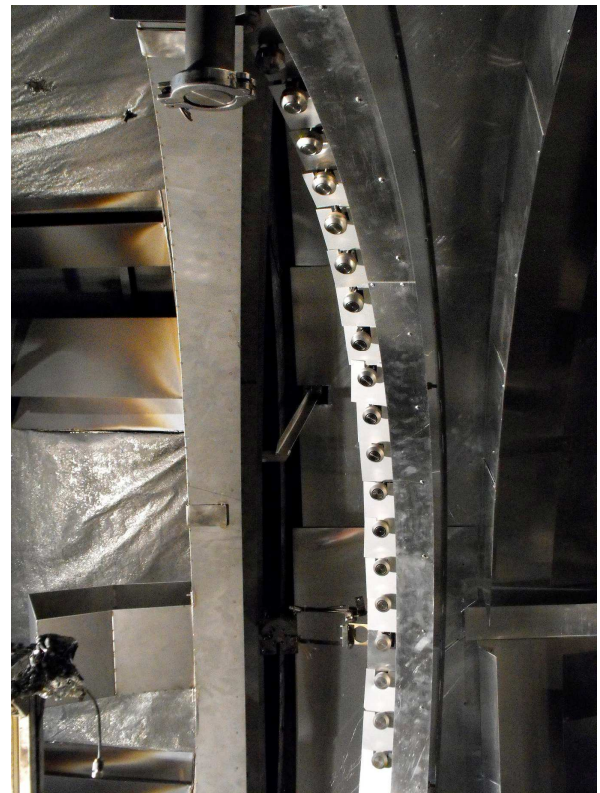


Figure 7. The Faraday diagnostics arm approaching to its housing.

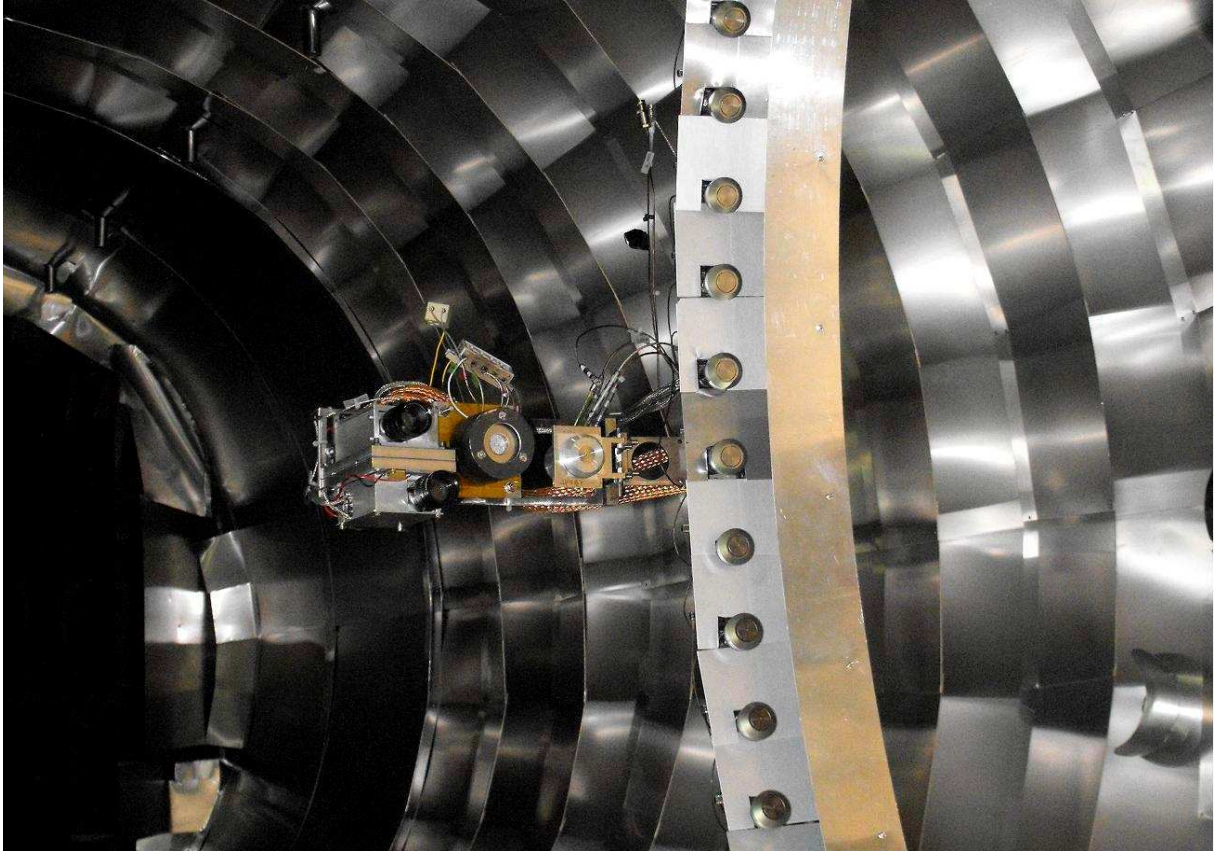


Figure 8. Diagnostic tools on the LVTF-1 arm: Faraday probes, Thales RPAs, thruster inspection HD videocameras.

IV. LVTF-1 reliability during Lifetime Test

The HEMPT Lifetime Test was started at the end of May 2015 after the shakedown test demonstrated the readiness and good performances of the LVTF-1 vacuum chamber, including the pumping capacity with HTMs firing simultaneously, the beam diagnostics operation, emergency and safety procedures, etc.

After the chamber conditioning, the HTM-QM1 and the HTM-QM2 were first switched on according to the Lifetime test plan at the end of August 2015. Up to now, the HTM-QM1 + PSCU-EQM have accumulated more

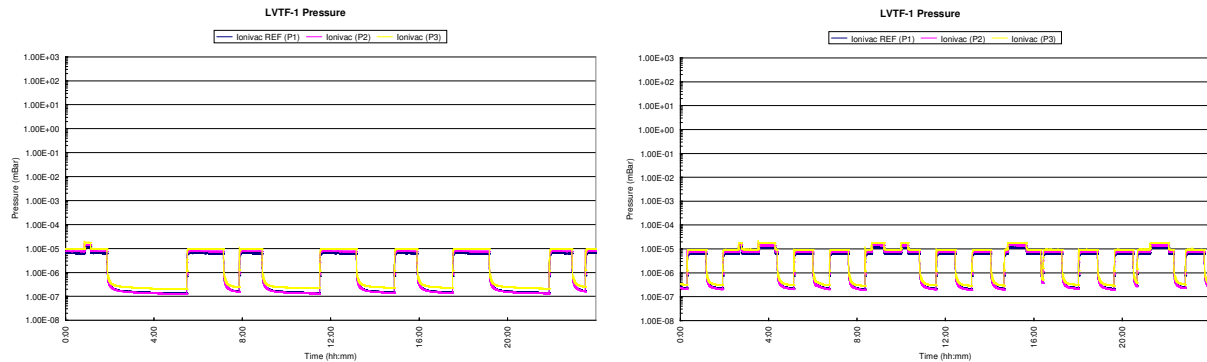


Figure 9. Two different firing sequences of the thrusters.

Table 1: List of failures during Lifetime Test.

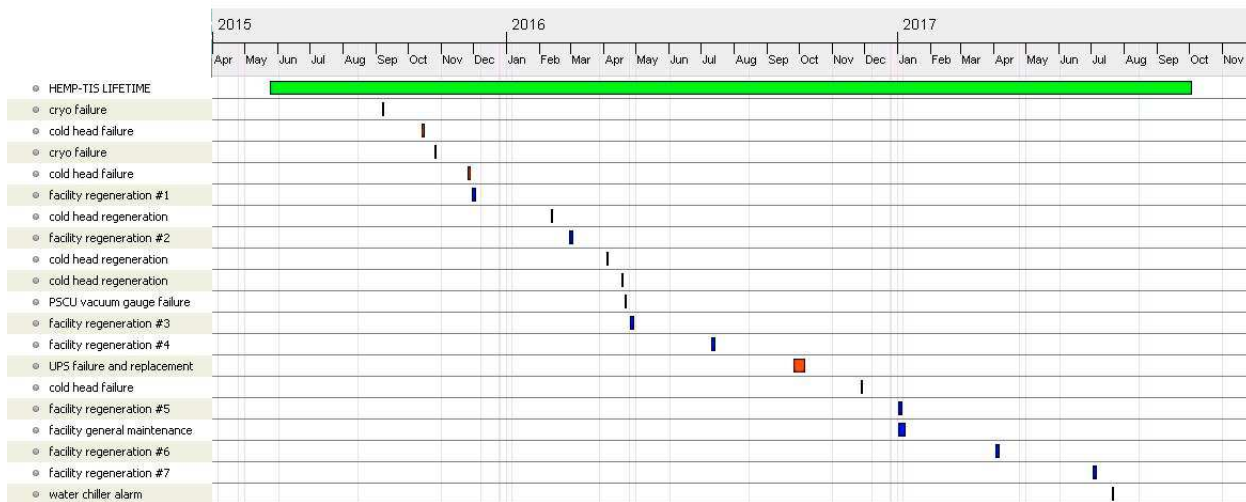
<i>Event</i>	<i>Date</i>	<i>Pause duration</i>
Cryo failure	06/09/2015	23 hrs.
Cold head failure	14/10/2015	48 hrs.
Cryo failure	26/10/2015	20 hrs.
Cold head failure	27/11/2015	46 hrs.
PSCU vacuum gauge failure	21/04/2016	13 hrs.
UPS failure and replacement	26/09/2016	270 hrs.
Cold head failure	28/11/2016	24 hrs.

failures, regenerations and maintenance were minimized and short-lived. The only important failure, which resulted in a significant test pause, involved the UPS system at the end of September 2016; considering the importance and sensitivity of this apparatus, it was decided to replace it with a new one for reasons of reliability.

Table 1 summarizes the test pauses related to the different failures occurred up to now during the progress of the Lifetime Test. Most of them have affected the cryogenic pumping system, anyway taking into account the long duration of the test exceeding 2 years they can be considered insignificant; in fact all of the failures, except for the UPS as described above, have been quickly recovered within 48 hours and not compromised the smooth conduct of the lifetime test. Moreover it must be underlined that all the facility failures have been recovered without breaking the vacuum conditions.

The LVTF-1 pumping capacity was maintained steady along the test,

Concerning the PSCU small chamber it is continuously operating from the start of the Lifetime Test; the vacuum requirement (i.e. $P < 1.0E-05$ mbar) was maintained up to now without any significant interruption (Fig. 11).

**Figure 10. HEMP-TIS Lifetime progress.**

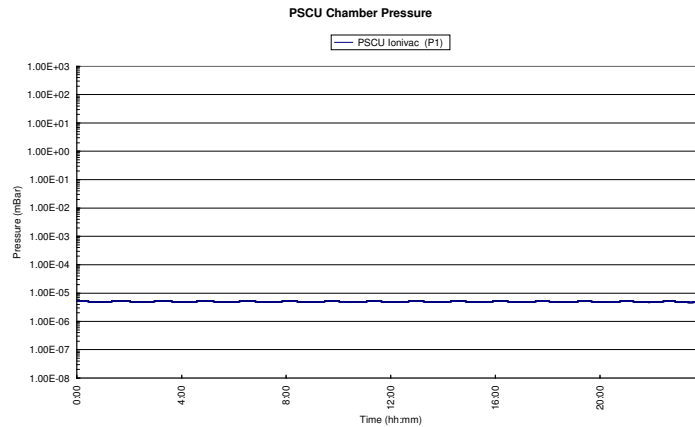


Figure 11. PSCU chamber pressure.

V. Conclusion

The Aerospazio LVTF-1 vacuum facility is hosting under the supervision and control of Thales the Lifetime Test of two qualification HEMP Thruster Modules (HTM-QM1 and HTM-QM2) and one qualification power supply and control unit (PSCU-EQM). This Lifetime Test is one of the most complex ones in the field of the electric propulsion because of the simultaneous firing sequences of two thrusters in the same vacuum chamber.

The LVTF-1 vacuum chamber is demonstrating up to now an high reliability and is guaranteeing the good progress of the Lifetime Test. In these early months of testing few brief interruptions occurred; anyway all the failures on the test facility have been promptly solved without breaking the vacuum operations. The vacuum test requirements are fully complied and the pumping performances are stable over the long-term with no degradation.

This all augurs well for the continuation of the Lifetime Test.

Acknowledgments

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