INVESTIGATION OF THE SPT PERFORMANCE IMPROVEMENT POSSIBILITY

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ABSTRACT.

As it's well known, so-called Stationary Plasma Thrusters (SPT) already many years are operating on board of Russian Space vehicles. They are in qualification process also for the Western Space technology and there are several projects of SPT practical usage in the West. One of the disadvantages of SPT is significant plume divergence. For example the SPT-100 plume half-angle $\beta_{0.9}$ for 90% of accelerated part of ion flow is about 36° and it was interesting to study the possibility of the plume divergence decrease. It's evident that the solution has to be found allowing to reach goal without decrease of thrust efficiency and other output parameters.

The main way to solve the mentioned task was SPT design modification and operating mode optimization. As a result of this investigation it was obtained that it's possible to reduce the $\beta_{0.9}$ value for the SPT-100N with improved design diagram to the 24...26°, i.e. almost by 1.5 times in comparison with SPT-100. The magnitude of $\beta_{0.9}$ was estimated from the measurements of the angular accelerated ion current density distributions made by energy analyzer.

At the same time it's possible to increase the thrust efficiency of thruster by (3...5)%. Estimations show also that for the SPT-100N it's possible to obtain high enough lifetime.

Similar results were obtained for the SPT-N of other dimensions. Thus results of investigation show that it's possible to decrease significantly plume divergence with simultaneous increase of thrust efficiency.

INTRODUCTION

Stationary Plasma Thruster (SPT) has high performance level in the most interesting for the modern Space technology range of specific impulses I_{sp} =(1000...2000) s and are used successfully on Russian spacecraft (S/C) already more than twenty years[1]. One of them namely SPT-100 will be qualified soon for the Western Space Technology by International Space Technology, Inc company (ISTI)[2], and there are several projects to use SPT-100 on board of Western S/C. So, SPT has good prospectives for the wide usage in the Space Technology and it's necessary to investigate the possibility of further improvement of thruster design and performance. One of the evident goals of such investigation is to reduce SPT plume divergence, because for example, for the SPT-100 a half angle of thruster plume for 90% percents of accelerated ions is ~36°. It's desirable also to increase efficiency and lifetime. To solve this complex task it's necessary to use the new solutions. And investigations started earlier in Russia and continued in the frames of ISTI R&D efforts show that its possible to find solution for this task. Some obtained results are presented in the paper.

1.POSSIBILITIES FOR SPT PERFORMANCE IMPROVEMENT.

The SPT performance level is determining by the following factors:
- Magnetic field topology and intensity in the accelerating channel.
- Accelerating channel sizes and geometry.
- Working gas properties and mass flow rate.
- Discharge voltage magnitude.
- Power supply circuitry.
- Discharge chamber material properties.
- Cathode type and its operating mode.
- Position of cathode relative to the accelerating channel.

So, optimization of the thruster operation and performance is very complicated task and a lot of efforts were spent to reach modern level of SPT development.

Let's underline the main steps of the SPT optimization efforts already done. As a first very important step we could call the generation of general SPT design diagram made in USA and in Russia in the early sixties. And first results obtained in USA and in Russia were similar as well as the first design diagrams of the thrusters. The efficiency of accelerator was obtained within (20...40)% while it operates on Ar, Kr, Cs in the range of specific impulses (1000-2000) s. And it was not clear that its possible to increase the efficiency because there were found the instabilities in accelerating channel, increasing the electron current across the magnetic field. Possibly this fact and relatively low level of achieved efficiency have caused the reduction of American scientists and engineers interest to SPT type thrusters. But in Russia the investigations were continued and gave good results well known today.

The second important point was to recognize that acceleration of ions in the SPT channel is quasielectrostatic one and that energy expences for gas ionization have big impact on thruster efficiency. Therefore the efforts gradually were concentrated on accelerators, operating on substances with heavy atoms (Xe, Cs,...) giving low ratio of the ionization potential to the atom mass. Besides Xe and Cs promised good propellant storage system performance. Modern SPT's are operating mainly on Xe but it's necessary to note that in MAI the accelerator thrust efficiency on Cs was achieved, nigher than 50% under discharge voltages (100...200) V.

It was recognized also that it's necessary to have the definit relation ship between free path of ionization λ_i and length L of the accelerating channel, i.e. $\lambda_i \leq L$, determining the limitations on the mass flow density in the accelerating channel. These limitations are causing the restricting relationships between mass flow rate, descharge voltage Ud and accelerating channel sizes[3].

The next point was the discovery of the possibility to supress significantly the instabilities in the accelerating channel, using the magnetic field disctribution with increasing magnetic induction to the exit of the accelerating channel. Such kind of distributions was appeared due to the intension of researchers to focuse the accelerated ion flow and to reduce the ion flow losses on the walls. And it was found by measurement of asimuthal current that effective value of $(\omega\tau) \sim (200...300)$ could be obtained[4], i.e. significantly higher than according to the Bohm relationship. So, at least in the part of the accelerating channel it's possible to obtain the electron mobility close to classical one. It means that plasma resistivity is high in the parts of accelerating channel with high values of magnetic induction and that controlling the magnetic induction distribution and magnitude in the accelerating channel it's possible to control the position of layer with high plasma resistance across magnetic field, i.e. to control the thickness and position of the accelerating layer with high intensity of electric field. And further optimization confirmed this conclusion. It was found also that optimal position of accelerating layer is near the exit of accelerating channel, when ion losses on the discharge chamber walls are minimal also. Nevertheless it was impossible to obtain high efficiency of accelerator, positioning the maximum of the magnetic field induction outside of the accelerating channel. It could be explained by the neccessity to have definit level of electron current through the accelerating layer to obtain efficient ionization and to maintain the discharge. Classical mechanizms, providing transverse electron mobility inerease, are the collisions of drifting electrons with the heavy particles (mainly neutral atoms) and walls. So, it was recognized that for SPT the interaction of plasma flow with the walls is important factor.

Latter one is determining the necessity to leave more or less intensive interaction of accelerated ion flow with walls causing their sputtering and necessity to create great enough margin for the wall erosion. The simplest way is to increase the thickness of the exit parts of discharge chamber walls. But to obtain the optimal magnetic field topology with the magnetic system having increased gap between the magnetic poles it was necessary to invent new type of magnetic system with so-called magnetic sireens[5]. And optimizing the magnetic system elements configuration it's possible to obtain the necessary magnetic field topology in the accelerating channel even if its exit part is outside of the magnetic system counter and to ensure high enough margin for the wall erosion and high level of the thrust efficiency. Such magnetic systems are realized in the SPT-70 and SPT-100 and hole experience of their development and tests including later ones are confirming the effectiveness of the developed solution. Let's add that SPT-100 is the first sample of the thruster with closed drift of electrons having main part of accelerating layer, positioned outside of magnetic system counter at least at the beginning of thruster operation.

There are another possibilities to control the thruster operation and processes in the accelerating channel. For example it's possible to optimize the plasma interaction with the walls taking into account that for SPT of classical type this interaction as it was mentioned, is important. Investigation of such possibility was made and some obtained results will be presented in the next part of this paper.

2. NEW RESULTS OF INVESTIGATIONS.

To optimize the plasma flow interaction with the accelerating channel walls it's necessary to take into account the wall material properties, their potentials and configuration. Then it's necessary again to choose the magnetic field topology and intensity to optimize the processes in a hole thruster. So, it's necessary again to realize new stage of optimization mainly by experiments, because the state of theory is not allowing to calculate and predict all effects. And some steps of such optimization were made earlier in Moscow Aviation Institute and then in RIAME MAI, partially according to the ISTI orders during last years. These investigations allow to conclude that optimizing the mentioned interaction of plasma flow with the walls it's possible:

- to increase thrust efficiency by 3...5% in comparison with existing SPT-70 and SPT-100,
- to reduce the SPT plume divergence by ~1,5 time, i.e. to obtain the value of half-angle for the 90% of accelerated ions ~24...26° against ~36° for SPT-100 (Fig.1),

- obtain high operation life time of the SPT of new type (SPT-N).

During last year the 380-hours test of SPT-100N model was made and it was confirmed that operation modes with high level of efficiency were stable during the test. And it's planned to continue these test up to ~1000 hours.

- increased level of thrust efficiency and lower divergence of SPT-100N plume were confirmed by tests at different test facilities (RIAME/MAI, Fakel, SEP). So, SPT design could be improved and ensure more high level of performance.

CONCLUSION.

Presented data show that SPT as every other thruster has reserves of the design and performance improvement and SPT experts have developed solutions allowing to realize such improvement.

REFERENCES.

1. A.S.Bober, V.Kim, A.S.Koroteev et al. State of work on Electrical Thrusters in USSR - AIAA paper IEPC-91-003.

2. M.Day, Th.Randolph, W.Rogers. SPT-100 Subsystem Qualification Status - Paper AIAA-95-2666.

3. A.I. Bugrova, V.Kim, N.A.Maslennikov, A.I.Morozov. Physical Processes and Characteristics of Stationary Plasma Thrusters with closed Electrons Drift - AIAA Paper IEPC-91-0079.

4. V.G.Demyanenko, I.M.Zubkov. Inductive method of asimuthal drift current measurement in a accelerators with closed drift of electrons and extended zone of acceleration - Jurnal Technicheskoy Physiki (in Russian, 1978, v.48, issue 3, pp.634-635).

5. B.A.Arkhipov, V.M.Gavryushin, V.Kim et al. Plasma accelerator with closed electron drift. USA Patent No 5359258, Int. Cl. H 01 J 1/52, issued on Oct.,25,1994.

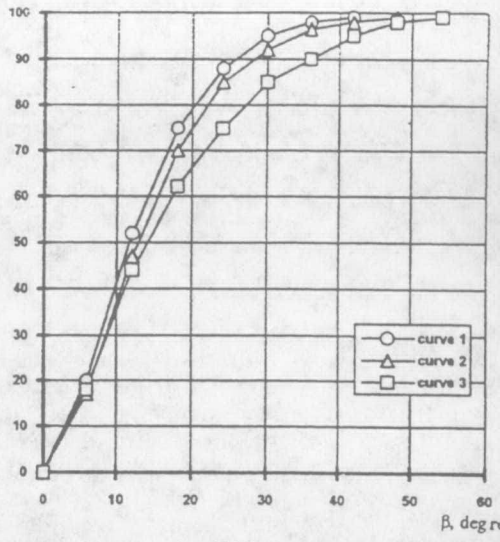

Fig. 1. Relative value of ion current $\bar{I}_i(\beta)$ within the cone with a half angle

curve 1	curve 2	curve 3
SPT-100N	SPT-100N	SPT-100, F/R
U_d=300 V	U_d=350 V	U_d=300 V
I_d =5.1 A	I_d =5.1 A	I_d =4.5 A
P_c =5.2·10^{-5} Torr	P_c =4·10^{-5} Torr	P_c =5.2·10^{-5} Torr