INVESTIGATION OF THE POSSIBILITY TO REDUCE SPT PLUME DIVERGENCE BY OPTIMIZATION OF THE MAGNETIC FIELD TOPOLOGY IN THE ACCELERATING CHANNEL[1]

Michael Day ,
International Space Technology, Inc., Palo Alto, USA
Vladimir Kim, Vyacheslav Kozlov, Alexei Lazurenko, Garry Popov, Alexander Skrylnikov
Research Institute of Applied Mechanics and Electrodynamics of Moscow Aviation Institute (RIAME MAI), Mocsow, Russia.

Abstract.

The existing Hall thruster models have significant plume divergence. Therefore it's interesting to study the possibility to reduce it. Some earlier attempts to solve this problem did not give satisfactory results, because it's necessary at the same time to maintain high level of thrust efficiency and life time. New results obtained at RIAME MAI in the frames of the ISTI R&D efforts are related to the SPT and represented in this report. Two possibilities have been studied:

- Optimization of the magnetic field topology at the exit part of accelerating channel, changing the geometry of general magnetic system element configuration.
- Usage of the additional magnetic poles and coils allowing to deviate at least part of ion flow in the definite planes across the longitudinal direction. These magnetic poles and coils could be used also to correct magnetic field topology and to reduce plume divergence.

To determine the plume divergence there was measured the ion current distribution along the circular curve in the plane, containing the thruster axes with the center, positioned at the intersection point of the exit plane and thruster axes by ion probe having the grid to divide electrons from ions and collector, having the potential +50V relatively to the cathode. So, the accelerated part of ions only was registered and processed.

Nonaccuracy of the ion current measurements in the peripheral parts of the plume was $\pm 0.3\ \mu A/cm^2$. The angular range of measurements was $\pm 90°$ relatively to the thruster axis.

Plume divergence was characterized by half angle β of cone containing ion trajectories corresponding to the 95% of total measured ion current.

Obtained results show that it's possible to reduce the SPT-100 plume half angle at least by 3-5 degrees using the mentioned possibilities as well as to deviate ion flow by such a way that thrust vector could be turned in a definite direction electromagneticaly and 3-5 degrees deviation angle could be reached. It's possible also to reduce plume divergence till ~30° using the thrust vector control unit as an collimating and focusing system.

Thus, obtained results demonstrate the significant possibilities to control SPT plume.

Introduction.

Stationary plasma thrusters (SPT) are used in the Russian Space Technology already 25 years and have demonstrated high enough effectiveness and reliability. Therefore there were started the preparation works to their practical application on board of Western Spacecrafts (S/C), namely: SPT-100 based propulsion subsystem has been qualified according to the American standards by International Space Technology, Inc. joint company [1] and there are at least several programs of implementation of such subsystems for their practical usage in USA and in Europe [2]. One of the specific features should be taken into account when someone is considering the Hall thruster application is the significant their plume divergence, which is very close for SPT and thrusters with so-called anode layer (TAL) [3]. More over according to the Russian experience interaction of SPT plume could create additional torque moments, erosion of the structural elements introduced in the plume and so on [4]. Therefore it's reasonable to reduce SPT plume divergence what will simplify the SPT integration issues.

It's interesting also to develop the thrust vector deviating unit which is able to replace somewhere the gimbled platform typically considered for electric thruster mounting on board of S/C. Taking the mentioned into account an investigation of possibility to reduce SPT plume divergence by optimization of the magnetic field topology as well as the development of the thrust vector control unit (TVCU) and study of its capabilities have been fulfilled within the frames of ISTI R&D efforts.

Obtained results are represented in the paper.

1.Thruster model and TVCU design.

As a basic one for the investigation has been chosen the SPT-100 laboratory model having most part of elements typical for the standard SPT-100. But there was the possibility to change the magnetic pole and screen configuration (Fig. 1). Then there has been developed, manufactured and tested the TVCU model consisting of eight additional magnetization coils and four additional poles to create asimuthally nonsymmetric magnetic field at the thruster outlet (see Fig.1). The TVCU magnetic system elements have been protected by insulator from the sputtering by accelerated ions. Using the additional magnetic poles and coils it was possible to change the magnetic field line configuration in the different sectors along the azimuth by different ways.

As the magnetic field lines are in a first approximation controlling the electric field equipotential lines, it was expected that it will be possible to turn ion trajectories in different sectors to the axes or to the opposite direction. If all ion trajectories are turned to the axes this has to cause plume divergence reduction. If in a one sector ions are turned to the axes and in the opposite sector they are turned off axes, the thrust vector is to be deviated (Fig. 2).

Let's add that proposed TVCU design (see Fig. 1) is changing the magnetic field topology mainly near the external discharge chamber wall. Therefore its impact was expected mainly for the outer peripheral part of accelerated ion flow. Therefore the main magnetic system correction possibility has been studied respectively to the near internal wall part of ion flow, i.e. the studied changes have been made for the internal magnetic pole and screen. From the previous measurements it was clear that near the internal discharge chamber wall ions have significant radial component of velocity [4]. Then from the some measurements made with usage of so-called plume shield it was found that SPT axes is "transparent" for the ions crossing the near axes space. Therefore if it will be possible to reduce the ion velocity radial component and this will give the plume divergence reduction.

So, it was supposed to correct trajectories of ions outflowing near the external wall by the TVCU magnetic system and trajectories of ions outflowing near the internal wall - by the correction of the internal magnetic pole and screen configuration.

Plume divergence and plume deviation due to the magnetic field topology correction has been estimated from the angular ion current density distribution measurements by RPA probe having the grid to avoid the electron penetration inside RPA and ion collector potential +50 V [4]. This probe was mounted on the rotating boom. So probe registered ion currents along the circular curve with center at the thruster axes and exit plane cross-point within the angles ±90° in the plane consisting of the thruster axes and at a distance from thruster ~0.7 m. As a magnitude, characterizing the plume divergence there were used the angle $\beta_{0.95}$ containing 95 % of ion current. The flow deviation angle was determined by integrating of the ion current distribution and calculating its center-line. Change of the mentioned center-line position was considered as a deviation angle. The value of deviation angle has been checked by the measurement of the radial thrust component. This check gives satisfactory agreement with the angles determined from the plume measurements.

2. Results of experiments.

Results of study to reduce plume divergence by correction of internal magnetic pole/screen configuration show that it's possible to reduce SPT-100 plume divergence by (3-5)°

(Fig. 2). Nonsignificant impact in this case is understandable if we take into account that control is limited by internal part of ion flow. But this impact is detected very clearly (see Fig. 2). Therefore for the further study the magnetic configuration giving the lower plume divergence has been used.

Results of the plume divergence measurements show that under optimized magnetic field even without applying the currents in the TVCU coils the plume divergence angle $\beta_{0.95}$ is reduced till (33-35)° due to the magnetic field topology change and collimating impact of the insulator protecting the TVCU magnetic system elements when their length is (20-50) mm (Fig. 4). Usage of all TVCU magnetic coils to focuse ion flow could reduce the $\beta_{0.95}$ value till ~30° (Fig. 5), i.e. by ~1.5 times in comparison with the standard SPT-100. That means that it's possible to reduce plume divergence significantly using additional system like studied TVCU. But in this case due to the additional ion losses on the TVCU elements surfaces the thrust efficiency is reduced by ~5% (see Fig. 4).

Study of possibility to deviate ion flow and respectively thrust vector shows that it's possible to obtain the deviation angle till ± 5° (Fig. 6). But the more deviation the higher the thrust efficiency reduction. If the deviation angle is limited by ± 4° the efficiency reduction could be within 5%.

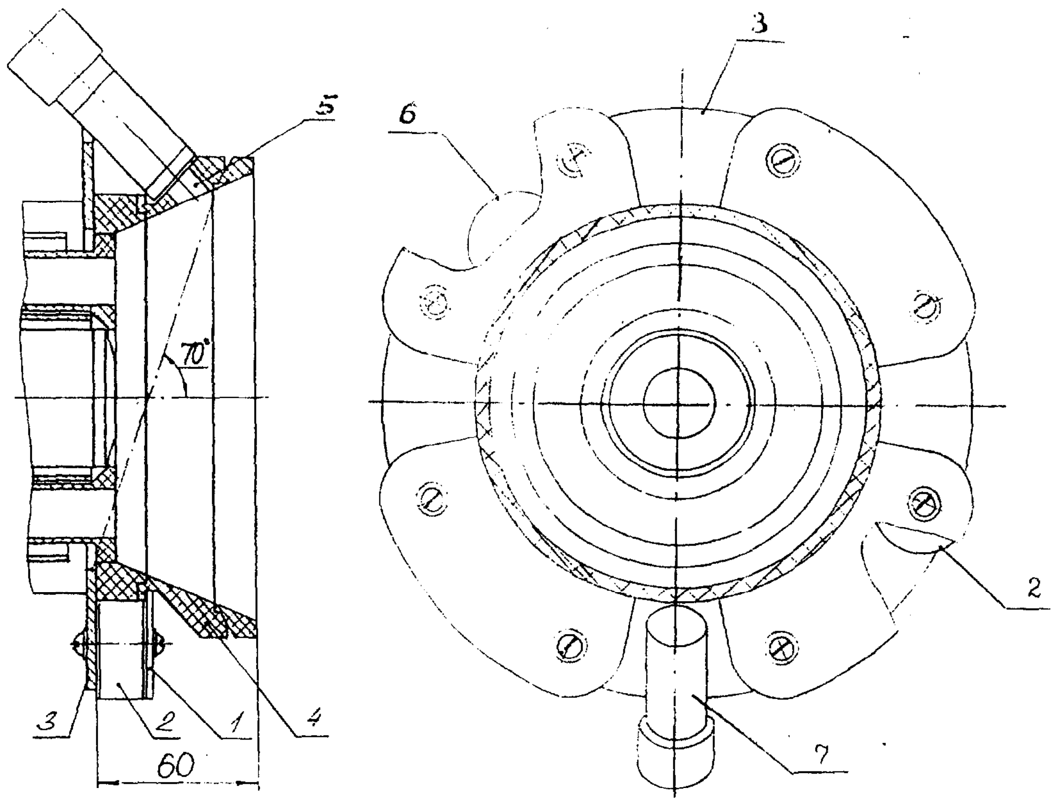

Fig. 1. TVCU design diagram.

1- TVCU magnetic pole
2 - TVCU magnetization coil
3 - SPT external magnetic pole
4 - protecting insulator
5 - hole in insulator
6 - SPT magnetization coil
7 - cathode

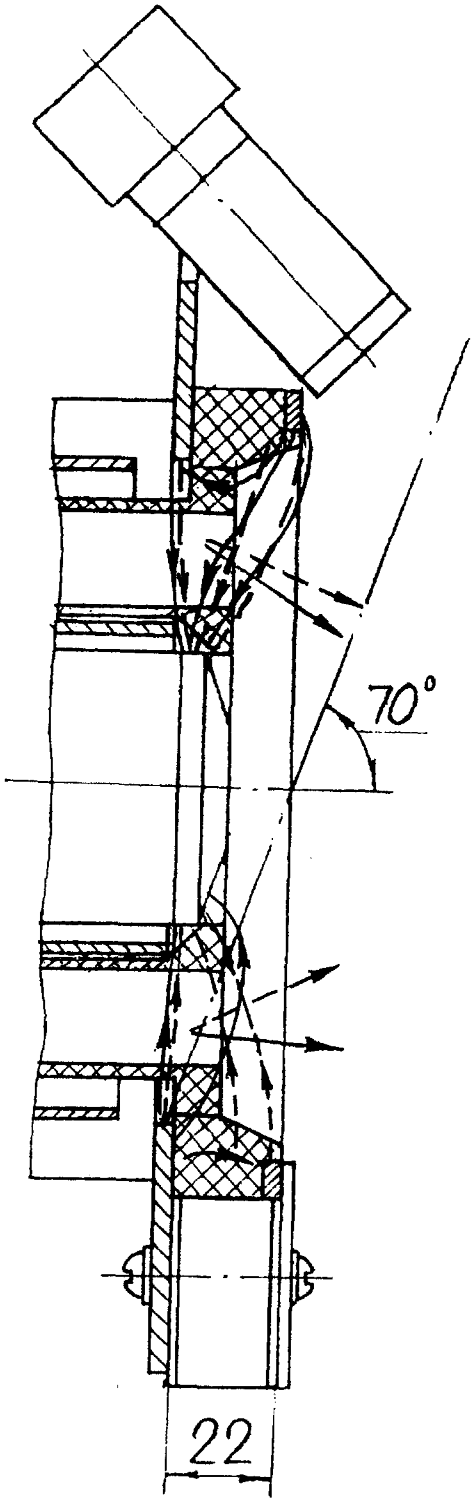

Fig. 2. Schematic of the magnetic field topology change by TVCU.

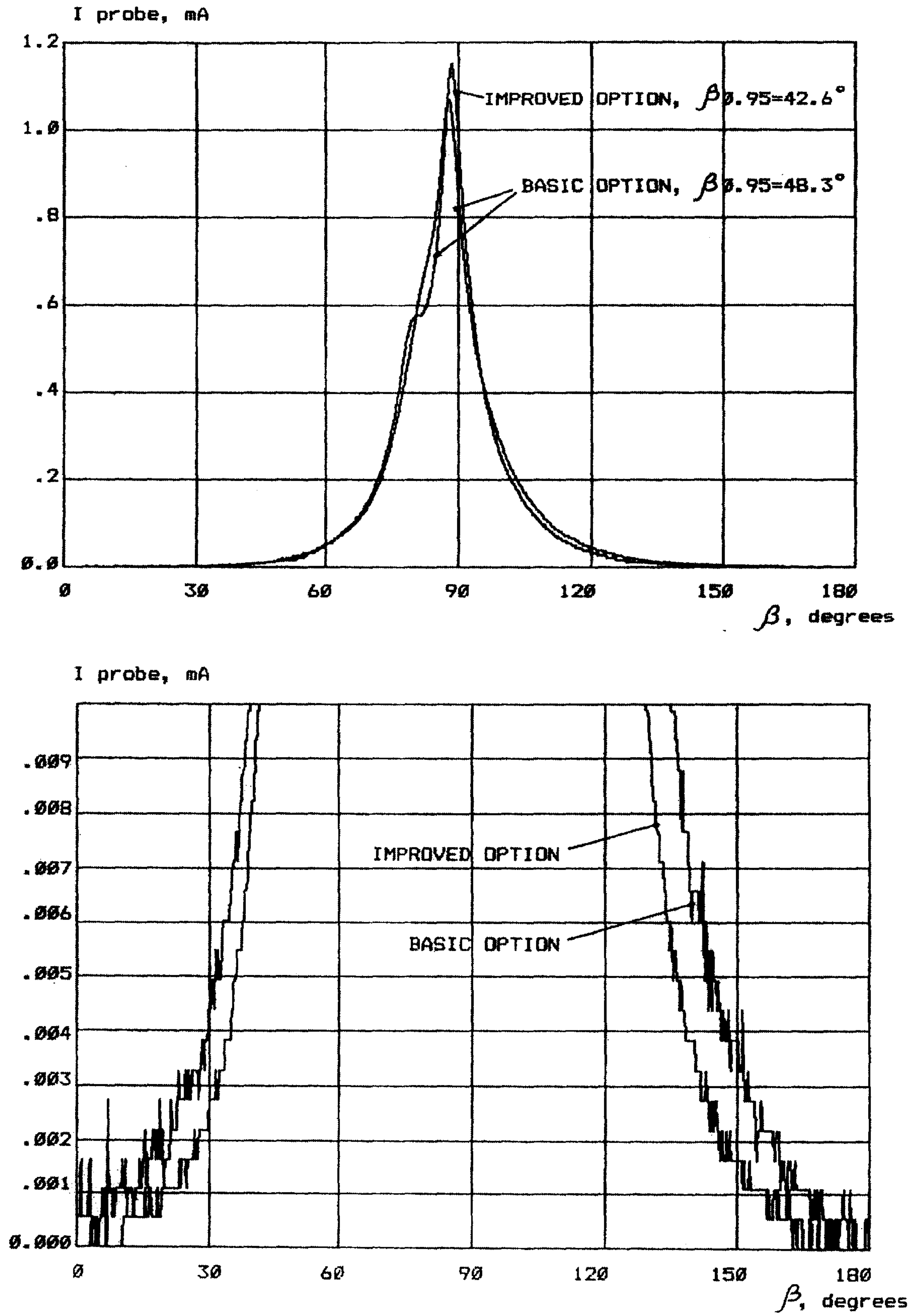

Fig.3. Accelerated ion current distribution versus the plume half-angle.

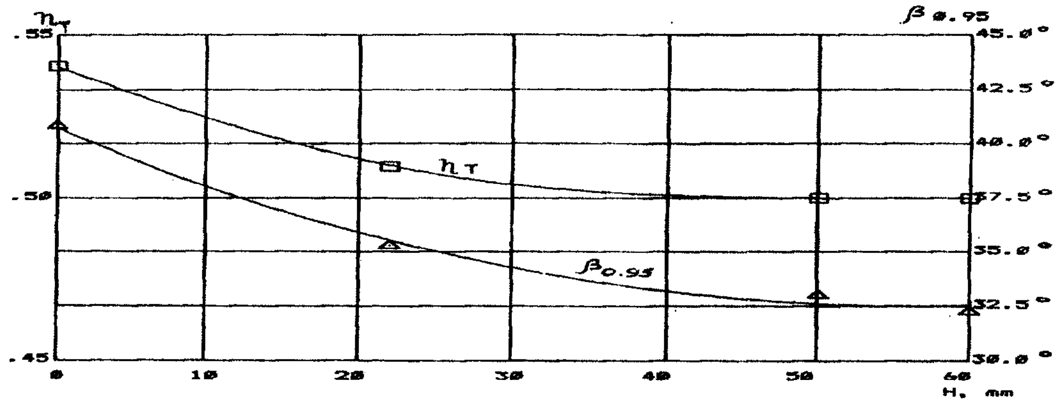

Fig. 4. Thruster performance versus the length of insulator, protecting the TVCU elements.

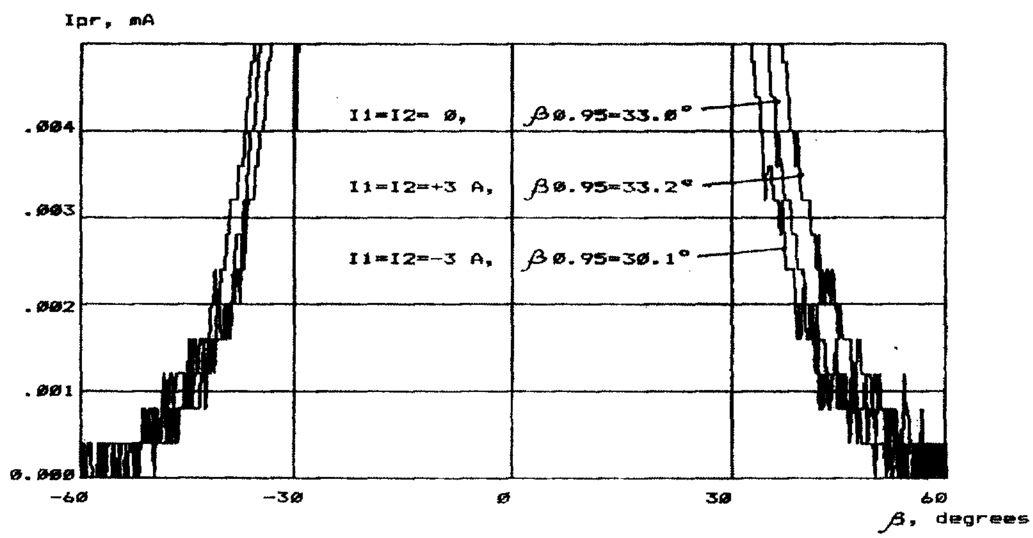

Fig. 5. Ion current distribution under different magnetization currents in TVCU.

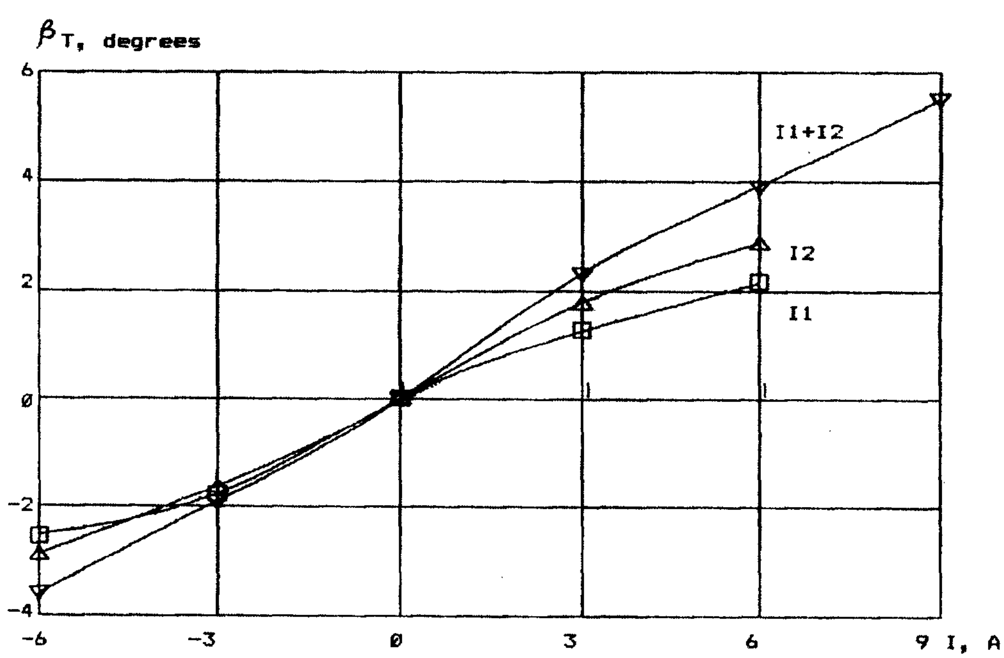

Fig. 6. The plume deviation angle versus the TVCU magnetization current.

Conclusion.

Presented information demonstrates the possibility to reduce significantly the SPT plume divergence and to deviate ion flow and thrust vector till ± 5° with help of the special thrust vector control unit.

References.

1. M. Day, N.Maslennikov. Stationary plasma Thruster-100 Subsystem Qualification Status. - Paper AIAA-96-2173. Lake Buena Vista, FL, USA.
2. Valentian, C. Koppel. Present and Future applications of SPT M2 thrusters. - Paper IEPC-95-36 in the Proceedings of 24-th International Electric Propulsion Conference (IEPC), Moscow, 1995.
3. D.Manzella, J. Sancovic. Hall Thruster Ion Beam characteristion. - Paper AIAA -95-2926, San Diego, CA, USA, 1995.
4. Yu.P.Rylov, I.A.Perkov, Yu. A. Romanovsky. Change in the spacecraft environment with an electric thruster in operation. - Report at the 2-nd European Conference on Space Propulsion. - Nordwijk, 1997.