HT-100 Development Status

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Abstract: The paper deals with new results of test campaigns carried out at Alta on HT-100 low-power HET, under development since 2003. Characterization tests with the new Low-Thrust Balance have shown some performance improvement, especially in the low-thrust range with respect to past tests, when a 500-mN full scale balance was used. Through long firing campaigns, HT-100 T01 engineering model has accumulated 600 hours of firing, during which the chamber walls erosion patterns have been well characterized; these results allow to be confident in the achievement of 1500-hour lifetime at the nominal power (100 W). HT100 is ready to enter its qualification phase, for applications such as microsatellites, drag compensation in LEO, attitude control and small maneuvers of orbit control onboard of large platforms.

I. Introduction

IN the last decade, low-power HET systems have been the object of a great deals of interest by both research teams and industrial groups especially in Russia, USA and Europe. Recently the BHT-200, 200-W thruster by Busek Co. entered in operation on the Tec-Sat2 military satellite, for drag compensation application.

In western Europe, HT-100 small HET unit is under development at ALTA since 2003[1-3], following the identification of an interesting application niche for microsatellites, with low power availability but still in need of high performance propulsion[4]. A recent study by Alta on this type of application is shown in a companion paper[5].

Besides microsatellites, the application scenario of HT-100 comprises drag compensation for remote sensing missions from very-LEO and Formation Flying coarse maneuvers (i.e. FF reconfigurations), with thrust requirement in the 1-15 mN range[6]. Looking at the Italian scenario, HT-100 is fully applicable onboard of MITA by Carlo Gavazzi Space (GA) and similar platforms for attitude control and small maneuvers of orbit control.

HT-100 is the smallest and lowest power HET ever developed in Europe; its performance and characteristics represents the state-of-the-art in the segment. The unit has a nominal operating power with xenon of 100 W and implements some design solutions, including a permanent magnets configuration, to simplify manufacturing and integration, thus maintaining recurring costs to a minimum.

The development of the HT-100 subsystem (including the thruster assembly, power supply, and propellant management) entered in Phase 2 in 2006. A number of important milestones have been already achieved, including the delivery of an EM-level Power Supply and Control Unit (manufactured by Alta’s subcontractor Skytech S.r.l.) and several extensive test campaigns on EM-level thrusters, which are summarized in Table 1. Test campaigns until September 2007 have allowed to explore the complete performance envelope of the thruster, to deeply characterize a 2-thruster cluster and to investigate thruster behaviour during first 100 hours of firing at 175 W. The results of those tests have reported in Ref. 3.

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The present paper deals with the results of the experimental campaigns of 2008, aimed to verify thruster performance with the use of a tailored Low-Thrust Balance (LTB) and to assess lifetime thruster capability through a long-firing test.

II. Thruster Description

ALTA's HT-100 is a Morozov-type Hall thruster, equipped with permanent magnets, instead of electromagnets as in conventional SPT devices. At its design point HT100 has a discharge power of 100 W, at voltage and current of 180 V and 0.53 A respectively and is able to provide a thrust of 4.5 mN and a specific impulse of 950 s.

The thruster design is described in detail in Ref. 1 and 2, while in Figure 1 one can see on the left T01 and T02 engineering models mounted on a common structure for cluster tests and on the right the performance envelope of T01 as resulting from the experimental campaigns of 2007. As observable the performance envelope especially lies above the nominal power, until 275 W and the thruster is capable of both high-thrust and high-Isp operations.

Campaign	Period	Place	Objective	Firing hours
1	May 2006	Alta	Prel. Charact.	1.23
2	June 2006	Estec	Prel. Charact.	15.31
3	May - July 2007	Alta	Mapping and cluster test	138.18
4	Sept. 2007	Alta	Short endurance	5.26
5	Dec. 2007	Estec	LTB test	7.17
6	Feb. 2008	Alta	LTB test	55.49
7	Apr. 2008	Estec	LTB test	26.40
8	May-June 2008	Alta	Mapping & Endurance	323.20
Cumulated firing time, hours				573.44

Table 1. HT-100, Phase 2 tests campaigns history. In yellow tests whose results are the subject of the present paper

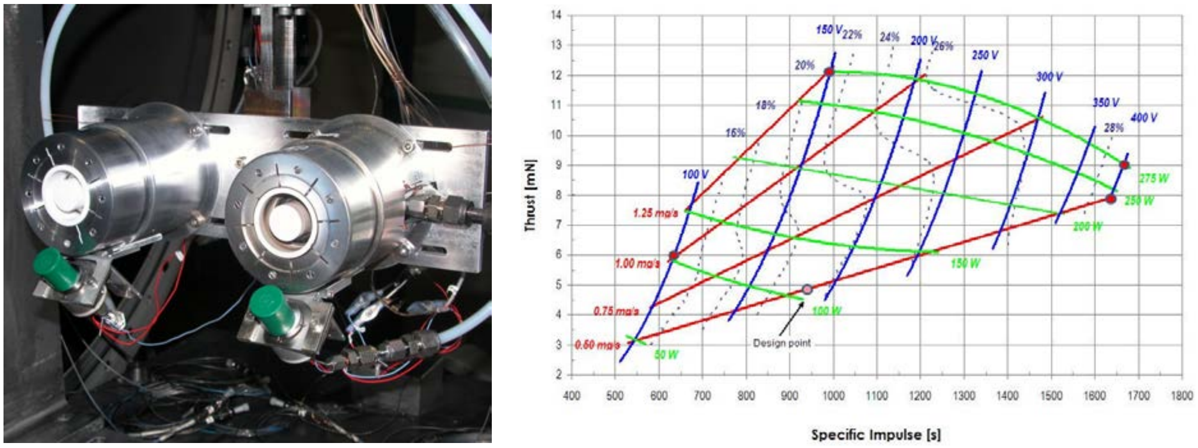


Figure 1. HT-100 in cluster configuration (left) and its performance envelope (right).

III. Thruster Characterization with LTB

Test campaigns in the 2008 were carried out on T01 model with the new Low-Thrust Balance (LTB), developed by Alta under funding from ESA. Except for the thrust balance, the experiment set-up was the same of the previous campaigns and it is amply described in the relevant reference papers.

A. Low-Thrust Balance Description

The Low-Thrust Balance (LTB) has a measurement system based on a laser displacement transducer and a double pendulum geometry. The trim of the stand can be measured with a high sensitivity inclinometer sensor; a couple of stepper motor actuators allows the correction of the stand pitch and roll angles. The stand can be equipped with up to three ¼' gas lines for the thruster propellant supply. The thermal drift effect on the measured thrust, due to the heat flow during thruster operation, is minimized through the optimization of the thruster support geometry and the choice of the used materials. Moreover, a regulated pre-heating system eliminates the long term effects of the residual heat flow towards those components more sensitive to the thermal expansion effects. The calibration of the thrust measurement system can be performed also during the in-vacuum operation, by means of an electromagnetic device. The LTB final specifications are listed in Table 2, while in Figure 2 one can see the balance with HT-100.

Stand overall dimension	380 x 380 x 460 mm
Max operating temperature, stand	100 °C
Max temperature @ thruster interface	200 °C
Thrust measurement full scale (typical, depending on setup)	10 mN
Thrust measurement accuracy (typical, depending on setup)	2 % F.S.O.
Thruster max overall weight	2 kg
Thruster max external diameter	150 mm

Table 2 LTB main specifications

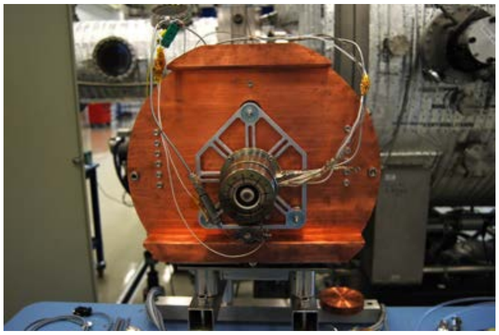


Figure 2 HT 100 on the LTB

B. Test Results

Figure 3 shows the comparison between the thrust data measured by the LTB and those gathered during test campaign of July 2007, when the thrust was still measured by the 2-axis thrust balance for medium to high power thrusters. In both tests the thruster has been equipped with the heaterless cathode SHC-1000 by Kaufman & Robinson (K&R), for industrial application.

The thrust level measured with the 2-axis thrust has the same trend but it is usually lower than the corresponding values obtained with the LTB. The difference can be an artifact due to the 2-axis thrust stand being stiffer at the low thrust values (due to harness, piping etc.) than the mean value obtained by the calibration on the full thrust range (500 N).

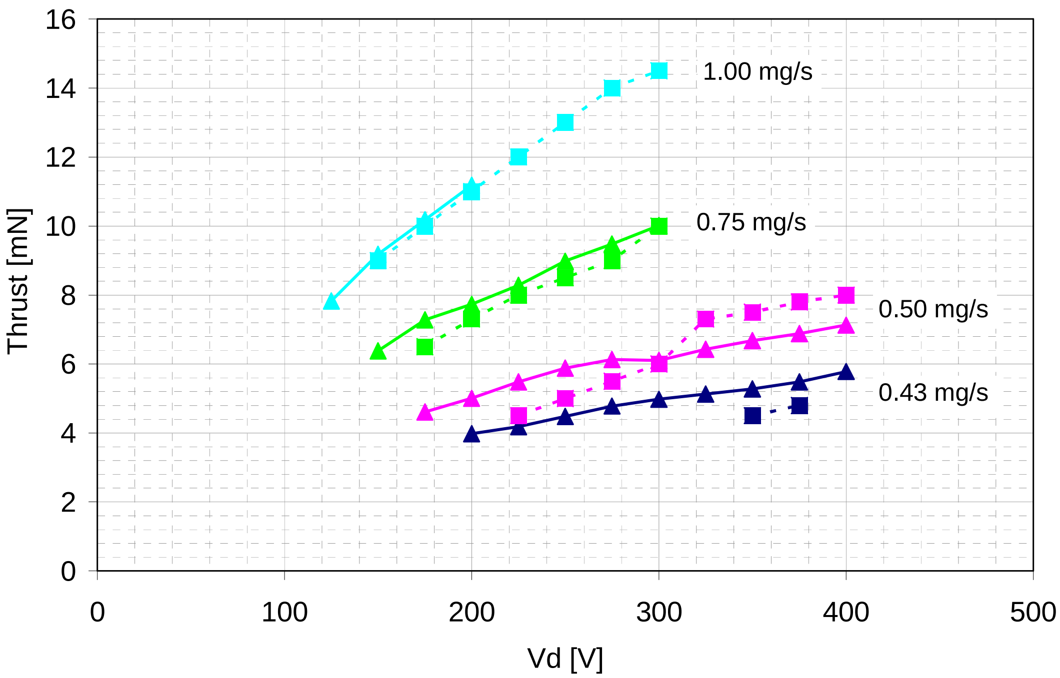


Figure 3. Thrust measurements with LTB (triangle) and with the 2-axis high-thrust balance (square), at different anode flow rates

The sets of data are also separated in time by about 200 hrs of firing during which the shape of the inner wall has changed, leading to a reduction of the interaction with the plasma jet, possibly causing a real increment of the thruster's overall performance. However this phenomenon was seen to extinguish within the first 100 hours of operation, as revealed by the trend of the thruster reference temperature (Figure 4 from Ref. 3), which levels off after about 50 hours, when probably the initial conditioning of the discharge chamber ends, thus reaching the steady state erosion rate.

In any case, LTB allows to be more confident on the thrust measurement; in addition the sensitivity of the LTB has allowed to measure a thrust of 0.6 mN, produced by the cathode discharge on its keeper at 1.5 mg/s, with the thruster off.

The thruster performance as calculated from experimental campaigns with LTB is updated, at least in the explored range, and reported in Figures 5-7, in terms of anode specific impulse, anode efficiency and discharge power.

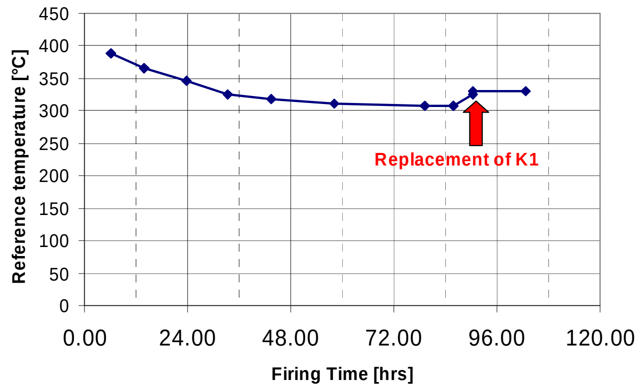


Figure 4. Thruster reference temperature during the first 100 hours of endurance[3].

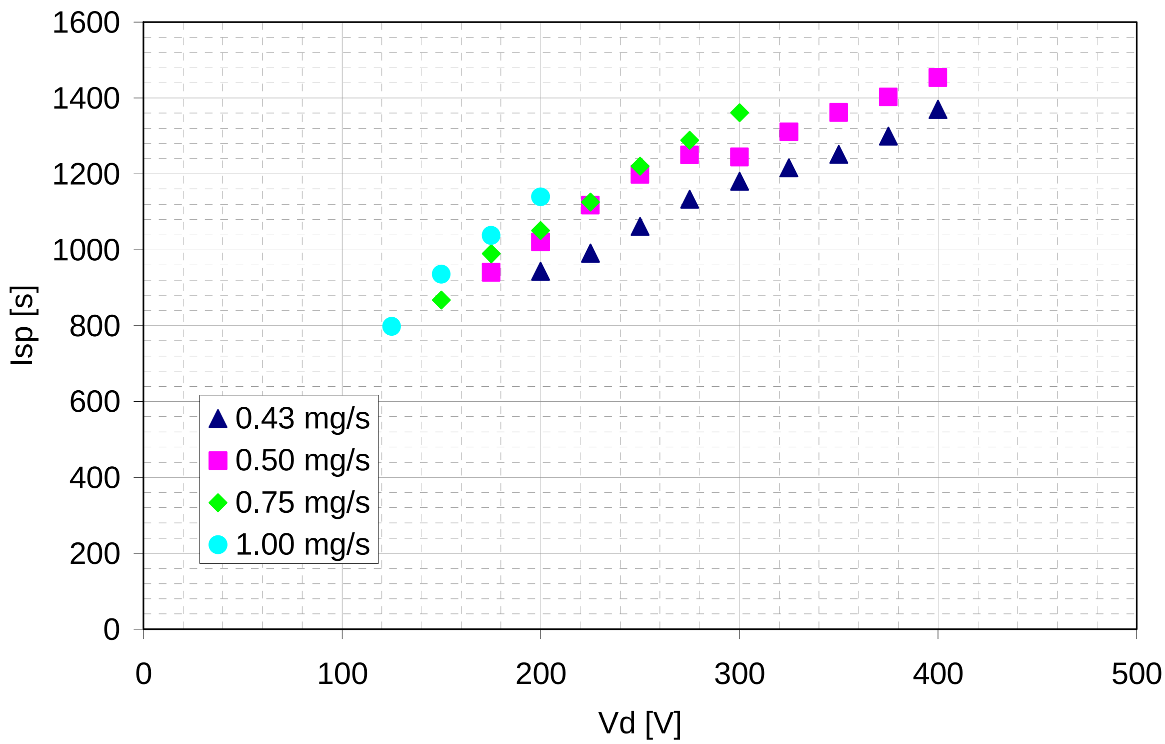


Figure 5. HT100 anode specific impulse from thrust measurement with LTB

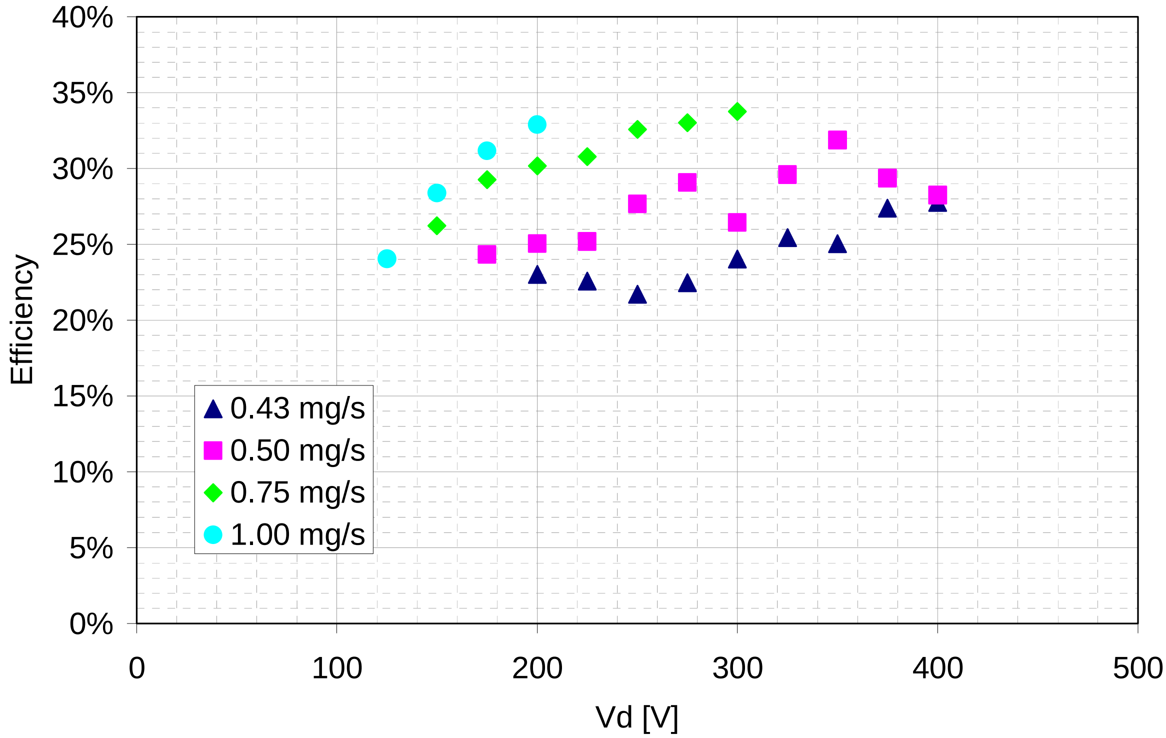


Figure 6. HT100 anode efficiency from thrust measurement with LTB

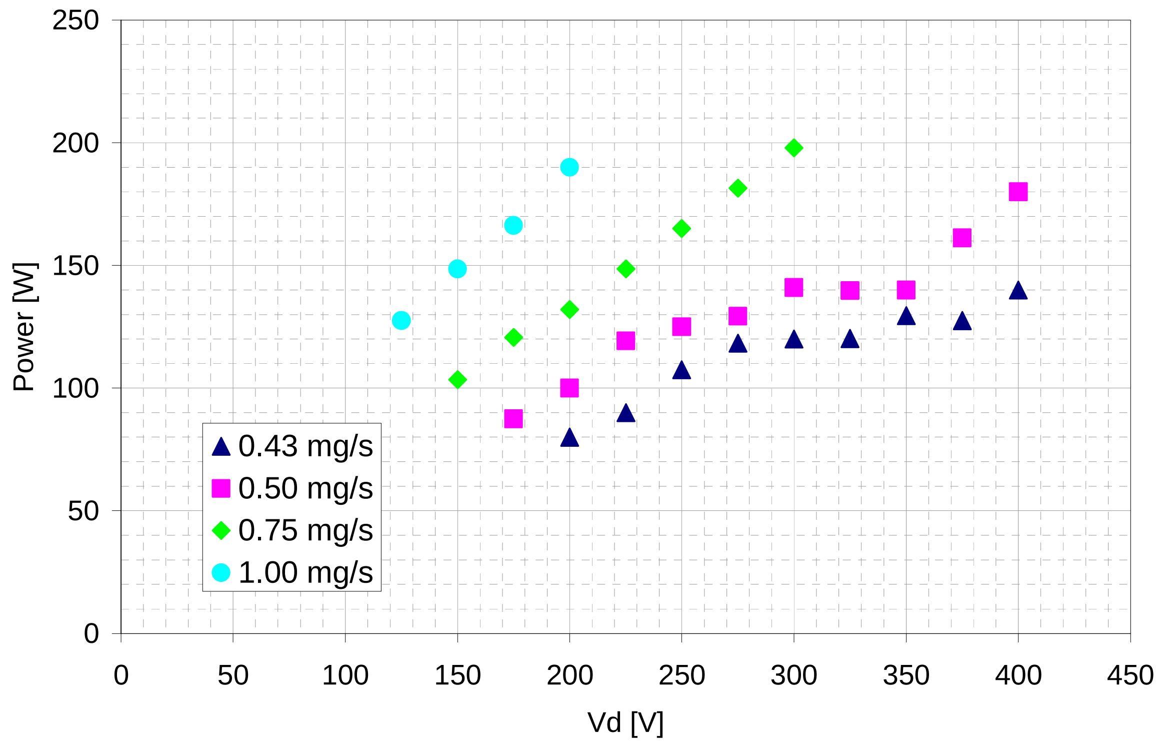


Figure 7. HT100 power discharge

IV. Endurance

By far, T01 model has accumulated 600 hours of operation, most of them during a couple of long-firing campaigns carried out in September 2007 and May 2008, with the thruster operating at 175 W.

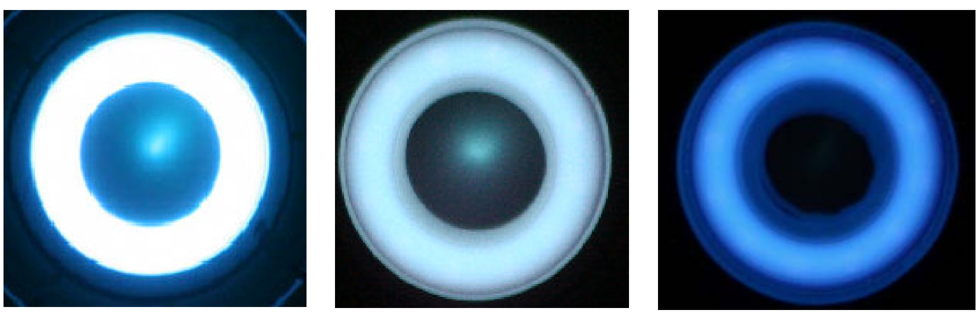
From the point of view of chamber erosion, a number of phenomena has been observed during thruster operation. The erosion of both external and internal walls has been measured by image processing of front-view channel pictures, taken through the flange of the chamber, at almost regular time intervals. Figure 8 shows some of these picture taken after 30, 125 and 300 hours.

Figure 9 reports the evolution of the profile of the inner and outer wall thickness at the channel exit, both normalized with the corresponding initial value, during the first 500 hours. For the internal one two different profiles are reported corresponding to the points of maximum and minimum erosion, since, as can be seen from the middle picture of Figure 8, after about 125 hours the internal wall contour started to become oval.

Without further information, Figure 9 can be misleading, since one could conclude that HT-100 lifetime is limited by the erosion of the external wall, having the internal wall still 50% of its initial thickness after 500 hours against the remaining 30% for the external wall. In fact some millimeters upstream of the exit, the inner wall thickness reduces drastically for internal magnet positioning. At that location the erosion rate is lower than at the exit, but after about 300 hours (see right picture in Figure 8) a hole started to form and progressively to grow in the circumferential direction until to cause after about 600 hours the complete detachment of the part of the ceramic, covering the internal magnet. However the thruster continued to operate, apparently with no significant changes in performance, as also observed in other HET devices. As a matter of fact at that time the test has been stopped because of cathode contamination.

Taking in consideration that the thruster has operated at a power level 75% greater than the nominal one for most of the time and at much higher power during several characterization phases, this result is providing confidence in the capability of HT100 of reaching the estimated lifetime of 1500 hours at its nominal power point.

In any case the trend of erosion has suggested some minor, but probably (and hopefully) very effective modifications of the magnetic configuration, which have been already implemented in the design of the third EM which will be manufactured and tested during the next months.



30 h **125 h** **300 h**

Figure 8. Pictures for erosion measurement. Note the ovalization of the internal wall contour at after 125 hours, the formation of the hole in the ceramic upstream the exit plane (slim dark region at about 45° from the bottom, clock-wise direction) after 300 hours.

V. Conclusions

HT-100 thrust measurement by a Low-Thrust Balance, appropriately designed for low-power thrusters, has confirmed previous results or indicated better performance especially in the low-thrust range. Endurance test allowed T01 engineering model to accumulate about 600 hours of operation, most of them at a discharge power of 175 W, against the nominal 100 W. Chamber wall erosion rate seems compatible with the estimated lifetime of 1500 hours at the nominal power. Nevertheless the erosion patterns have suggested some modifications of the magnetic configuration for extending the lifetime also at higher powers and possibly further improving the thrust efficiency.

A third EM has been recently designed at this purpose under ESA contract. In the frame of the same contract an important activity will focus on the optimization of the cathode (model, position etc.) to improve its coupling with the HT-100 anode. Phase 2 of HT-100 development should be concluded in the middle 2010, when the thruster will be ready to enter its qualification phase.

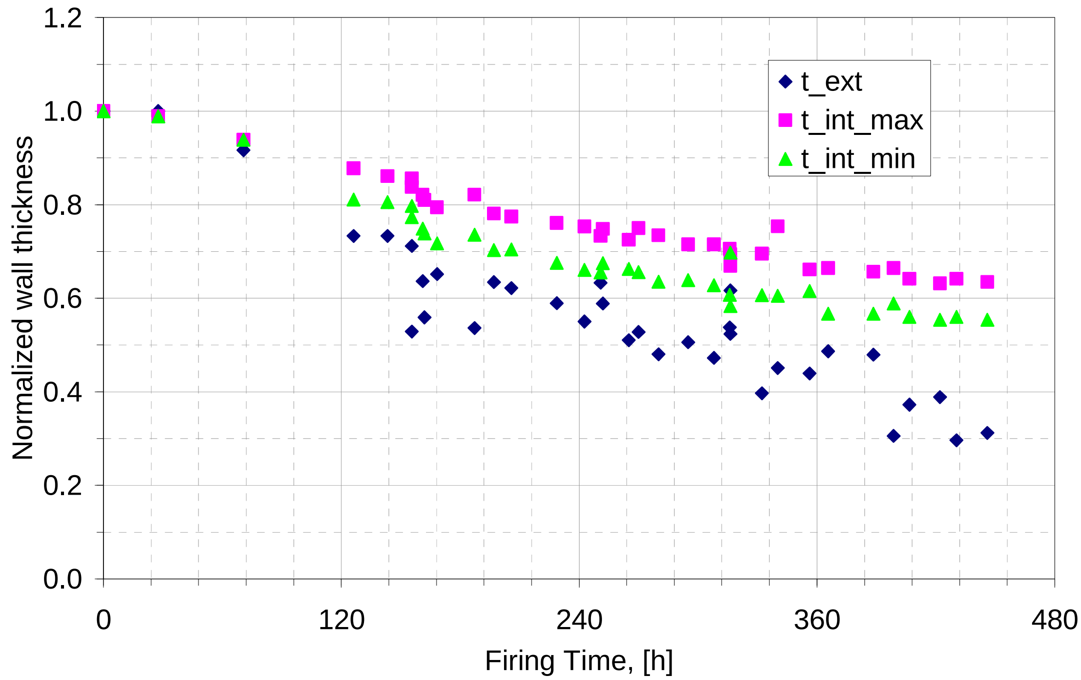


Figure 9. Internal and external wall thickness evolution

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