

PERFORMANCE OF STATIONARY PLASMA THRUSTER PPS1350 AND ITS QUALIFICATION STATUS IN RUSSIA

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Abstract

Stationary Plasma Thruster PPS1350 test data obtained during Acceptance and Qualification testing at FAKEL with development model Russia (DMR).

Thruster qualification is being done at FAKEL within a framework of developing 1500 W thruster with SNECMA, division SEP. The thruster was developed using experience of development SPT thrusters at FAKEL, which thrusters flown since 1971 on board of Russian spacecraft Kosmos, GALS and EXPRESS, and also experience of qualifying the SPT-100 to Western standards and delivered for spacecraft SESAT and others.

Development of laboratory and engineering models started at FAKEL in 1995. More than 10 thruster modifications were tested and the baseline design was selected with the best performance in respect of future work. Magnetic and discharge assemblies were optimized. The basic design underwent 1000 hour test to demonstrate the operation reliability at 1350 W power level at FAKEL. Mechanical stress testing was done at the same time. Thruster mockup completed qualification mechanical test in France.

In 1998, development model PPS1350 DMR was developed at FAKEL. This thruster was provided with optimized magnetic and discharge assemblies, improved structural strength; manufacturing technology was improved as well. PPS1350 DMR completed acceptance test at 1300...1630 W. In 1999, after Currently, thermovacuum and mechanical tests are being performed. In a 1999 after qualification thermovacuum and mechanical tests, qualification 7000 hour life test will start.

PPS-1350 DMR performance data at two power levels and voltage 350 V are summarized in table below.

Power, kW	Thrust, mN	Specific Impulse, s	Efficiency
1.35	80.6	1680	49
1.5	89.5	1740	51

The manufacture of Qualification Model (QM) is now completed and the acceptance and qualification tests are begun.

Introduction

SPT/PPS is the Stationary Plasma thruster with closed electron drift (Hall thruster). This kind of thrusters has been flown since 70es in the former USSR and Russia^{1...3}.

The SPT100 thruster has undergone extensive testing and is delivered for Russian spacecraft GALS and EXPRESS as well as SESAT, STENTOR⁴ and ASTRA.

SNECMA, division SEP and FAKEL have jointly developed since 1995 the PPS 1350 Hall Effect Plasma thruster^{5...6}. This thruster is derived from the existing flight proven SPT 100 and is the result of the combination of patents of both companies. The PPS1350 has improve magnetic field distribution and the mechanical design.

Specification requirements

The thruster specifications have been established with CNES, ALCATEL Space, and MMS in the frame of the French Technologic Satellite Stentor where will be used two PPS1350 thrusters and two SPT100 thrusters. Requirements are summarized in below.

Reference specifications

Thrust	88 mN
Discharge voltage	350 V
Discharge current	4.28 A
Xenon flowrate	5.2 mg/s
Discharge power	1500 W
Specific impulse	1720s
Total efficiency	51%
Total impulse	1.44 MNs
Cumulated duration	4800 h
Operating cycles	5200
Divergence	42°

Environmental specifications by temperature and mechanical requirements was represented earlier⁷.

Development Phase

Performance optimization:

Different configurations of discharge chamber have been tested during the second half of 1996; they

are listed in table 1; the best results have been obtained with the A610c configuration.

Table 1. A61 configurations result

Thruster	Id, A	Ms, mg/s	F, mN	Isp, s	Eff
A614	3.92	4.84	78.0	1643	46
A615	3.70	4.67	72.9	1591	44
A618 4200 h	3.90	5.25	73.6	1429	38
A616	4.00	4.93	80.4	1663	47
A610c	4.32	5.15	89.3	1767	51
A617	3.90	4.82	80.4	1701	49
A617-1	3.80	4.83	79.0	1667	49
A619-1	3.93	4.90	80.0	1663	47
A619	4.00	4.92	82.2	1703	49

The comparison tests of model A610c at various benches were conducted.

Table 2. A610c test results at different test bench

Test bench	Id, A	Ms, mg/s	F, mN	Isp, s	Eff
Fakel					
# 71-1-84	3.86	4.90	80.0	1663	48
# 71-3-90	3.87	4.87	80.4	1684	49
SEP	3.71	4.77	80.0	1710	52

At tests A610c at different benches are obtained practically identical.

The improved magnetic system gives increase of specific impulse up to 50... 100 sec and efficiency up to 5... 8%.

These works, done with Fakel and SEP, allowed to prepare the PPS1350 for life testing in order to assess fully the compliance of this configuration to the requirements, specially the life time.

The selected optimized configuration has been the A610 c used up today.

Life testing

The 1100 h life test was performed on the A610c with periodically magnet optimization. Fig. 1 shows the thrust measurement at power 1350 W.

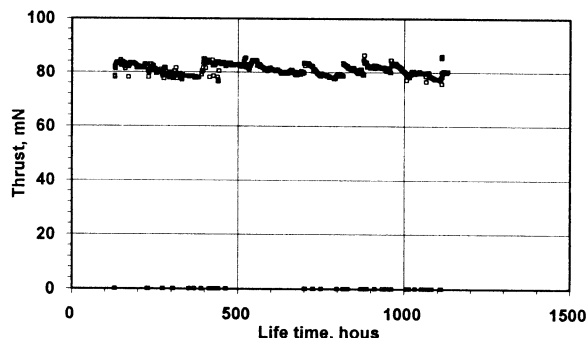


Fig. 1. A610c thrust vs. life time

The positive results life test performed on the A610c and SEP model PPS1350 #1 allowed to freeze the functional design of the thruster.

Mechanical Mock Ups

For the mechanical optimization of the thruster, different vibration tests have been carried out at sub-assemblies and thruster level at Fakel:

- sub assembly discharge chamber with gas distributor;
- sub assembly cathode brackets with cathode mock up.

Vibration tests have been carried out at Fakel's thruster mock up with two real cathodes at SEP. These cathodes are used in DMR

Qualification Phase

Acceptance tests of DMR thruster

The manufacture of DMR thruster was begun in December 1997 after realization of the Preliminary and Critical Design Reviews at SEP in April 1997 and in August 1998.

The view of a DMR thruster after manufacture is shown at a Figure 2. The mass of thruster is 3.6 kg.

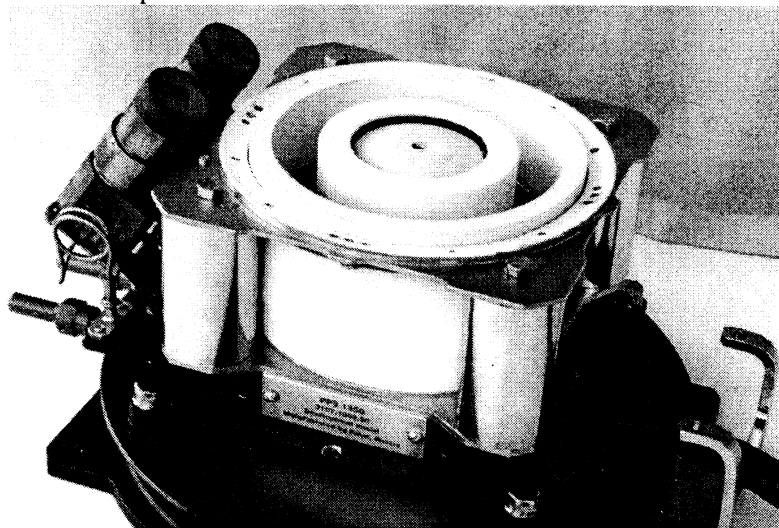


Fig. 2. PPS1350 DMR thruster

The following sequence of acceptance has been done on DMR thruster:

- Inspection and electrical checks
- Firing Test
- Thrust vector alignment
- Thermal cycling acceptance test
- "Hot" firing thermal cycling
- Acceptance vibration test
- Firing Test
- Inspection and electrical checks

Figure 3 give the thruster performance at acceptance tests and Figure 4 give the stability thrust vector alignment at acceptance tests results for the DMR thruster.

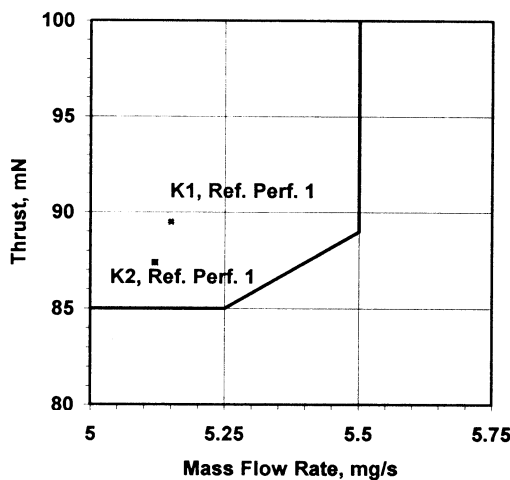


Fig. 3. Acceptance Performance of DMR thruster

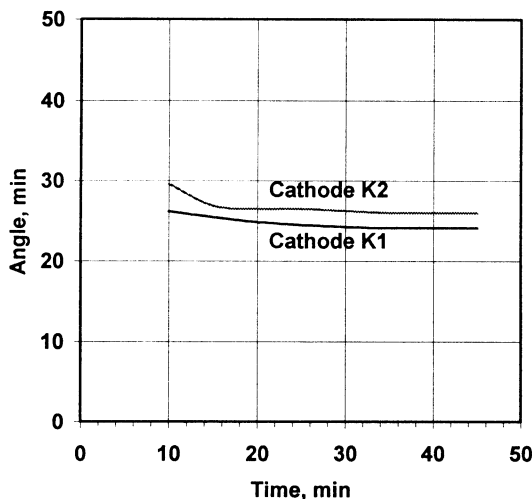


Fig. 4. Thrust vector alignment vs. time of DMR thruster

Qualification tests of DMR thrusters

The following sequence of Qualification tests has been done on DMR thruster:

- Acceptance test
- 5 Thermal Cycles
- Burning test
- Sinusoidal Vibration
- Random Vibration
- Shock
- Reference Performance
- Thruster Fire Tests
- 5 Thermal Cycles
- Reference Performance

The thruster now is exposed life test and the following tests of qualification are planned:

- Life Test
- Reference Performance
- Thrust Vector Alignment Examination

The acceptance and qualifying thermal cycles for XFC has been done with coldest temperatures in relation to required:

- AT: -35 °C (-10 °C);
- QT: -40 °C (-15 °C).

Outcomes the lowest natural frequency of vibration test are following:

- anode unit 260 Hz;
- cathode unit 215 Hz;
- XFC 950 Hz.

Before life test DMR thruster had lifetime and cycles:

- cathode K1 56 h 13 min / 48 cycles
- cathode K2 18 h 20 min / 36 cycles
- (*) total 74 h 33 min / 84 cycles

DMR thruster life test

The life test has been started at 26 of May 1999. The test plan for this test is mainly based on the use of only one cathode (which is the worst case of flight use) and is given below:

- Ton 50 minutes;
- Toff 10 minutes;
- Cathode K2 start every 80 h.

The vacuum facility diagram is shown in Fig. 5. The thruster (1) were inside 20 m³ tank with diffusion pumps (2). The thruster was mounted on the torsion arm thrust stand (3). Thrust was measured with accuracy 2.5%. Propellant and power were provided by the test facility. Xe flow rate was measured with accuracy 3%, electrical parameters - 0.5%.

The diffusion pumps limit performance stability for durable life test. It is confirmed by earlier numerous outcomes of SPT life tests in such conditions.

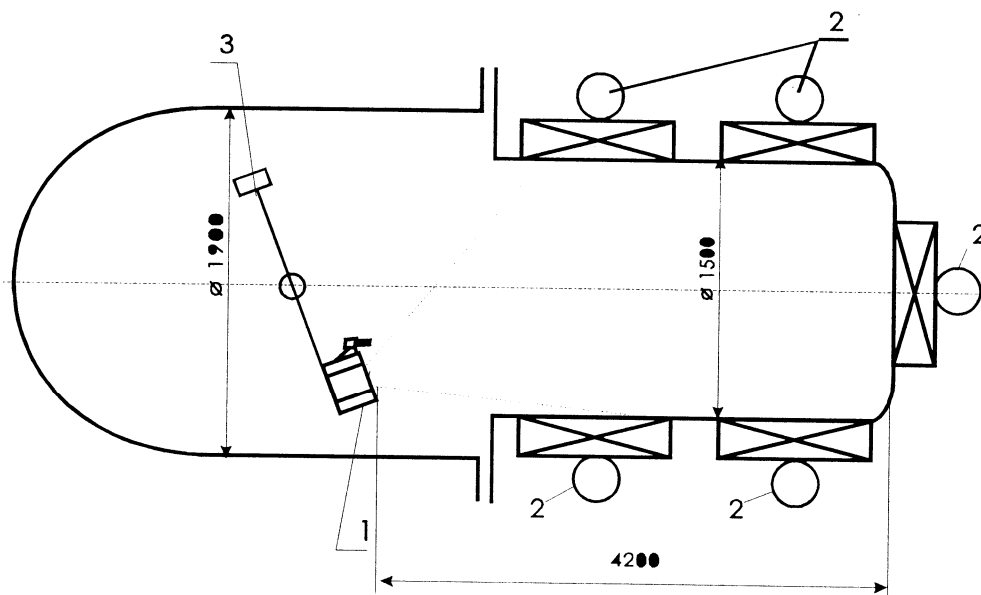


Fig. 5. Vacuum Test Facility and Thruster on the Thrust Stand

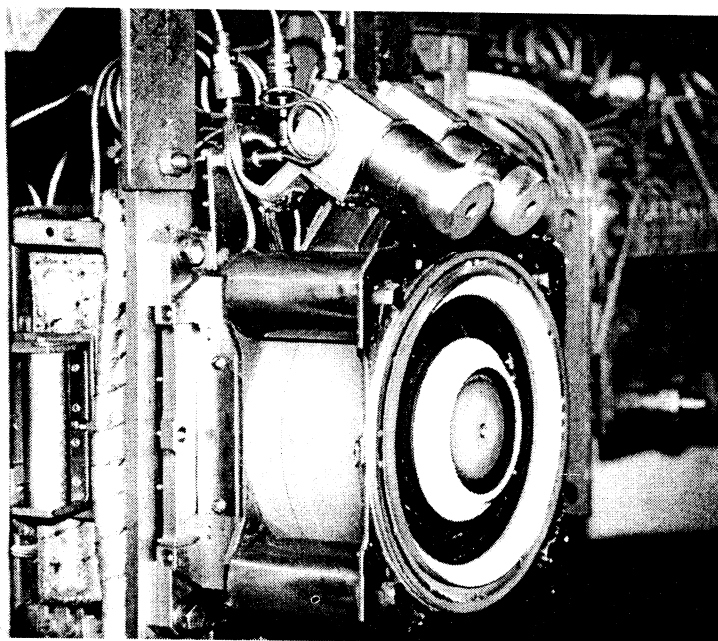


Fig. 6. DMR thruster on the thrust stand

Taking into account FAKEL's experience for life test in such conditions, the discharge chamber was cleaned after 600 hours.

In October 1999 vacuum facility will be arranged with the cryogenic system and life test will be executed in cryogenic vacuum.

The thruster after 1500 h is shown in Fig. 6.

The lifetime data represented in the report, have achieved:

Lifetime	1510 hours (w/o *)
Cycles K1	1804 (w/o *)
Cycles K2	21 (w/o *)

Figures 7...10 give the results obtained on the DMR thruster after 1510 hours and 1804 cycles.

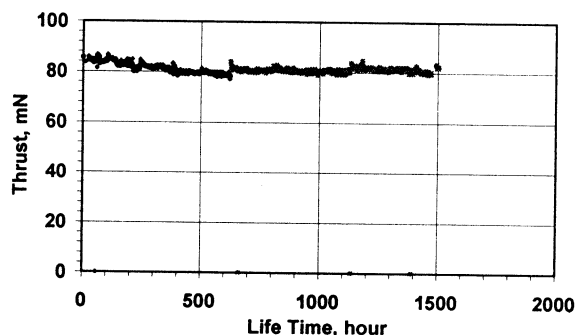


Fig. 7. DMR thrust vs. time

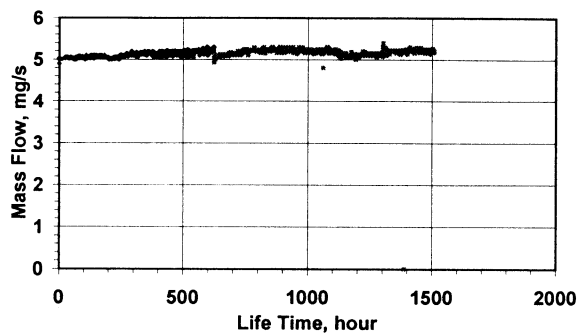


Fig. 8. DMR mass flowrate vs. time

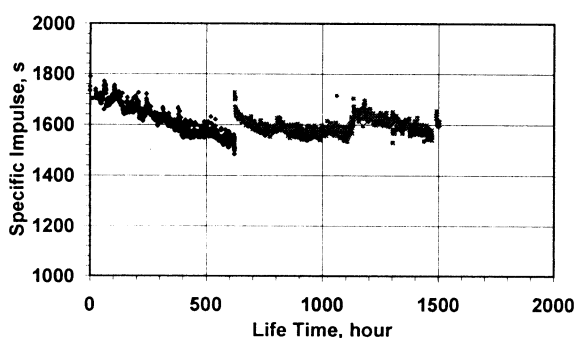


Fig. 9: DMR specific impulse vs. time

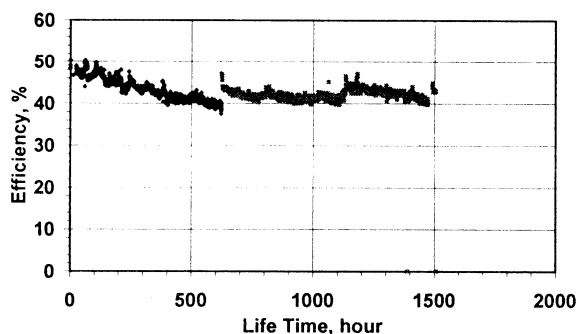


Fig. 10: DMR overall efficiency vs. time

Qualification thruster

The manufacture of Qualification Model of Russia (QMR) thruster was begun in May 1999 after realization of the Critical Design Reviews at Fakel in April 1997 and in August 1999.

QMR thruster will be tested during Acceptance and Qualification tests at environmental requirements in this year.

Conclusion

The PPS 1350 thruster is qualified for the satellite STENTOR.

The lifetime demonstrated is 1500 hours and 1800 cycles of activation with improved specific impulse and efficiency.

The life test on DMR thruster is planned be continued till 7000 h.

Acknowledgments

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