*ATON-Type SPT Operation at High Voltages

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Abstract: The purpose of this work is the investigation of SPT of the second generation of ATON type under the increasing of the discharge voltage up to 100V. The integral parameters of SPT ATON models, differing by the dimensions, are represented. The particular attention has been paid to the models operation under high voltages. In the voltage increasing up to 1000V the maximal specific pulse was equal to 3400s. The discharge current oscillations have not exceeded 20%, The half-angle of divergence under the high voltages has been equal to 18^0. SPT input power has not exceeded 1500W.

Nomenclature

U_d	=	discharge voltage.
W	=	power
$\dot{m}$	=	mass flow rate
F	=	thrust
η	=	efficiency
$F/\dot{m}$	=	specific pulse
I_d	=	discharge current

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I. Introduction

THE physical processes in the accelerator with the closed drift of electrons, named by SPT, are described in detail in the number of papers[1,2].

There is manufactured and tested the parametric series of SPT models of the second generation (of ATON type), operating on Xe, in MIREA[3-5]. These models differ by the dimensions of the discharge chamber and accordingly operate in the different bands of the mass flow rates. The mass flow rates, under which the model operates with the maximal efficiency, are chosen in the accordance with the criteria of the similarity[6,7]:

$$\Lambda = \frac{\lambda_{ion}}{L} << 1 \quad (1)$$

Therewith it is necessary the satisfaction of the following condition:

$$\alpha = \frac{\dot{m}}{S} \cdot b \cong 2 \cdot 10^{-2} \text{ mg/(s·mm)} \quad (2)$$

where b is the channel width, S is the area of the exit field of the channel, $\dot{m}$ is the mass flow rate of the propellant, λ_{ion} is the distance of the free pass of the neutral atom before the ionization, L is the typical system dimension, where the "essential" electrical field strength exists.

II. A-5 Integral Parameters

Model A-5 has the diameter of the external channel, equal to 100mm, and the area of the exit cross-section $S=4{,}2 \cdot 10^3 mm^2$.

In accordance with the demands of Eqs.(1) and (2) this model has been studied in the band of the mass flow rates from 1,5mg/s up to 3,5 mg/s. The discharge VACs under the different Xe mass flow rates are shown on Fig.1. In every experimental point the optimization of the model operation in the magnetic field has been carried out. The minimum of the discharge current has been used as the criterion of the optimization. As the experiments have shown with the increase of the discharge voltage the magnetic field at the model exit had to be to increase. It is seen from the Fig. 1, that under the small Xe mass flow rates (up to 2,5mg/s) the discharge current begins sharply to increase under the increasing of the discharge voltage, starting from the U_d=500-600V.

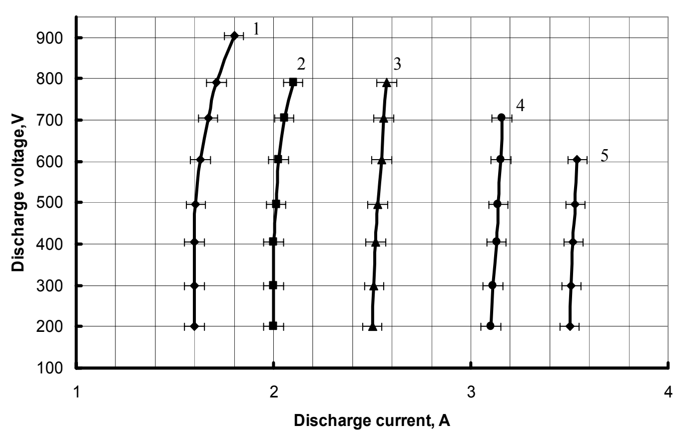

Figure 1. The dependence of the discharge current from the discharge voltage (A-5). *1 - $\dot{m}$ =1,5mg/s, 2 – $\dot{m}$ =2mg/s, 3 – $\dot{m}$ =2,5mg/s, 4 – $\dot{m}$ =3mg/s, 5 – $\dot{m}$ =3,5mg/s.*

With the growth of the mass flow rate up to (2,5÷3,5)mg/s the operation of the model A-5 becomes more effective. The plasma flow, observed visually, acquires well focused shape. The discharge VACs, shown on Fig.1 (curves 4,5) are more vertical.

The measurements of the discharge current oscillations have shown that under Xe mass flow rate (1,5÷2,5)mg/s under the discharge voltage up to 600V they have the magnitude $I_d^{\sim}/I_d^{=} \approx 10\%$ and with the further growth of the discharge voltage their level has increased up to (12÷20)%.

With the increase of the mass flow rate from 2,5mg/s up to 3,5mg/s the tendency of the growth of the discharge current oscillations level with the increase of the discharge voltage is remained, however their level is significantly lower, than in the first case. Under U_d=600V and $\dot{m} = 3{,}5 mg/s$ the discharge current oscillations have been equal to (8÷10)%.

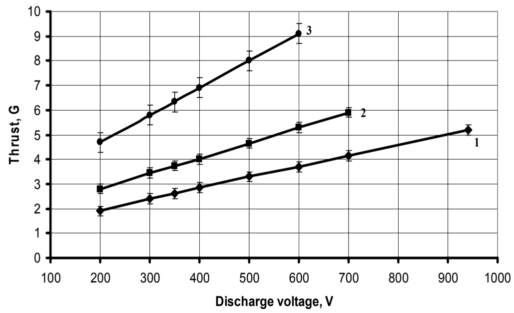

Figure 2. The dependence of the thrust from the discharge voltage (A-5).

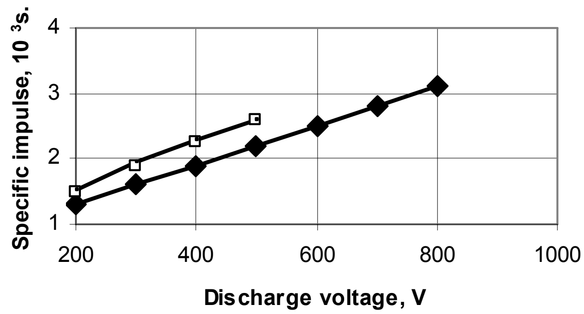

Figure 3. The dependence of the specific pulse from the discharge voltage (A-5).

♦ - $\dot{m}$ =1,5mg/s, – $\dot{m}$ =3,5mg/s.

The measurement of the thrust has been carried out with the help of the torsion three fibers balance. The thrust plotted against the discharge voltage for different mass flow rates is represented on the Fig.2. It is seen from the figure, that for $\dot{m}$ =3,0mg/s the thrust increases from 4,5g up to 9g under increasing of the discharge voltage from 200V up to 600V.

The graphs of the specific pulse versus discharge voltage are shown on the Fig.3. The specific pulse achieves the maximal value under $\dot{m}$ =1,5mg/s and the discharge voltage U_d=800V. Under these input parameters it is equal to ~3100s. The experiments have shown, that the maximal thrust, obtained on the model A-5, has been equal to ≈11g under the mass flow rate $\dot{m}$ =4mg/s and U_d=500V; therewith the efficiency has been equal to 65% and the specific pulse had the magnitude I=2750s.

The further increase of the discharge voltage for the mass flow rate 4mg/s has been limited by the model input power.

III. A-3 Model Integral Parameters

The dimensions of model A-3 are smaller than the dimensions of model A-5. The diameter of the model external channel is equal to 60mm and the area of the exit cross-section is $S=1{,}8\cdot10^3 mm^2$. Therefore the mass flow rates, under wich the model A-3 has been investigated, are smaller, than for the model A-5 and have been varied in the band from 1mg/s up to 2mg/s. The discharge voltage has been varied from 200V up to ~1000V.

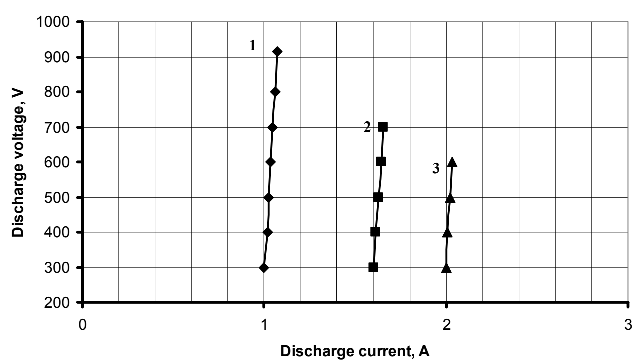

Figure 4. The dependence of the discharge current from the discharge voltage (A-3).

1 - $\dot{m}$ = 1mg/s, 2 – $\dot{m}$ = 1,5mg/s, 3 – $\dot{m}$ = 2mg/s.

The volt-ampere characteristics of the discharge for the mass flow rates $\dot{m}$ =1,0 mg/s, $\dot{m}$ =1,5 mg/s and $\dot{m}$ =2,0 mg/s are shown on the Fig.4. The optimization of the model operation in the magnetic field has been carried out in every working point. It must be noted, that as it has been observed for the model A-5, the tendency of the increase of the magnetic field at the model exit takes place. It is seen from the Fig.4, that for mass flow rates, less than 1,5mg/s, the discharge current of the model A-3 increases from 1A up to 1,2A with the growth of the discharge voltage from 300V up to ~1000V. With the transition to the filed of mass flow rates 1,5mg/s and

2,0mg/s the inclination of the curves decreases. For the curves 1-3 the magnitude α varies from the value $0{,}7\cdot10^{-2}$mg/s·mm under the mass flow rate 1mg/s up to $1{,}4\cdot10^{-2}$mg/s·mm under the mass flow rate 2mg/s. The increase of α leads to the most verticalability of the VACs.

Under the xenon mass flow rate $\dot{m}$ =2,0 mg/s and the discharge voltage U_d=350V the discharge current oscillations have the magnitude $I_d^{\sim}/I_d^{=}\approx10\%$ and with the growth of the voltage up to 600V their level increases up to (12÷14)%. In decreasing the mass flow rate down to $\dot{m}$ =1,5 mg/s the tendency of the growth of the discharge current oscillations level with the increase of the voltage remains. Under U_d=300V the discharge current oscillations level is equal to $I_d^{\sim}/I_d^{=}\approx12\%$, and under U_d=800V it is equal to $I_d^{\sim}/I_d^{=}\approx15\%$. Under the xenon mass flow rate $\dot{m}$ =1,0 mg/s the oscillations level is approximately the same throughout the whole range of the discharge voltages and is equal to ~18%.

The graphs of the thrust versus discharge voltage for three xenon mass flow rates are shown on the Fig.5.

The graphs of the specific pulse versus the discharge voltage under the different mass flow are shown on the Fig.6.

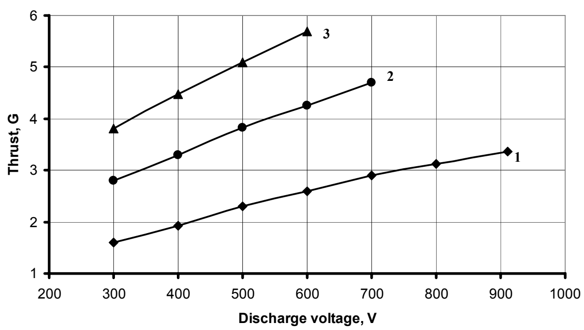

Figure 5. The dependence of the thrust from the discharge voltage (A-3).
1 - $\dot{m}$ = 1,0 mg/s, 2 – $\dot{m}$ = 1,5 mg/s, 3 – $\dot{m}$ = 2,0 mg/s.

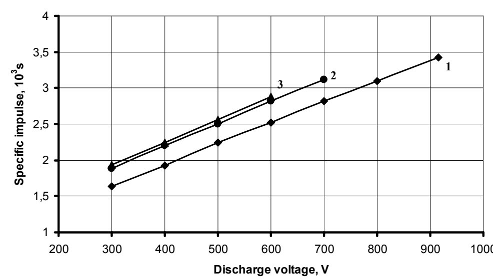

Figure 6. The dependence of the specific impulse from the discharge voltage (A-3).
1 - $\dot{m}$ = 1 mg/s, 2 – $\dot{m}$ = 1,5 mg/s, 3 – $\dot{m}$ = 2 mg/s.

It is seen from the figure, that the specific pulse achieves the maximal value I_{max}=3400s under $\dot{m}$ =1,0 mg/s and $U_d\approx$910V.

IV Measurements of the stream divergence of model A-3.

The distribution of the ion current density was measured in radial direction for determination of divergence of the source's plasma stream.

The double directed probe was used [3]. One probe's surface was oriented parallel to the stream and fixed a chaotic current - $J_{\parallel}$, the second surface was oriented athwart to the plasma stream for measuring of sum of directed and chaotic ion currents - $J_{\perp}$. The probe was mounted at the distance Z=30cm from the cut of the source on the co-ordinate device, allowing to move it in radial direction. The radial distribution of currents was measured on both surfaces of probe. By measured values of currents settled on probes the size of the directed ion current density was calculated

$j_i=(J_{\perp} - J_{\parallel})/S$,

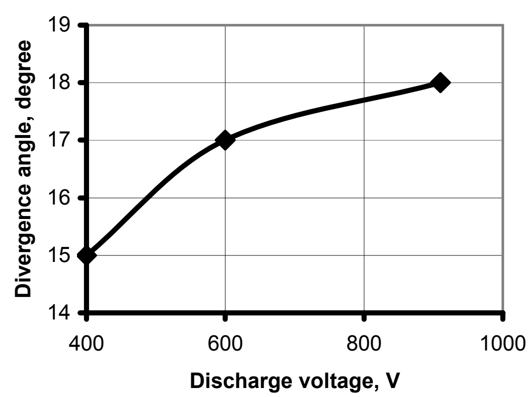

Figure 7. The graph of the half-angle of the divergence $\alpha/2$ versus discharge voltage U_d (A-3) $\dot{m}$=1mg/s.

where S is an area of each probe collector.

A criterion on determination of the half-angle of the divergence α/2 was a hit of 95% of ion stream in a cone with angle α at a top. The dependence of α/2 from the discharge voltage is shown at fig.7. From this figure it is seen, that at the Xe mass flow rate 1mg/s with growth of the discharge voltage the half-angle of the stream divergence is increased from 15° to 18°.

V Influence of correlation of ion multiplicity parts on the integral parameters of stationary plasma thruster.

On integral parameters It is possible to calculate the parts of single, double ionised atoms $\dot m_1$ and $\dot m_2$ and part of particles, dyeing on the walls of channel $\dot m_*$ [3]. The results of calculations are resulted at fig.8-9, the integral parameters of model A-3 are represented at the same figures.

From comparing of dynamics of change of parts of ions of the first and second multiplicity to the dynamics of efficiency it is possible to see that efficiency os maximal, when the parts of ions of the first and second multiplicity became equal (it takes place at voltages 600V – 700V).

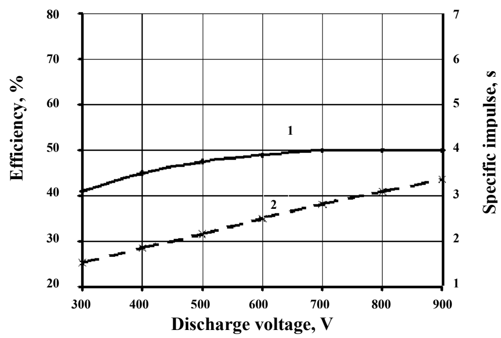

Figure 8. Integral parameters of SPT A-3. The dependence of efficiency (──) and specific impulse (- - - -)from the U_d $\dot m$ =1 mg/s.

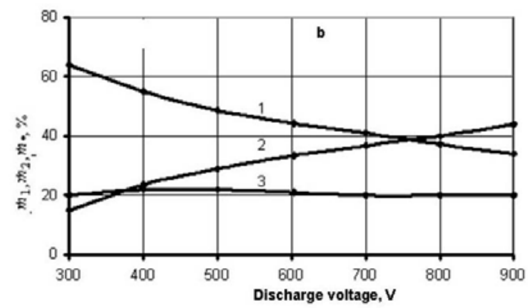

Figure 9. SPT A-3. The dependence $\dot m_1(1)$, $\dot m_2(2)$, $\dot m_*(3)$ of U_d $\dot m$ =1mg/s. Flows are given in percent accordance with mass flow rates.

From this it is follows, that it is possible to define source's efficiency in optimum working mode without detailed researches of the source.

From experimentally measured VAC and thrust, let's find the discharge voltage U_d^* at which $\dot m_1(U_d^*) = \dot m_2(U_d^*)$:

$$F(U_d^*)/\sqrt{\frac{2e}{M}(U_d^* - \Delta U)} = (1+\sqrt{2})\left(J(U_d^*)/\frac{e}{M}(1+k) - \dot m \right) \qquad (3)$$

Then maximal efficiency can be estimated by formula:

$$\eta_{max} = \eta(U_{d0}) + \left[\frac{\partial \eta_d(\dot m, U_d)}{\partial U_d}\right]_{U_d = U_{d0}} \cdot (U_d^* - U_{d0}), \qquad (4)$$

Here $\eta(U_{d0})$ - value of the efficiency at $U_{d0} < U_d^* \approx$ 600 V.

VI Conclusion

As a result of this activity on research of SPT work at high voltages it is shown, that:

1. Model SPT of ATON type can acts effectively at large voltages. So for example at Xe mass flow rate 1mg/s and voltage 910V on the model A-3 the specific impulse I=3400s at efficiency 50% is obtained.
2. The stream divergence for this mode is not more then 18°, and level of discharge currant oscillations is 20%.

3. Experimentally found out an important fact, following from this three-component model. It is that the maximum of efficiency of work of plasma source of SPT type arrived at equality of concentrations of the first and second multiplicity charged particles.

4. Maximum efficiency of the classic SPT of this construction at the small input powers can be estimated by formula.

Acknowledgments

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