PPS®-1350-G Qualification Status
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1 - INTRODUCTION

PPS®-1350-G, an advanced design of PPS®-1350 Hall Effect Thruster is undergoing qualification at Snecma-Moteurs for geostationary NSSK needs as defined by ALCATEL SPACE
This paper deals with the qualification status of the thruster. An overview of the heritage from other versions (PPS®-1350 Stentor type), of the initial development tests (with partial life tests), of the current qualification program, will be done. Then, we will describe the current status of the first application in flight conditions : the Smart-1 main propulsion.

2 – HERITAGE OF THE STENTOR DEVELOPMENT

From the Stentor program, the PPS® 1350 demonstrate a lifetime of 2250 hours on ground, which meets Stentor life requirements (including margin)

The development tests were based on an engineering model (called 'MI') which was foreseen to make demonstration of the lifetime specification and on the Stentor qualification model (called 'MQ') that was dedicated to environmental qualification tests plus lifetime.

One of the main concerns was the lifetime behaviour of the thruster so that the 'MI' thruster was tested.

Fig. 1 : PPS® 1350 MI during final expertise

MI Performances at 2250 h :

Number of cycles :	2527
Discharge voltage :	350 V ± 5 V
Discharge Current :	4.27 A ± 0.1 A
Total flow rate :	5.47 mg/s ± 0.05 mg/s
Thrust :	87 mN ± 3 mN
Specific Impulse :	1630 s ± 60 s
Efficiency :	47 % ± 3 %

The Stentor qualified design was validated by qualification model called 'MQ' : thruster was submitted to the environmental tests prior to life test.

'MQ' model was first tested together with Power Processing Unit and Filter Unit during 740 h and 840 cycles (see ref. (1)). Then, an additional lifetime with bench electric supply was performed and achieved additional 1661 h and 1184 cycles
This covers the needs for Stentor program (a total of 2402 h with 2026 cycles has been performed).

MQ Performances at 2250 h :

Number of cycles :	1918
Discharge voltage :	350 V ± 5 V
Discharge current :	4.27 A ± 0.05 A
Total xenon flow rate :	5.41 mg/s ± 0.05 mg/s
Thrust :	89 mN ± 3 mN
Specific Impulse :	1680 s ± 60 s
Efficiency :	48.5 % ± 3 %
Demonstrated total impulse :	0.77 10^6 Ns

Fig. 2 : PPS® 1350 MQ after life test

3 – PPS® 1350-G, AN UPGRADE STANDARD OF PPS® 1350

After first development phases, ALCATEL SPACE refines the requests to a total impulse of 3.5 10^6 Ns with 9127 cycles.
In order to meet these new requirements, changes were made to specific parts of the thruster. In particular, materials adapted to long lasting missions were implemented.
Furthermore, inorder to industrialise the PPS® 1350-G production, it was decided to adopt a simplified architecture in two stages that reduce dramatically manufacturing cycles.

This leads to an upgrade design called PPS® 1350-G :

Fig 3 : *PPS® 1350-G MQ on its tooling for acceptance thermal cycling*

4 – LIFE TEST VALIDATIONS OF PPS®-1350-G MODEL BY PARTS OF PPS®-1350 MODELS

PPS 1350-G parts designs and technologies have already demonstrated a long life capability, but on different hardware configurations.

The table hereunder gathers a synthesis of the current lifetime partial demonstration.
(These are oldest parts lifetimes)

Critical Part (PPS® 1350-G type)	PPS® 1350 n°1	PPS® 1350 MI	PPS® 1350 MQ	PPS® 1350 MI	PPS® 1350-G MQ	Total (Remarks)
Chamber with anode	3547 h / 195 cycles	-	-	1694 h / 1565 cycles	-	5240 h / 1760 cycles
XFC #2 (1470747)	-	3171 h / 3530 cycles	1902 h/ 1504 cycles	940 h/ 895 cycles	-	6041 h / 5983 cycles (with A.T.)
Cathode ME1 (*)	-	5102 h / 5738 cycles	-	768 h / 680 cycles	-	5870 h / 6418 cycles
Assembly of all parts	-	-	-	-	86 h / 79 cycles (December 2002)	Model under qualification test

(*) Two other cathodes where submitted to 6000 cycles of 1 h with success (without thruster).

Picture hereunder shows PPS® 1350 MI at the end of lifetime, after refurbishment by using ceramic chamber with anode of former PPS® 1350 n°1. It can be seen that cathodes are not at all eroded after 5870 h of firing ($1.8\ 10^6$ Ns).

Fig. 4 : PPS® 1350 MI thruster after lifetimes

Figures 5 and 6 show that performances of chamber and anode during more than 5200 h are well inside the requirement and quite constant over the life.

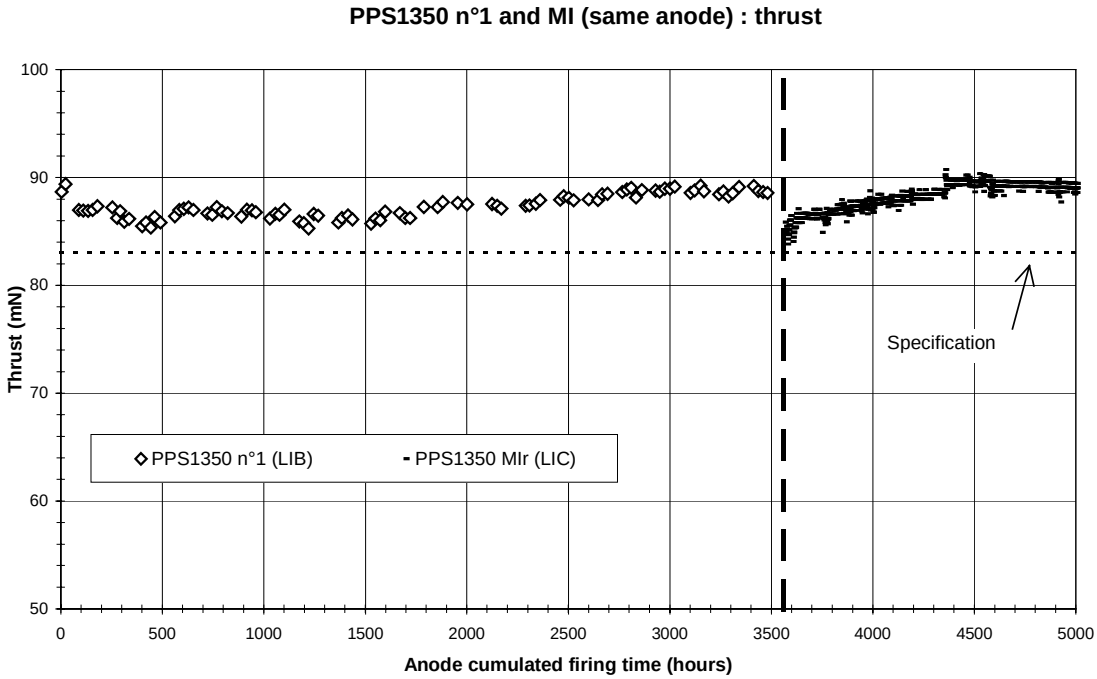

Fig. 5 : PPS 1350-G type Chamber and anode : Thrust

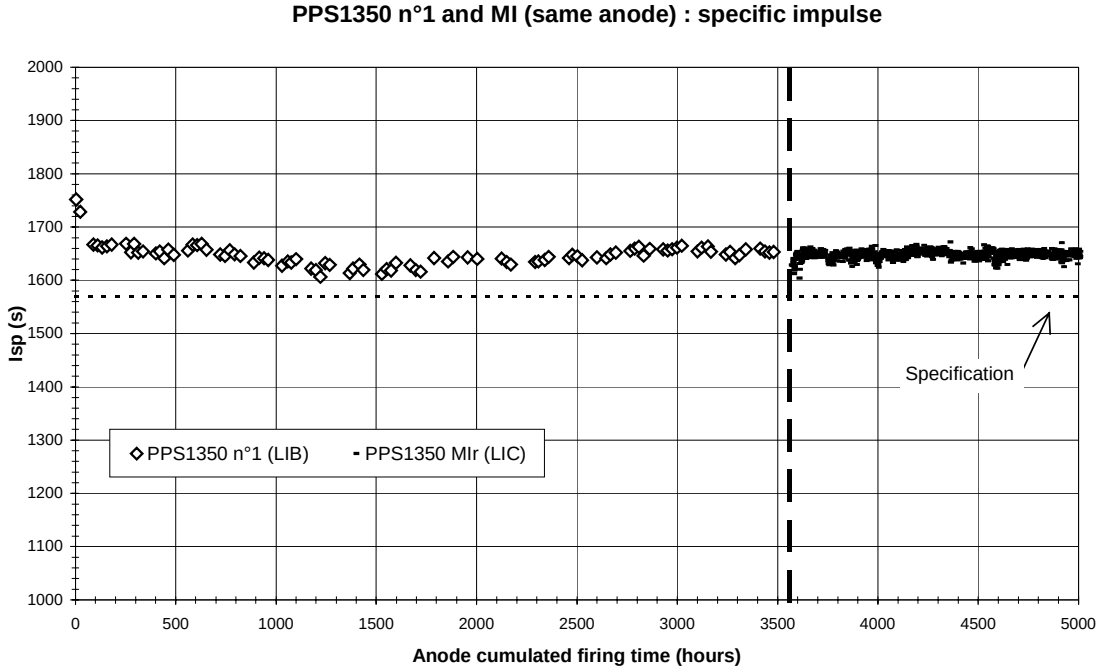

Fig. 6 : PPS 1350-G type Chamber and anode : Specific Impulse

Conclusion : Already demonstrated life of PPS® 1350-G parts give confidence in the capability of this thruster to comply with ALCATEL SPACE life requirements

5 – QUALIFICATION CAMPAIGN OF PPS®-1350-G

The qualification campaign was built around two main steps : an environmental qualification and then a lifetime to achieve 3.5 10^6 Ns total impulse.

The first step was achieved during the year 2002. It is declined in the following major tests :
- Reference performance (initial)
- Qualification thermal cycling
- Thrust vector control
- Additional firing tests
- Qualification vibrations
- Shocks
- Reference performance (end of step 1)

PPS® 1350-G Qualification model performances during initial characterisation (Cathode 1, nominal power) :

Discharge voltage :	351 V
Discharge current :	4.28 A
Total xenon flow rate :	5.32 mg/s
Thrust :	89,1 mN
Specific Impulse :	1706 s
Efficiency :	49.6 %

The two reference performances show that the thruster cross the environmental tests without problems.

The second step, the life test, is under progress.

It is divided in cycles with a first sequence of 7964 h of firing (2.38 10^6 Ns impulse), followed by a second sequence with 1969 h (0.59 10^6 Ns impulse) firing, and followed by a third sequence to achieve at least 3.5 10^6 Ns impulse.

Test conditions are driven by the Snecma-Moteur LIB test bench conditions (ambient temperature of the vacuum chamber), so it is also foreseen to realise during the campaign several temperature cycling in cold conditions in the LIA test bench in order to simulate representative space operating conditions.

We started the test during January 2003 and it shall last until end of 2004. Conducted emissions will be characterised at different stages of the life test and radiated emissions will be characterised on a separate development model.

Coupled tests with flight representative Power Processing Unit will be performed in the course of the life test with the objective of providing a fully qualified Plasma Propulsion Subsystem by the end of the thruster qualification

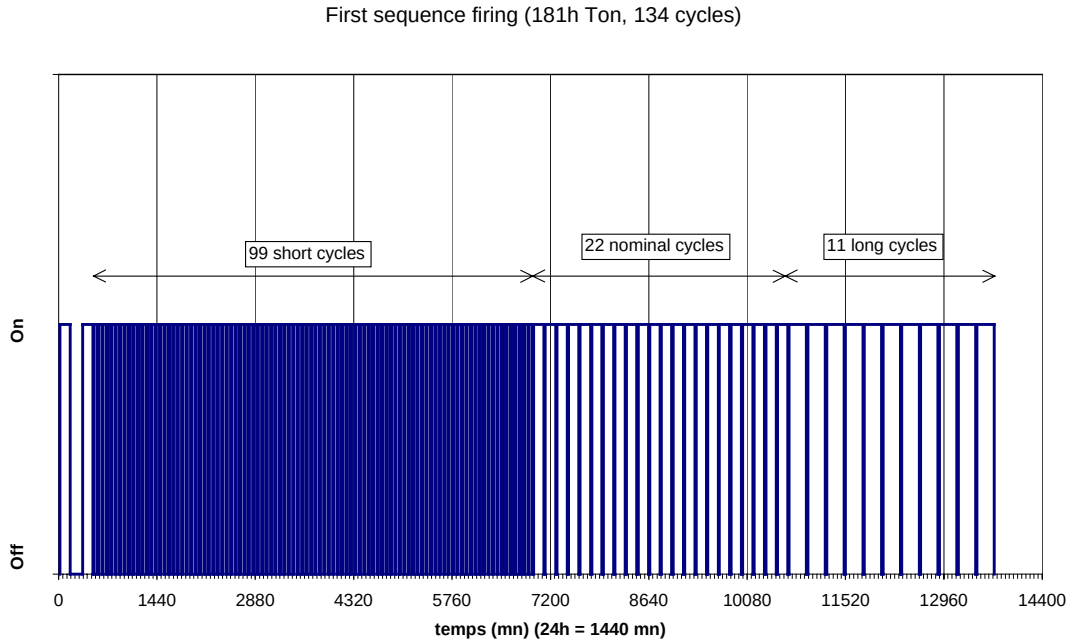

Fig. 7 : typical On/Off sequence during life test

6 – THE PPS® 1350-G FOR SMART-1 APPLICATION

The thruster used in the frame of the ESA program Smart-1 is the PPS® 1350-G that was manufactured in the same time as the PPS® 1350-G QM model. The two designs are strictly identical for what concern the active and internal parts of the thruster. The use of the thruster is however very different from the one foreseen when integrated into a geostationary platform: The Smart-1 thruster is used as a main propulsion system (in the Electric Propulsion subSystem (EPS)) aboard the lunar probe, and not as an orbit control thruster for North-south station keeping. The main difference are dealing with

- The number of switch ON/OFF (10 time smaller for Smart-1)
- The input power (117 power levels are available for the Smart-1 EPS in automatic mode)
- The starting power (always at very low anode power, 462 W, for Smart-1)
- The maximum power (20% lower for Smart-1 because of power constraints aboard the 350 kg probe)
- The xenon mass used for the mission (up to a maximum of 82 kg for Smart-1, ie It <= 1.28 MNs)
- The cumulated lifetime (7 830 hours for Smart-1, taking into account the variable power feature)

In order to verify the performances and the operation of the Smart-1 thruster with respect to the above changes, three tests campaign have been performed:

First a very preliminary short tests campaign has been performed at the Pivoine vacuum chamber facility (GDR) in order to check the feasibility of the starting conditions of the thruster at low power. That successful test was the key issue that allowed the Smart-1 program to progress.

A second test campaign has been performed on a system point of view. The system was composed of the PPS® 1350 MI thruster, a breadboard Filter Unit (FU) and a breadboard Power Processing Unit (PPU) compliant with the Smart-1 requirements. The major goal of those tests was the check of the behaviour of the system during the ignition of the thruster. The inrush current (transient current on the power leads of the satellite power bus) was measured with high bandwidth measurement devices for a number of starts. Those tests showed a full compliance with the predicted data. Moreover, the behaviour of the PPU breadboard was completely checked at that time, including the automatic sequence performed by the PPU software when a request of power change has been sent. That successful campaign was once more the key issue to perform the full development of the EPS.

The last development tests campaign has been performed with the PPS® 1350 MQ, in order to characterise the performances of the thruster in the Ud/Id domain. During the test campaign it was performed also the set up of the trimming parameters able to minimise the thruster oscillations over the large operational map. That parameter is the Magnet trim, an additional current provided by the PPU in order to modify the magnetic characteristics of the thruster. The completion of that tests allowed the final release of the PPU requirement specification, which included the lockup table required to be able to use, in automatic mode, the full range of the 117 power levels of the thruster.(see ref. 2).

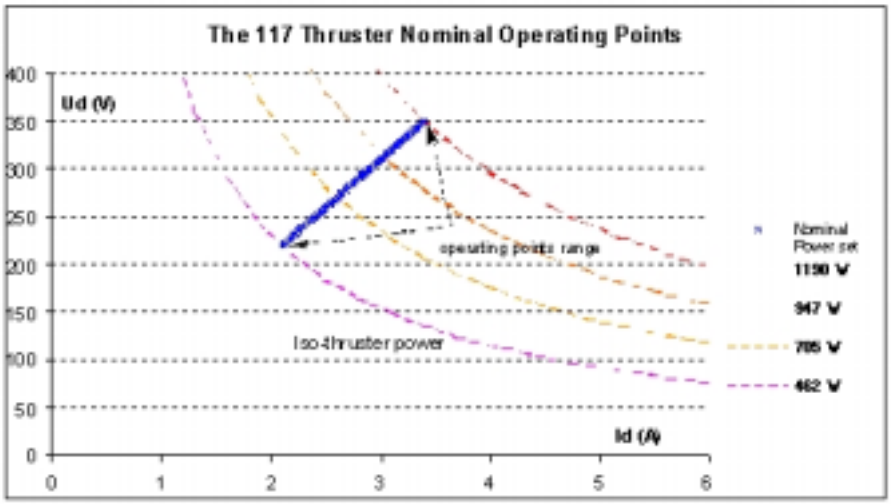

Fig.8 : The diagonal with the 117 steps of the variable power feature of Smart-1 with some iso-Power lines

The PPS® 1350-G Flight model of Smart-1 has been tested during three acceptance test campaign:

First, a common acceptance test campaign including magnet measurement, start ON and performance measurement, environmental tests,… has been performed in order to establish the manufacturing quality.

The second FM campaign was a coupled test campaign with other FM devices: FM PPU and FM FU. The test sequences (at different power levels) were fully checked during that campaign, as well as the right behaviour of the FM devices in real conditions (with the real thruster instead of the usual thruster simulators). The results of that campaign can be considered as the Reference State of the EPS.

Finally, the test of the thruster, at satellite level (End to End tests) has been successfully performed by the Swedish Space Corporation (SSC), the Smart-1 prime contractor in an adequate ESTEC vacuum test facility (large enough for the whole satellite). For the EPS, the goal of that tests was the right behaviour of the whole System, including the sequences foreseen for the xenon lines venting and the behaviour of the xenon pressure regulation. Moreover, the compliance between the different system of the satellite has been checked particularly during the two thruster firing (firing using first the nominal branch, and second firing using the redundant branch). The results of that campaign can be considered as the Reference State of the EPS into the satellite.

On the base of the tests campaign, as described here above, performed in the frame of the Smart-1 program, the thruster PPS® 1350-G has shown its ability for application as a Main Propulsion subSystem.

7 – CONCLUSION

After several years of Snecma and institutions funding in the field of Electric Propulsion, the PPS® 1350-G qualification campaign will demonstrate that an European source of Hall Effect Thruster is available for GEO station keeping missions. Now foreseen end of 2004, such demonstration will significantly improve European competitiveness in the field of commercial satellite and will allow bigger, longer-lasting platforms to be proposed to operators. Other specific scientific missions such as Smart-1 are also achievable with 150-350 kg mass satellite with high ΔV needs.

ACKNOWLEDGEMENT

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