PLUME STUDY OF MULTIMODE THRUSTER SPT-140

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Abstract

Plume test data of Multimode Stationary Plasma Thruster SPT-140 are presented. This testing was carried out at FAKEL within a framework of thruster Development Model (DM) qualification.

This work is being carried out at FAKEL in a framework of advanced Hall thruster development effort under the program Integrated High Payoff Rocket Propulsion Technology (IHPRPT). Special requirement to the SPT-140 was capability of operation in a wide range of power from 2000 up to 4500 W at efficiency over 55% and life 7200 hours. The thruster was developed on a basis of SPT developed at FAKEL in 1988 and using experience gained in joint efforts with ISTI in 1996...1997, in which efforts RIAME MAI was a participant. Experience of qualifying the SPT-100 to Western standards was also used.

SPT-100 was tested in 90-es in Russia and the USA at pressure as low as $10^{-5}...10^{-6}$ torr (by Xe), using various probe kinds (Planar, Planar with Guard Ring, Faraday Cup, etc.). Analysis of data indicated that, using a Retarding Potential Analyzer (RPA) in ion current measurement mode, background plasma is cut off and data of measurements taken at 10^{-5} torr agree with those taken at 10^{-6} torr.

The measurements were taken at three nominal power levels: 2000, 3000 and 4500 W (discharge current 6.67, 10.0 and 15 A, discharge voltage 300 V). Discharge parameters and total Xe flow rate during thruster operation were maintained by test facility power and propellant subsystems. Plume test was carried out in parallel with qualification thrust test in test facility equipped with cryogenic Helium vacuum pumps. Vacuum during test was as low as $1.6*10^{-5}...3.2*10^{-5}$ torr by Xe at current 6.67...15 A.

Angular distribution of ion current density was measured during the testing while ion energy was measured with a 1-grid RPA probe. The probe was moved in a horizontal plane along an arc within an angle 180°. Center of rotation was coincidental with thruster exit plane, rotation radius was 1 m. The probe grid had negative potential to cut off electron component of current while collector had positive collecting potential.

This test demonstrated that the least divergence and hence the most optimized plume shape occurred with thruster operating at 4500 W. At this power level, plume divergence decreases by 6...8° in respect of 2000 W operation mode. Plume divergence in 2000 W mode is close to that of SPT-100.

Introduction

Stationary plasma thrusters with closed electron drift have been widely used for about 28 years in former Soviet and Russian spacecraft systems for orientation and positioning[1...5]. This flight heritage and the SPT's unique performance characteristics make the possibility of exploiting them on western spacecraft a topic of considerable interest[6...8]. One of the most important issues is the compatibility of the SPT with onboard systems of the spacecraft. Effects of the SPT-100 plume, including forces and consequent attitude disturbances, heating, erosion and contamination on spacecraft surfaces and solar panels, was be quantified[9...11]. The SPT plume influences on the spacecraft solar arrays include force, heating, erosion and contamination. The SPT plume contains fast ions, neutral atoms, and slow ions that appear due to charge exchange between fast ions and neutral atoms, as well as particles of sputtered and evaporated material from SPT components. The ion flow in the SPT plume is capable of substantial erosion rates, especially in the center.

This paper is described plume test of multimode thruster SPT-140[12, 13].

Test Subject

This paper is included test results SPT-140 in different life configuration:

- new thruster at Acceptance Test;
- thruster after Qualification Test (100 h);
- thruster during life test: 1080 h; 2250 h.

Test Conditions and Procedure

The tests were conducted at FAKEL, to measure the distribution of current density and ion energy at far SPT plume.

The SPT-140, which nominally operates at a discharge current 6.67, 10.0 and 15 A, discharge voltage 300 V, was located at the axis of a vacuum chamber having cryogenic pumps, a diameter of 2.5 m, and a length of 6 m (Fig. 1).

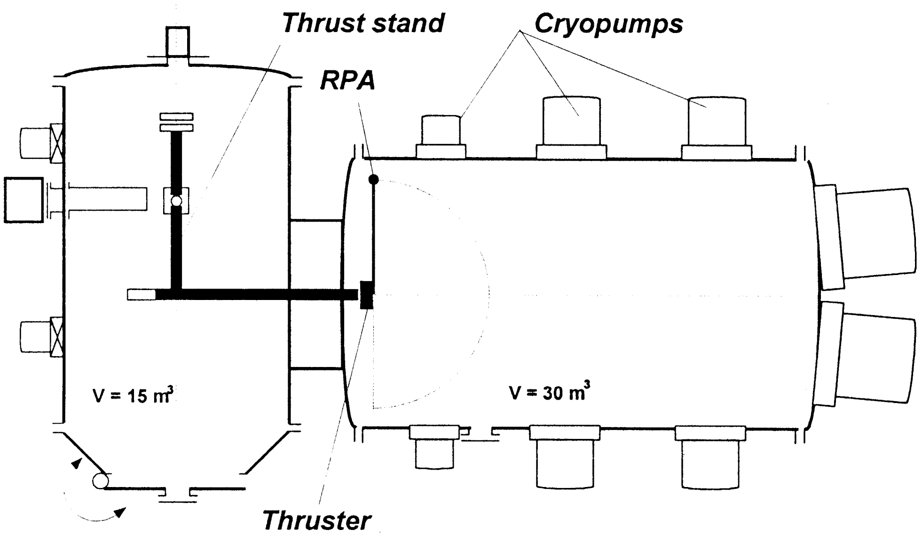

Fig. 1. SPT-140 placement on thrust stand in vacuum chamber

Plume measurements were performed simultaneously with performance and life tests. Operating pressure in the chamber during operation was $1.6*10^{-5}...3.2*10^{-5}$ torr by Xe at current 6.67...15 A[14].

Angular distribution of ion current and ion energy distributions were carried out by 1-grid Retarding Potential Analyzer (RPA) placed either on a move-able arm at R=1 m distance from thruster exit plane (Fig. 2). The probe was moved in a horizontal plane along an arc within an angle 180°. Center of rotation was coincidental with thruster exit plane, rotation radius was 1 m. The probe grid had negative potential to cut off electron component of current while collector had positive collecting potential.

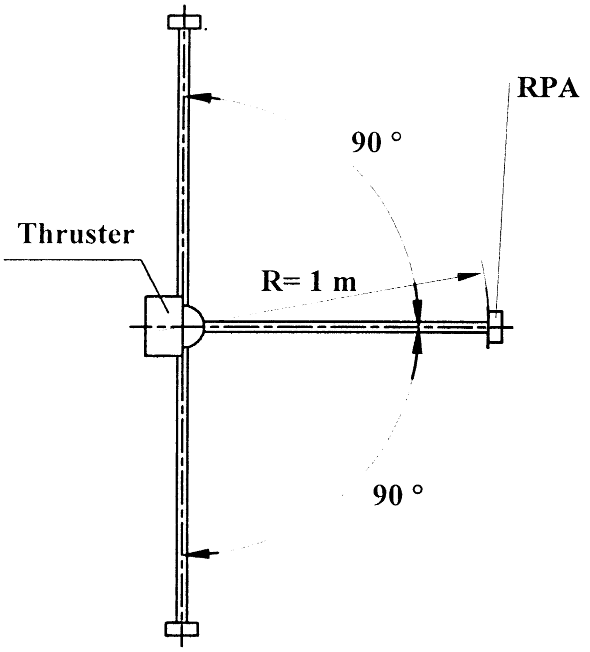

Fig. 2. The top view to thruster and moveable device placement

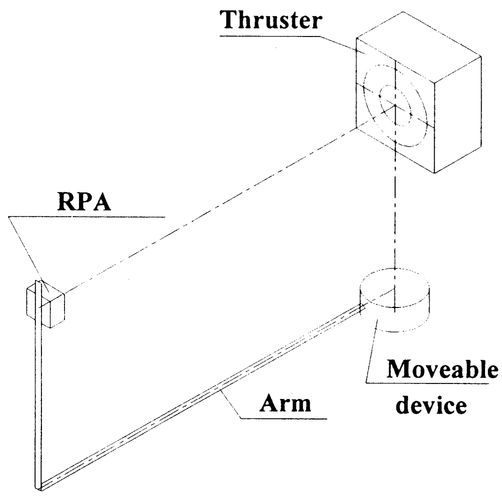

Fig. 3. Placement of RPA on the moveable device

The current density and ion energy distribution were measured by RPA probe, with a collector potential applied relative to the ground. The ion energy was determined by measuring curves of retarded current at the collector of the one grid RPA probe (Fig. 4)

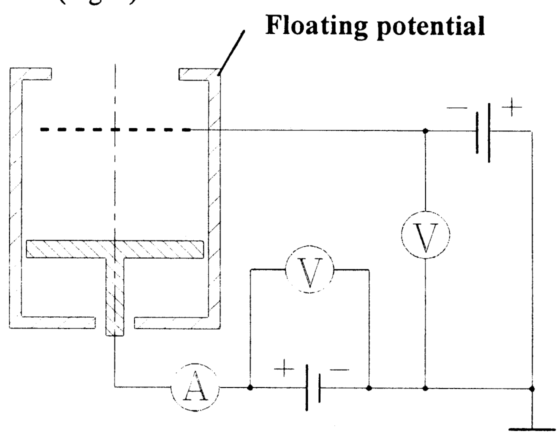

Fig. 4. Electrical schematics of the PRA probe

Tests Results

Current density distributions

Measurement of current density distribution on a spherical surface with radius R=1 m shows the substantially non-uniform nature of this distribution. (Fig. 5). The results show impact exceeding collector potential from the plasma potential and compact ion distribution.

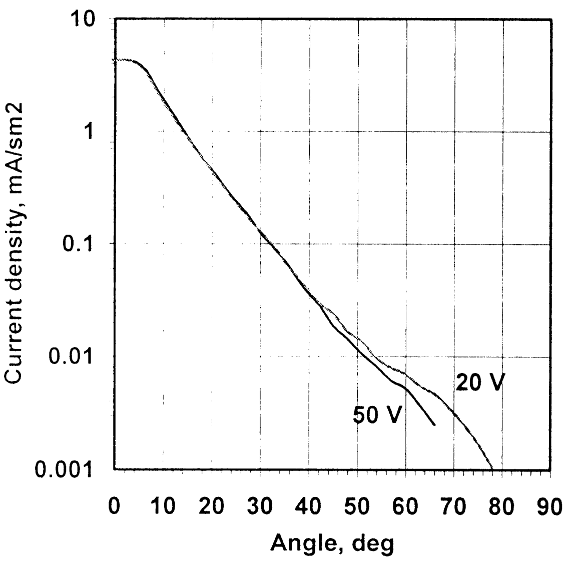

Fig. 5. Measured ion current at collectors of 20 and 50V

Plume divergence at 90% and at 95% ion current is increased by 1.5 degrees and 3 degrees, correspondingly, when collectors potential 20 V.

This test demonstrated that the divergence the most optimized plume shape occurred with thruster operating at 4500 W (Fig. 6).

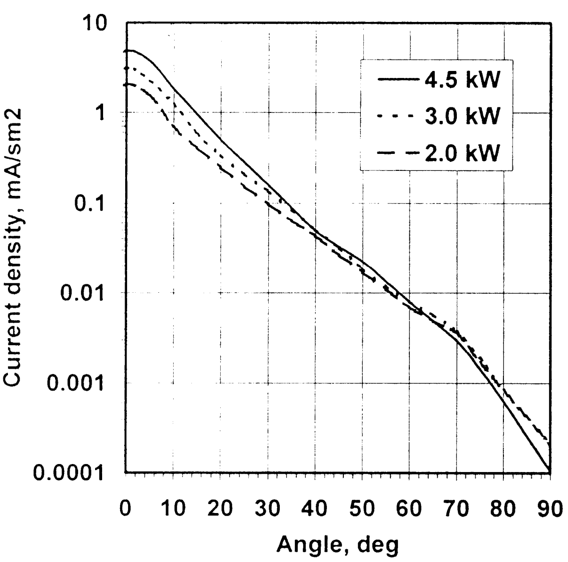

Fig. 6. Measured ion current at modes 2.0; 3.0 and 4.5 kW

At this power level, plume divergence decreases by 6...8° in respect of 2000 W operation mode (Fig. 7). Plume divergence in 2000 W mode is close to that of SPT-100.

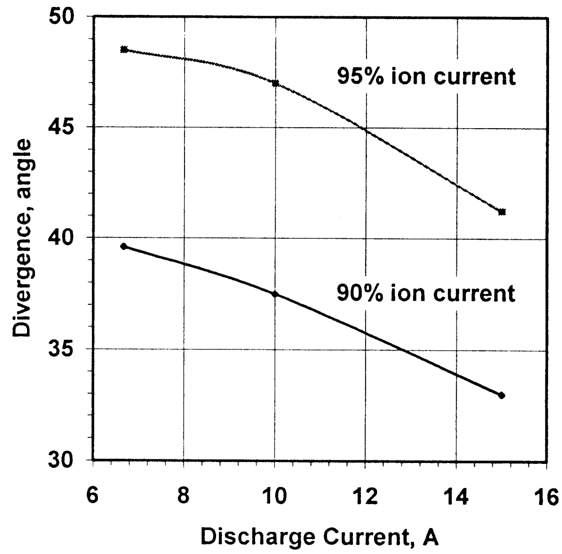

Fig. 7. Divergence vs. discharge current at collectors of 50 V

The widening of the discharge chamber exit due to erosion has no significant influence on the ion current angular distribution. The ion current density essentially does not differ at large angles in the case of a widened discharge channel (Fig. 8a and 8b). Plume divergence at 90% (30 degrees) and at 95% (36 degrees) ion current is not different at New an Old thruster.

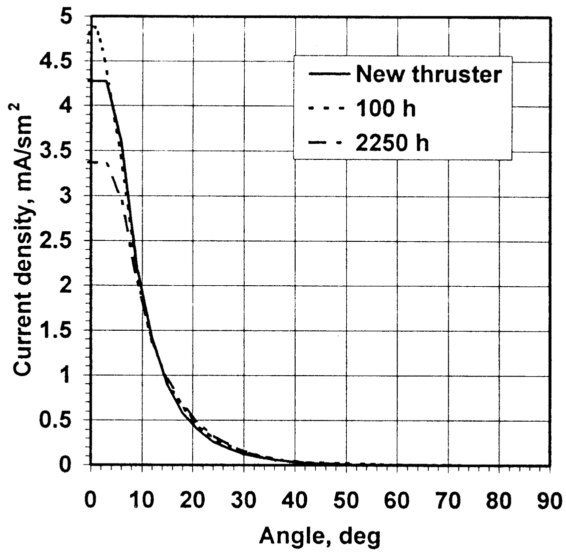

Fig. 8a. Ion current density distribution at new and old thruster

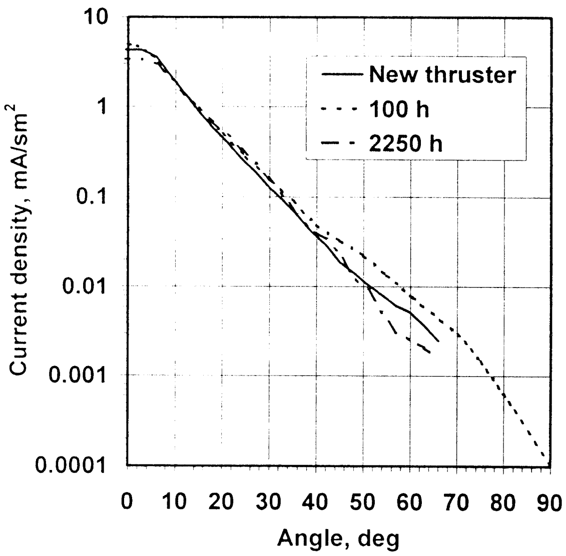

Fig. 8b. Ion current density distribution at new and old thruster

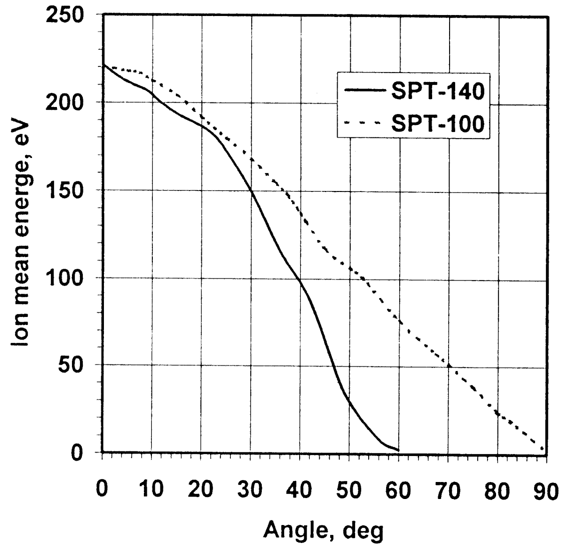

Fig. 10. Distribution of ion mean energy for thrusters SPT-100 and SPT-140

Ion energy distributions

The ion energy distribution was determined by measuring curves of retarded current at the collector (Fig 9).

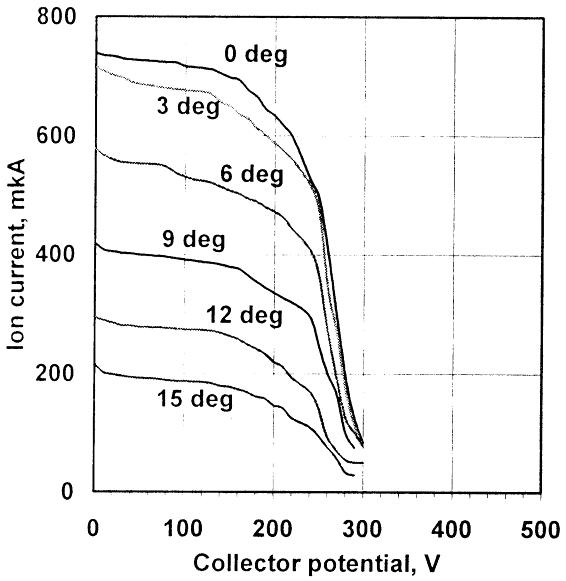

Fig. 9. Retarded collector current vs. collector potential at different angle. Thruster age is 1080 h

At this test power supply and RPA probe had failure after 300 V. The retard curve can be extrapolated in a kernel of plume up to collector potential 400...450 V. Average energy at this case is increased by 10...15 eV. Comparative distribution of ion mean energy for thrusters SPT-100 and SPT-140 is shown at Fig. 10. The ion energy distribution in the axial part of the flow has a characteristic maximum at angle of 0 degree (central axis of thruster).

The SPT-140 plume has the more compact divergence and considerably smaller energy of ions at angles greater of 30 degree. The possibility low erosion impact to a spacecraft components is confirmed by a state of a sample from steel. Sample placed at angles of 40... 60 degrees, has not sputtering at angles, greater of 50 degrees. These data will be well agreed outcomes shown at fig. 10.

Ion power distributions

The data obtained allows determination of the angular ion energy distribution, that is carried by the ion flow (Fig 11).

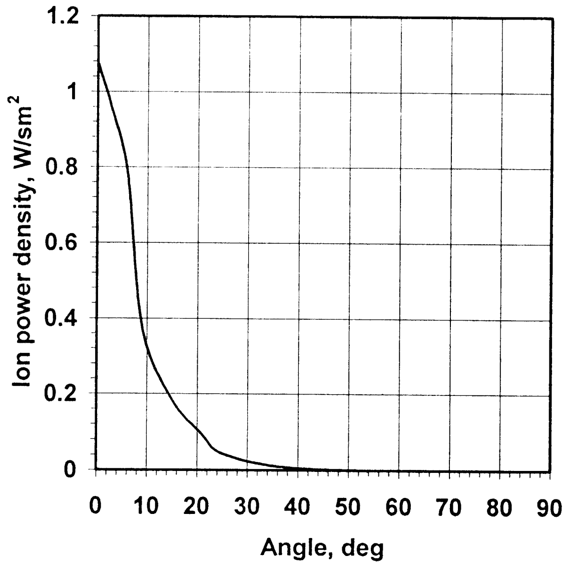

Fig. 11. Ion power density as a function of angle

Conclusion

The SPT-140 plume has the more compact ion current and energy divergence at comparative to SPT-100. These enables decrease erosion impact to a spacecraft components.

The test program produced data sufficient to estimate erosion, force and thermal influence of the SPT-140 plume on the spacecraft components that are exposed to the plume. This data will be used at SPT integrate to the spacecraft and enables optimization of thruster location.

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