ANALYSIS OF THE PLASMA PLUME OF THE SPT-20M LOW POWER UKRAINIAN HALL EFFECT THRUSTER

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ABSTRACT

The SPT-20M7 Hall Effect Thruster from the Electric Propulsion Department of the National Aerospace University "KhAI" Kharkov in Ukraine was manufactured at the middle part of 2007 and investigated in the GREMI laboratory at Orléans at the end of 2007 after 50 hours life-time test. During 2008 this thrusters has been tested in Ukraine for a 600h life test with a heaterless hollow cathode M05.5 by "KhAI". This SPT-20 model has been studied in the GREMI laboratory at Orléans for different operating conditions as mass flow rate and discharge voltage. The ion energy distribution was recorded and analysed in different points of the plasma plume by two Retarded Plasma Analyser (RPA).

1.SPT20M HALL EFFECT TRUSTER

The SPT-20M and its performances has been described in previous paper[1,2]. The SPT-20M7 is a low power thruster running with an electric power consumption lower than 100 W and operating with a Xenon mass flow rate of 0.1-0.35 mg/s and with a discharge voltage of 220-310 V. The chamber of the thruster is 23 mm in diameter for the outer ceramics and 15mm in diameter for the inner ceramic. The maximum value of the radial magnetic field is obtained near the channel exit with a value of 20 mT (from experimental data and modelling results). The thrust is from 1 mN to 4.5 mN for an input electric power from 40 to 90 W and the efficiency is in the range 25%-40%. The mean value of the anode discharge current is in the range 0.15 - 0.4 A which was supported by a PPU laboratory model and its time evolution shows a low frequency evolution. The figure 1 shows a schematic view of the SPT-20M

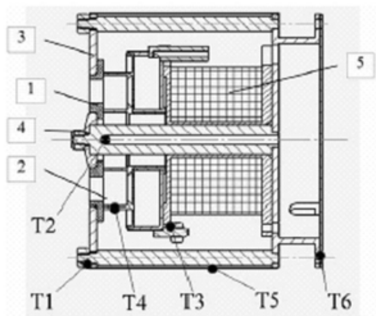
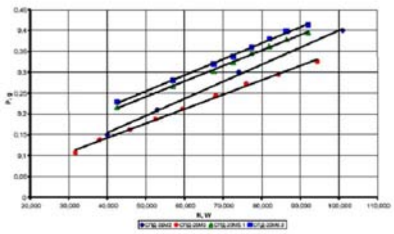


Fig.1 SPT-20M: Schematic view
1: ceramic, 2: anode, 3: metallic flat plate, 4: central pole, 5: magnetic coil
T1, …,T6: thermocouples



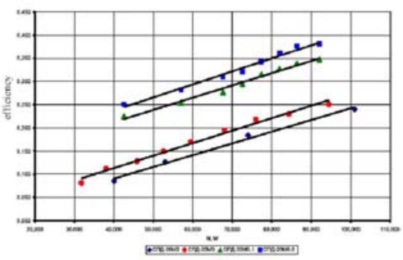


Fig. 2 Thrust and power consumption for the SPT-20M series

2.Ground test facilities

The SPT-20M7 model is studied in a vacuum chamber of the National Aerospace University “KhAI” at Kharkov and in a vacuum chamber at the laboratory GREMI. The first one is a stainless steel vacuum tank 1 m in diameter and 2.5 m long, equipped with the prime and two turbo-molecular pumps. The vacuum tank pressure is kept at the level of $5\text{-}7\cdot10^{-5}$ Tor (for air) under operations (Xe mass flow rate is up to 0.4 mg/s) **a**nd the second one is a stainless steel cylinder of 1 meter length, 0.5 meter in diameter and equipped with three turbo-molecular pumps which allow working pressure of around 4.10^{-5} mbar tarring on air.

Fig. 3 SPT-20M in the GREMI vacuum chamber

Fig. 4 Plasma plume of model SPT-20M6 (KhAI vacuum chamber)

3.Ion energy distribution in the plasma plume

The determination of the properties of the ions in the plasma plume is necessary to optimize the operating condition in order to minimize the plume divergence to increase the thrusters efficiency, to limit the plasma-solar panel interactions and to have some informations on the separation between the ionisation and the acceleration layers: a good separation produces a best acceleration efficiency inside the voltage profile. Morever, ion energy spectra are correlated to electric field fluctuations and the ion velocity can be used to rebuild the electric potential.

Three experimental methods are currently used to obtain the local ion velocity, ion energy or ion energy spectrum.

Langmuir electrostatic probe is a classic diagnostic mainly for electron properties as electron energy distribution, electron temperature, plasma potential and floating potential. Distortion of the characteristic curve (collected current as a function of applied potential) due to noise, hysteresis effect, surface effect, magnetic field effect and sheath instabilities give difficulties to extract satisfying results even in the case of a non collisonal potential sheath. A difficulty in the use of electrostatic probes in the plasma plume of Hall Effect Thruster can be found in the non stationary behaviour of the plasma (low frequency oscillations – “breathing mode”). However, plane probes are usually inserted in the plume to measure the density of the ion current. This current is obtained with a negative potential applies to the probe to repeal all the electrons arriving the boarder of the sheath.

Laser Induced Fluorescence (LIF) is a convenient method to determine the energy distribution velocity in the plasma plume. This method requires a plasma source as reference for the velocity and allows measuring only the component of the ions velocity along the laser beam axis.

A multi-grids probe (Retarding Potential Analyzer - RPA) consists of three or four parallel grids and a collector. The first grid facing the plasma is polarized with a negative potential, with respect to the plasma potential, in order to repeal the electrons from the plasma. The collector is only reached by the ions which energy is greater than a difference of potential between the plasma and the analyser grid placed behind the collector. The signal is obtained by changing the value of the analyser grid potential. It represents an integrated ions energy distribution from which differentiation gains the energy spectrum. Some difficulties can appear with RPA device by perturbation of the plasma (potential, large size, increase of pressure inside the RPA inducing charge exchange), grid effects (non parallel ion velocities) and secondary electron emission.

3.1. Ion energy spectra at the National Aerospace Institute “KhAI” (Ukraine)

The RPA manufactured at KhAI uses grids of

9 mm in diameter (maximal outer diameter of the probe - 19 mm) with holes having a diameter of 0.1mm. The collector is a nickel foil of 0.1 mm in thickness (nickel is used to minimize ion surface pulverisation). The distance between the RPA and the SPT-20M is 140mm and the RPA can be moved in radial direction from 0 to 285mm. The RPA axis is always viewing the center of the thruster exit.

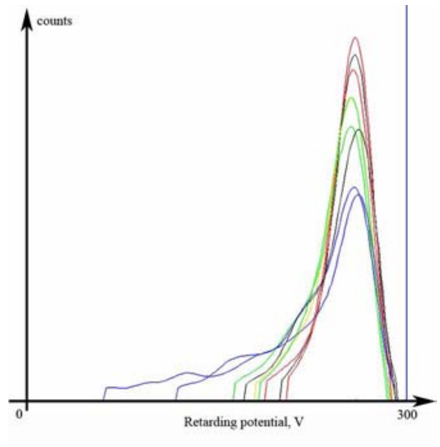
The studied SPT-20M has around 250 hours of running before the RPA measurements. The energy ion distribution was obtained for a xenon mass flow rate of 0.216mg/s, a discharge voltage of 300V giving a discharge current of 0.245A.

The analysis of the recorded data with the measured electric potential distribution in the plume allows an estimation of the ionisation length (about 2 mm and beginning approximately a distance of 2 mm from the anode). The ion energy is constant as a function of the angle related to the thruster axis. However, the shape of the spectrum is strongly disturbed as the RPA is moving toward the periphery of the plasma plume keeping a main pic at 300V. The results show that 95 % of the ionic current is located in a half angle of 42 … 46^{o} and only 30-35 % of the ionic current is found inside an angle less than 20^{o}.

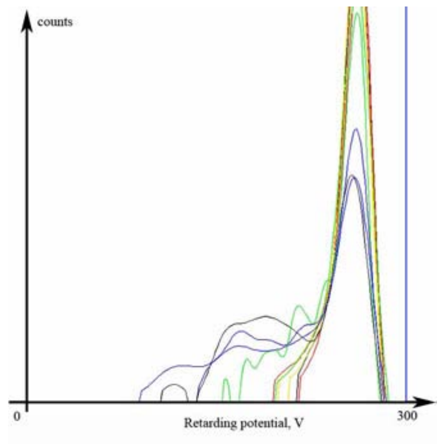
On figure 5(b) and 5(c) the measures recorded by the RPA probe for various angles in the plasma plume are presented with updating M6 and M7 SPT-20 models. For angles more than 20^{o} a characteristic “tail” appears in the domain of small energies but the maximum value of the ion energy spectrum is always located at 300V which is the applied voltage. This effect can be explained by the presence in the boarder of the plume of ions created in the acceleration zone of the thrusters (near the thrusters exit), these ions are accelerated by only a part of the cathode-anode potential. For the M6 model the potential of the cathode is -10….-12V and -20V (to ground reference) for the M7 model and this difference is usually related to different thruster behaviors. We also observe a difference for high energy ions: there is a lack of ions with energy more than 290V for M6 and more than 280V for M7 that correlates the previous remark.

The figure 5(a) details the energy spectrum for the SPT-20M6 for 5 angles 5.3°, 7.5°, 13.4°, 28.0°, 53.3° giving a decrease of the more probably potential <*Ei*> is ligthly decreasing from 262.8V to 258.3V and also a decrease of the mean ion energy at the half amplitude from 249.1V to 195.4V.

a)



b)



c)

Fig. 5 RPA beam diagnostic results (IEDF for (a, b) – SPT-20M6, (c) – SPT-20M7)

The Fig.6 presents the effect of the discharge voltage from 120V to 300V for the SPT-20M7. For this range of discharge voltage, the more probably potential <*Ei*> is quite constant with a value around 260V when discharge voltage is 300V.

The analysis of the presented data indicates that from one model to next model as presented in this paper from M6 to M7, but also from the first model, the performances are improved and the global efficiency growes from 23% to 38%.

3.2. Ion energy spectra at the GREMI laboratory (France)

The SPT-20M7 plasma plume has been analysed in the vacuum chamber of the laboratory GREMI (Dec. 2008) (Fig. 3) with a RPA manufactured by this laboratory. The two RPA devices exhibit some differences as potential of the first grid: -10V for RPA from GREMI or -60V for KhAI one, diameter of the holes of the grids: 0.4mm

(GREMI) or 0.1mm (KhAI), distances between the grids: 3 mm (GREMI) or less than 1mm (KhAI), range of retarding potential: 10..400V (GREMI) or -10..360 V (KhAI), material used for the collector stainless steel (GREMI) or Nickel (KhAI), outer diameter of the device: 23 mm (GREMI) or 19 mm (KhAI), inner diameter: 4 mm (GREMI) or 9 mm (KhAI), time of recording collected current: 3 minutes (GREMI) or depends on numbers of points and doublings, time of recording in one point 30-60 ms (KhAI), method of analysis of the signal: computer smoothing and derivative (GREMI) or computer automation with max number of points of 255 and nominal number of doublings of 16 (KhAI).

In the GREMI vacuum chamber the RPA is always viewing the center of the SPT-20M and can be angularly moved (maximum angle of 35°) at a distance from the thruster of 30 cm. The ions mean free path is greater than this distance to allow an imaging of the ions characteristics from the channel exit.

The curves of the figures 6 shows RPA characteristic curve and ions energy distribution function for two different angular views: 0° and 15°. The discharge voltage is 301 V and the mass flow rate is 0.27 mg/s. SPT-20M thruster, cathode and electric supplies are the same as for the tests carried out in the KhAI facility, but size, static pressure, pumping system of the chamber and mass flowmeter are different. Moreover, the number of previous hours of running of the thruster is different. It reached around 600 hours for the measurements by RPA at GREMI.

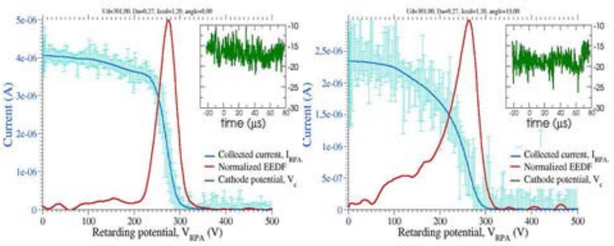


Fig. 6 RPA characteristics and ions energy spectra of the SPT-20M7 (GREMI laboratory). Coil current of 1.2A for at 0° angle (left) and 15° angle (right).

A characteristic "tail" appears at 15° in the domain of small energy spectrum (less than 200 eV) as in KhAI (see Fig. 5c). Due to the low operating pressure, the energy loss by inelastic collision can be throw into discard. The ions at these low energy domain should be created near the exit plan of the thruster where the accelerating field is lower.

A summary the angular results are presented in figure 7 for an operating condition of discharge voltage of 301V, mass flow rate of 0.27 mg/s and coil current of 1.5A. The viewing angles are from -25° to 35° with a step of 5°. The 0° angle is corresponding to a measurement on the thruster axis. The negative values are corresponding to the cathode side and positive values for the opposite side.

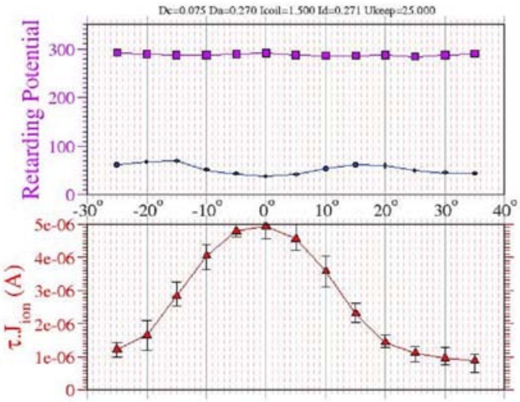


Fig. 7 Summery of the angular RPA measurements of the SPT-20M7 (GREMI laboratory). Squares: more probably energy, Circles: full with at half maximum of the main peak of the energy spectrum, Triangles: Relative ions current density.

The fig. 7 shows a great symmetry of the thruster plume. The same value is measured in the KhAI vacuum chamber and it corresponds to a retarding potential value of 280V which indicates a satisfying anode-cathode potential efficiency. This value is recorded for each angle. This result can be explained by the fact that the corresponding ions are created with the same potential energy. Because the operating conditions are the same, the ionization position in the channel can be estimated near the anode, in the ions source region, from the potentials distribution recorded in the KhAI vacuum chamber. The full width at half maximum of the ion energy distribution takes only in count the main peak of the energy distribution curve. The natural broadening of the RPA device is about 20 V and the broadening is about 20V on thruster axis which correspond to a great value.

The accessible angular amplitude in the GREMI laboratory vacuum chamber. do not allow measuring the half plume angle.

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