HT100D performance evaluation and endurance test results

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Abstract: During past two years, under ESTEC TRP program "Development of a mini-HET", the Alta low power Hall thruster named HT100, has been scaled up to increase its thrust capabilities in order to satisfy thrust requirement of more demanding drag compensation applications(10-20 mN). The thruster was designed, produced and tested in Alta using the great experience cumulated in the past years in low power Hall thruster field(previous versions of HT100 and HT400). The paper deals with the last results obtained during characterization and endurance test of HT100D performed at Alta during 2012-2013. At the beginning HT100D was coupled with an industrial electron source (SHC1000 by KRI™) to perform a preliminary characterization and a mini-endurance test(200h). In the meanwhile an hollow cathode (ALPHcA) was designed, produced and tested in Alta for low power Hall thrusters (100-800W). The thruster was then coupled with the ALPHcA cathode to perform a complete characterization, the results are shown below in the article.

Nomenclature

AMFR	=	anode mass flow rate
CRP	=	cathode reference potential
CMFR	=	cathode mass flow rate
Id	=	discharge current
Ik	=	keeper current
Vd	=	discharge voltage
Vk	=	keeper voltage

I. Introduction

The HT100 is a low power permanent magnet Hall thruster designed to work in the range 120W-400W. The new version HT100D is the result of the great experience gained by Alta in the last years in the field of low power Hall thrusters. Its design has been performed in order to optimize the thruster performance and to increase the lifetime.

With respect to the previous version the new model presents a completely new magnetic circuit. Great attention has been devoted to the topology of magnetic field that influences thruster performance and erosion processes. In addition, with respect to the previous models, the thermal design has been improved using a passive cooling system able to reduce the thruster working temperature for a fixed power level or to increase the operating power range. Furthermore HT100D is equipped with an internal stainless steel stiffness structure able to sustain all loads, even launch loads. The HT100D has been coupled initially (see Table 1) with an industrial electron source, SHC1000 by

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KRI™. In the meanwhile Alta has developed and tested a new cathode named ALPHcA cathode specific for low power range 100-800W. The cathode is effectively a laboratory model but has produced very good results when coupled with HT100D. It has been able to sustain the main discharge for the entire operating envelope of the thruster with low mass flow rates(0.1-0.2mg/s) increasing total thrust efficiency and total specific impulse.

Period	Items under Test	Test
14-12-2012 -- 23-01-2013	HT100D & SHC1000	Characterization and Endurance Test
25-03-2013 -- 27-03-2013	ALPHcA idle mode	Characterization Test
07-06-2013 -- 13-09-2013	HT100D & ALPHcA	Characterization Test

Table 1 Test campaign schedule

II. General description of the thruster and of the other items under test

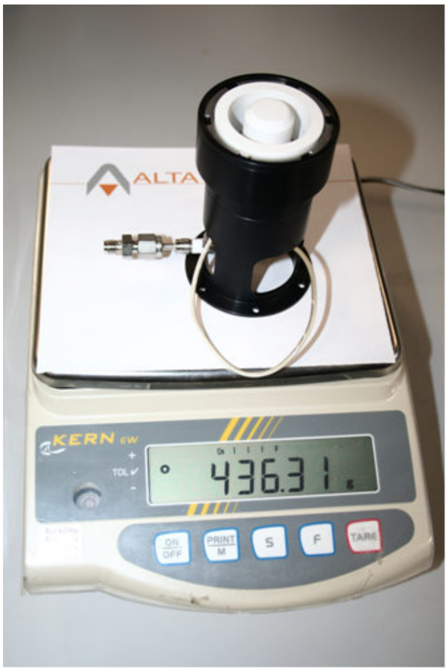

Figure 2 HT100D first assembly.

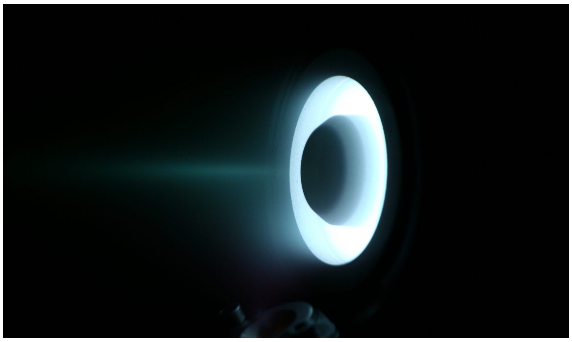

Figure 1 HT100D&SHC1000 firing in IV4 facility, Alta

Performance	HT100D	SPT35
Thrust, [mN]	6-18	10
Power, [W]	120-400	200
Specific impulse, [s]	800-1600	1200
Thrust Efficiency	0.2-0.40	30
Lifetime, [h]	~2000	2500
Mass, [kg]	0.4	0.4

Table 3 HT100D performance compared to the SPT-35.

The HT100D is a permanent magnets low power Hall thruster designed to work in the power range 120W - 400 W with a wide thrust range from 6 to 18mN. The magnetic circuit of this Hall thruster, like the one used in Alta's HT400, is made of two permanent magnets and a magnetic screen. It permits high level of symmetry of the magnetic field lines with completely radial magnetic field at the exit plane of the ceramic channel, maximum value of radial magnetic induction at the exit section, very high positive axial gradient of radial magnetic induction and a wide zone nearby the anode completely free from magnetic field. All this characteristics produce a magnetic configuration capable of very good focusing of ion trajectories on the channel centerline (that means low plume divergence) and high ionization efficiency (that means high ion yield). In total it produces high total thrust efficiency and low erosion rate of the ceramic channel. The second important feature of this thruster is relative to the use of a passive cooling system made by high thermo-conductive materials. It permits HT100D to operate in a wide spectrum of power in a stationary mode, keeping thruster sensitive elements at a relatively low level of temperature. The third feature is a stainless steel stiffness structure capable to sustain all loads applied to the thruster including launch loads. The frame has been designed reducing as much as possible the material used to limit the mass of the thruster(0.436 kg). Each component of the thruster is mechanically connected to the structure. Furthermore the anode has a continuum labyrinth-surface distributor in contrast to most of the anodes present in Hall thrusters. This allows the gas to be injected uniformly into the ceramic channel.

The SHC1000 cathode was used as neutralizer at the beginning of test campaign. Main characteristics of the cathode are presented in the Table 3. This model of cathode is not optimized for space applications and it was not optimized for the current thruster. In particular, the operating level of CMFR is 5÷8 times higher than it is necessary for a stabile operation of HT100. Excess of propellant injected by the cathode results in lower total efficiency and lower total specific impulse values. For this reason during the test campaign with this cathode lower mass flow rates values, out from the nominal range have been tested.

Discharge Current [A]	1-5
Maximum Discharge Current, [A]	10
Ignition tension, [V]	750
Xe MFR(nominal), [mg/s]	0.9-3
Mass, [kg]	0.25

Table 4 Main characteristics of the SHC1000 cathode by KRI™

The ALPHcA cathode designed and developed by Alta as a laboratory model has the characteristics shown in Table 5. The characteristics are optimized for low power Hall thrusters: 100-800W.

Discharge current [A]	1-3
Power, [W]	30
CMFR, [mg/s]	0.08-0.5
Ignition tension, [V]	400-700
Lifetime, [h]	10000
Mass, [kg]	0.2

Table 5 ALPHcA performance

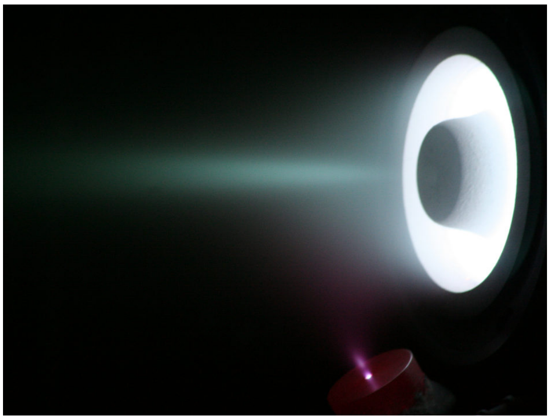

Figure 4 HT100D firing with ALPHcA cathode(KMFR=0.2mg/s) during the thruster characterization.

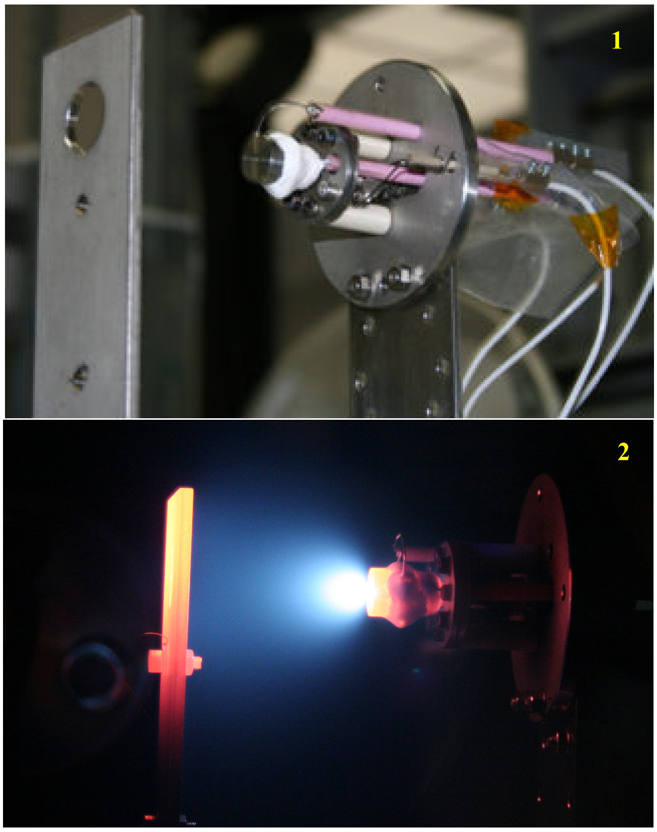

Figure 3 The ALPHcA cathode: on the test bench(1) and during preliminary test(2) on idle mode configuration.

III. Experimental Setup

All test campaigns have been carried out in Alta IV4 vacuum facility; the thruster has been mounted on a thrust balance, the same used in the past for HT-100. An accurate description of the facility, thrust balance and beam diagnostics can be found in Ref. 3. Xenon with a purity grade of 4.8 or superior has been used as propellant. The Electric circuit is based on laboratory power supplies and it is represented in Figure 5. Data acquisition and control system is completely automatic; it has been developed in Labview language.

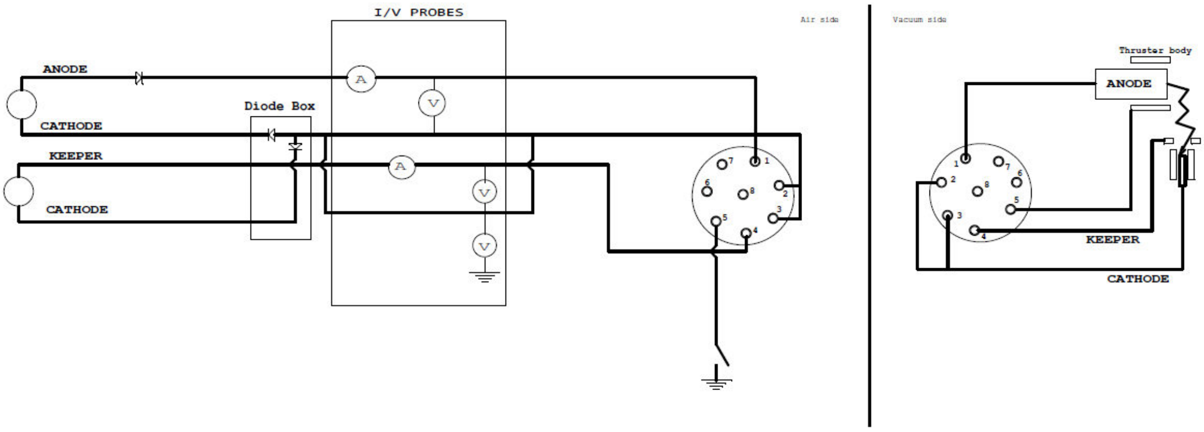

Figure 5 Electrical scheme

IV. Vacuum facility

Alta's IV4 facility consisting of a main vessel (Auxiliary Chamber – AC), 2 m in diameter and 2.5 m in length connected through a 1 m gate valve to a service chamber (Small Chamber - SC), 1 m in diameter and 1 m in length.

The two vessels are both built out of stainless steel AISI 316 L with low magnetic relative permeability ($\mu r<1.06$).

The main chamber provides the volume for expansion of the beam and contains the main pumping system, the beam target and the beam diagnostic devices. The SC is usually dedicated to the installation of the thruster, the thrust stand and all the connections (propellant, power lines, diagnostics) required for the thruster operation. However, for the present test, in order to improve the accuracy of the beam diagnostics, the thrust stand was placed in the AC and aligned with the Faraday cup rake's axis. At the far end of the AC, on the opposite side with respect to the thruster, a bi-conical, water cooled, Grafoil lined target is placed in order to dump the beam energy.

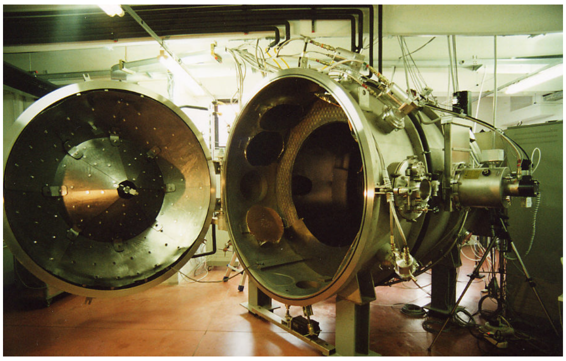

Figure 6 IV4 vacuum facility's layout.

V. Pumping system

The facility is equipped with two independent completely oil-free pumping systems: one connected to the AC and one connected to the SC for redundancy and emergency operations. The main pumping system includes, in addition to a 25 mc/hr rotary pump and a 2000 l/s turbomolecular pump used for evacuation, a cryogenic high vacuum stage based on 1 x 3000 l/s cryopump plus 6 x 12000 l/s custom cold plates. The total pumping speed is therefore in the order of 70000 l/s which ensured an ultimate vacuum <1e-7 mbar and a chamber pressure in the order of <2e-5 mbar (Xe) during the test campaign.
The pressure level within the chamber is continuously monitored by three Leybold-Inficon ITR90 Pirani/Bayard-Alpert sensors, two placed within the SC (i.e. behind the thruster) and one in the AC (nearly at the exit plane of the thrusters). A SRS RGA-200 is placed in the SC to monitor the composition of the residual background gas. Usually all the partial pressures of gases (except Xe) are <1e-7 mbar during thruster operation.

VI. Test Results and Discussion

In Figure 7 are shown some of the experimental results carried out with HT100D and SHC1000 at the beginning of the test campaign. KRI™ cathode is an industrial electron source not optimized for space application. In particular the cathode mass flow rate (0.7mg/s in this case) is higher than the necessary one for the thruster but it is not possible to reduce it because of the cathode operating limits.

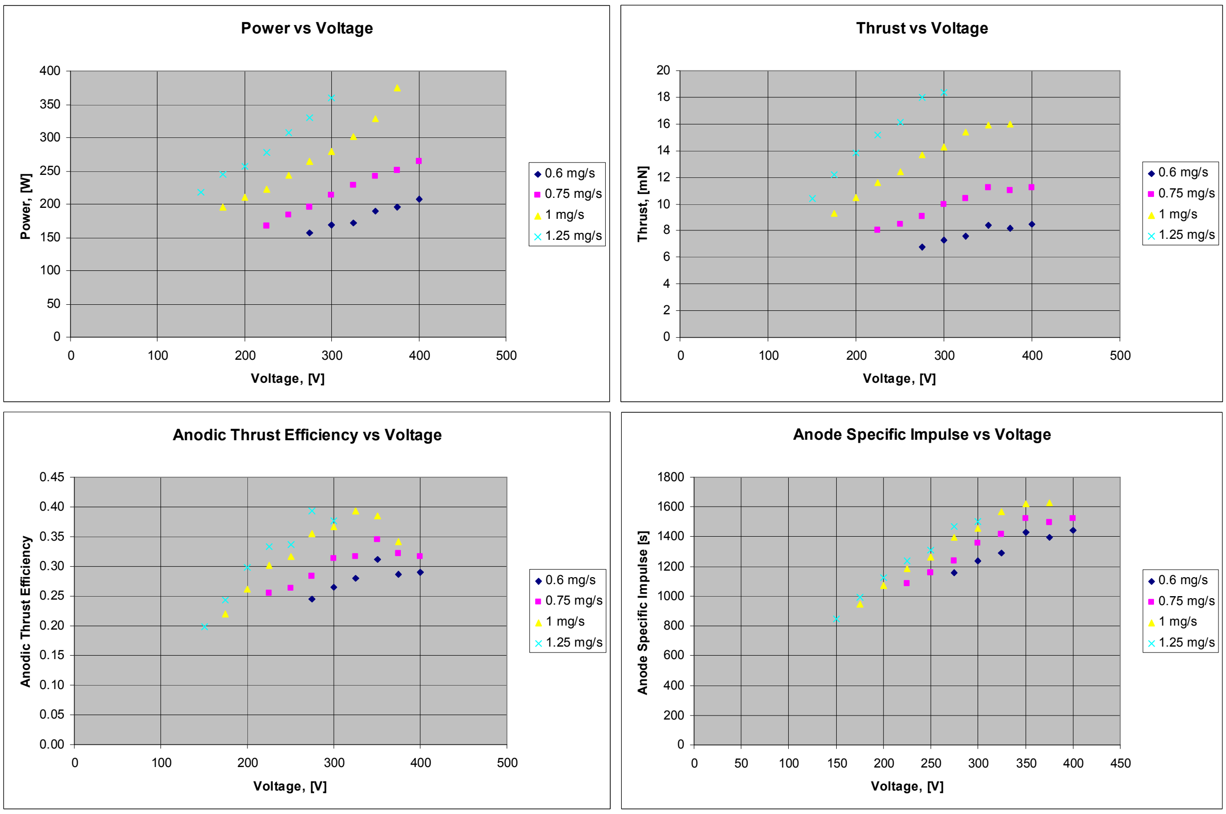

Figure 7 Experimental results of HT100D&SHC1000 (CMFR = 0.7 mg/s): Power, Thrust, Thrust Efficiency and Specific Impulse as function of discharge voltage for different anode mass flow rates

Using the ALPHcA cathode some very interesting results have been carried out. In particular the total efficiency of the thruster has been increased from 25%(with SHC1000)up to nearly 35%(with ALPHcA) and the maximum total specific impulse is now higher than 1400s with respect to 1000s with the SHC1000. These results are very near to the expected ones from the used scaling methods and are comparable with some of the best existing Hall thruster models for this class of power.

MF/V	150	175	200	225	250	275	300	325	350	375	400
0.6						x	x	x	x	x	x
0.75				x	x	x	x	x	x	x	x
1		x	x	x	x	x	x	x	x	x	
1.25	x	x	x	x	x	x	x				

x	Tested
	Stable
	No tried
	Diffuse mode

Table 6 HT100D & ALPHcA cathode. Operating envelope

HT100D&SHC1000 **HT100D&ALPHcA**

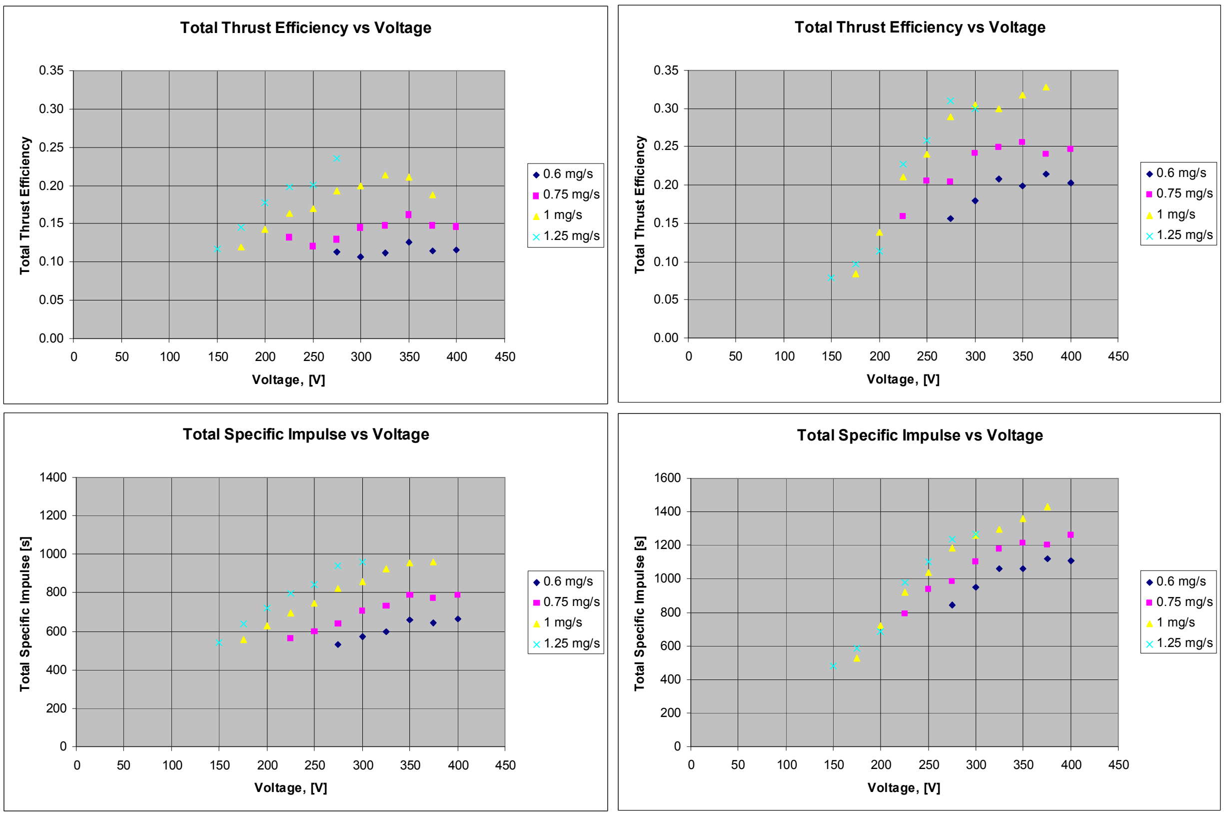

Figure 8 Experimental results obtained with HT100D coupled with the SHC1000 cathode CMFR 0.7mg/s (on the left) and coupled with the ALPHcA cathode CMFR 0.1 mg/s (on the right).

During the test campaign a mini endurance test of 200h has been performed to study the erosion processes and to measure the erosion rate of the ceramic walls. Erosion results are shown in Figure 10. In Figure 11 it is represented the comparison between HT100D and the two previous version of HT100: B-C. Basing on the experimental data the actual lifetime estimation is about 2000 hours.

The comparison between the HT100D and the HT100B(yellow and blue bars) shows lower erosion effects on the internal and on the external ceramic wall: 30% vs 55% (fraction of the initial diameter) on the inner wall and 13% vs 25%(fraction of the initial thickness) on the external wall. With respect to the HT100C(yellow and red bars) on the inner wall the situation is higher erosion effects for HT100D: 30% vs 15% (fraction of the initial diameter) and on the external wall is lower erosion product for HT100D: 13% vs 48% (fraction of the initial thickness).

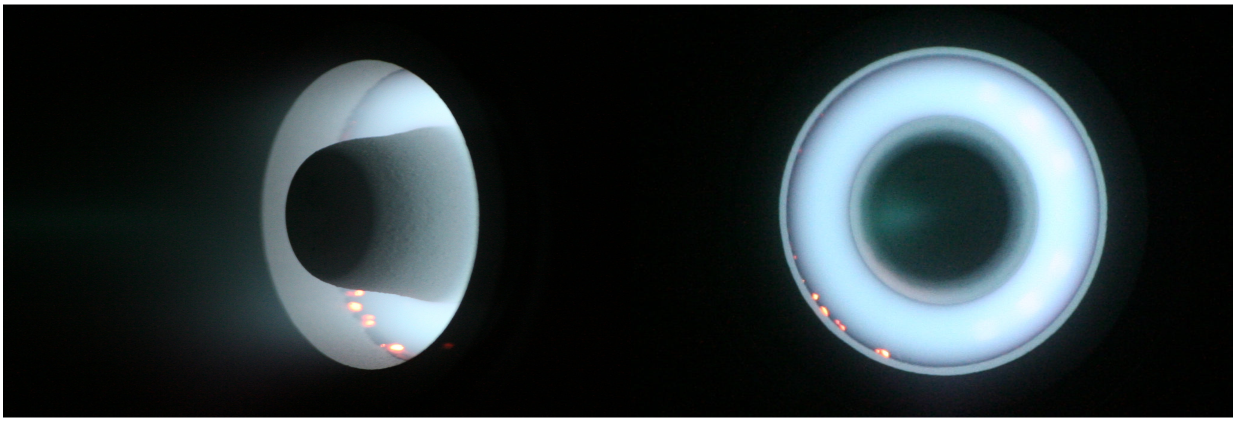

Figure 9 HT100D firing during endurance test at Alta (Vd = 300V, 175W). This picture has been taken after about 160h of test. It is possible to see some hot spots inside ceramic chamber during firing at the boundary between ionization and acceleration region.

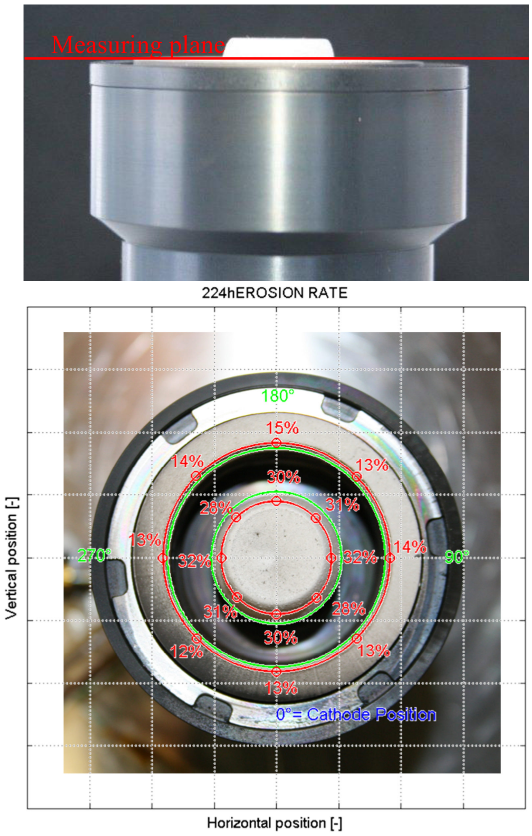

Figure 10 HT100D after endurance test: erosion measurement.

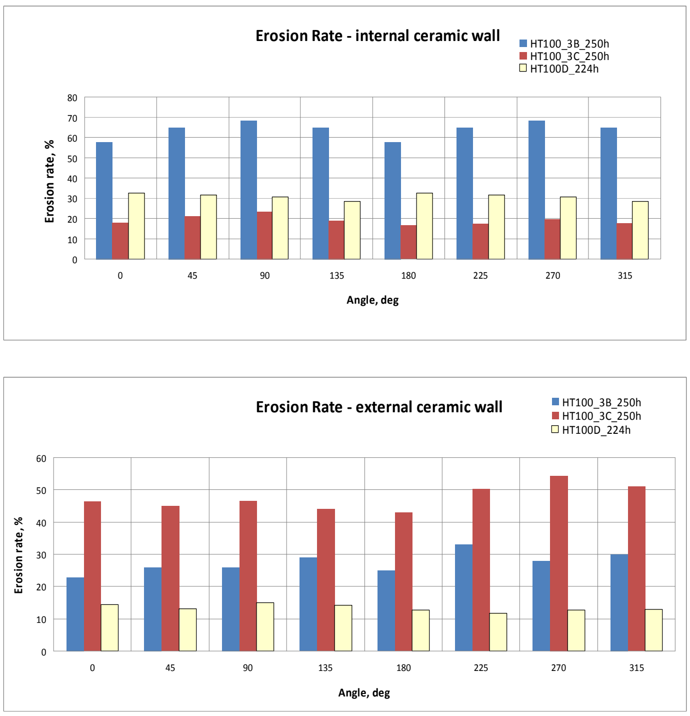

Figure 11 HT100 B-C-D internal and external ceramic wall erosion comparison.

VII. Conclusion

The test campaign carried out on the HT100D thruster allowed the experimental characterization (including direct thrust measurements) of its performance in a wide range of discharge voltages(150-400V) and anode mass flow rates(0.6-1.25mg/s). The results in terms of discharge current and thrust values have been found very near to the expected ones. The thruster has been characterized initially with an industrial electron source(SHC1000 by KRI^{TM}) not optimized for space application. Successive test campaigns performed with the ALPHcA cathode confirmed the good results obtained in the previous test session in terms of thrust values and stability of the discharge over the entire operating envelope. This cathode has been developed by Alta as a laboratory model for low power Hall thrusters(100-800W). Furthermore the reduction of the necessary CMFR from 0.7(minimum value for SHC1000) to 0.1mg/s produced very high Total Thrust Efficiency (up to ~35%) and Total Specific Impulse values (higher than 1400s).

In the meanwhile a mini-endurance test (200h) has been carried out to study the erosion processes and to estimate the lifetime of the thruster. The erosion results have been compared to the previous versions of HT100 and there was a net reduction in the erosion rate on the inner(30% vs 55%) and especially on the outer ceramic walls(13% vs 48%) with respect to the HT100B-C. Basing on these experimental erosion rates data an estimate of the lifetime of the thruster is about 2000h.

Future activities will focus on the optimization of the cathode(model, position etc.) and on the study of different materials for the ceramic channel in order to reduce the erosion effects and increase more the thruster lifetime.

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References

1 M. Berti, L. Biagioni, U. Cesari, M. Saverdi, M. Andrenucci, “Development and preliminary characterization of a low power Hall thruster prototypes”, AIAA 04-3944, *40th AIAA Joint Propulsion Conference and Exhibit, 11-14 July 2004, Fort Lauderdale, Florida*

2 L. Biagioni, U. Cesari, M. Saverdi, M. Andrenucci, “Development Status of the HT-100 Miniaturized Hall Effect Thruster System”, AIAA 2005-3875, *41st AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit, 10-13 July 2005, Tucson, Arizona*

3 M. Saverdi, L. Biagioni, M. Signori, “Experimental characterization of the HT-100 Hall thruster in twin engine cluster configuration”, IEPC 2007-320, *30th International Electric Propulsion Conference, Florence, Italy, September 17-20, 2007*

4 Rossetti, P., and Andrenucci, M.,” HT-100 Development Status”, IEPC-2009-126, 31st International Electric Propulsion Conference, University of Michigan • Ann Arbor, Michigan • USA, September, 20 – 24, 2009

5 Rossetti, P., Dignani D., Ducci C. et al., “Scaling HT100”, SP2010_1842423, Space Propulsion 2010, 3 - 6 May 2010, San Sebastian, Spain

6 Dignani D., Ducci C. et al., “HT-100 Hall thruster characterization tests results”, 32nd International Electric Propulsion Conference, Wiesbaden, Germany, September, 11-15, 2011

7 Ceccanti, F., “Miniaturized Electric Propulsion Systems,” Executive Summary, Alta/MEPS/PM-01, June 2003, Is.1.

8 Marcuccio, S., and Pegoraro, F., "Low Power HET Flight Demonstration and Plasma Experiments on a Microsatellite", IEPC-2009-215, 31st International Electric Propulsion Conference, Ann Arbor, MI, 2009

9 Rossetti, P., and Valentian, D.,” Analysis of Hall-Effect Thrusters application to formation flying and drag compensation”, IEPC-2007-307, 30th International Electric Propulsion Conference, Florence, Italy, September 17-20, 2007