Investigation of Physical Processes in SPT MAG

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Abstract: Distributions of local parameters in the first stage of the double-stage accelerator MAG are described. The streams of ions on the walls of the first stage and oscillation of ionic current in the volume of source are measured. It is shown that distribution of potential in the source determines integral characteristics of the system.

Nomenclature

$(\tilde{J} / \bar{J})$ = rate of the discharge current oscillations.
Z = axial axis of the thruster
r = radial axis of the thruster
U_d = *discharge voltage*
J_d = discharge current
$\dot{m}_a$ = anode mass flow rate
$\dot{m}_K$ = cathode mass flow rate
F = thrust
η = efficiency
I = specific impulse
φ = potential
T_e = electron temperature
n_e = particle concentration
Ii = ion current
Ji = ion current density

In 1999y. the ion plasma source of SPT type of the second generation ATON [1] has been created. For those times ATON had very high performances: its thrust efficiency has been up to 70%, the half-angle of divergence has

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been ~10^O and the oscillations level of discharge current $(\tilde{J}/\bar{J})$=(10-20)%. It has not found an application in the practice due to the fact, that here at first the problem of interaction of the vacuum chamber-thruster has arisen. The responsible scientific opinion has not been ready to the understanding and investigation of this problem. Therefore the problem to create a new source, which would have the advantages of ATON, but would not have its disadvantages, has been stated.

We has wanted to obtain next new quantities:

1. The high efficiency use of different working substances: cheap gases; vapors of metals; gases containing in the planet's atmospheres and so on.
2. The decrease of the divergence half-angle.
3. The decrease of the noises level.
4. The decrease of the part of neutrals, falling into the zone of the neutralization.
5. The decrease of the erosion rate.

One may obtain all these advantages by means of the transfer onto the two-stage system. It is explained by the fact, that in the first stage the task of the ultimate ionization of the working substance and the task of ions removal into the accelerated stage will be solved. Selecting the type of the discharge one may influence onto the noises level in the system.

The ion source of the second generation SPT-MAG [2] has been developed as this source (fig.1). The magnetic configuration with separatrix, containing a "zero" point of the magnetic filed, has been formed in the first ionizing chamber.

Probe measurings were carried out in the volume of the first stage, for understanding of physical processes accountable for forming of ion stream.

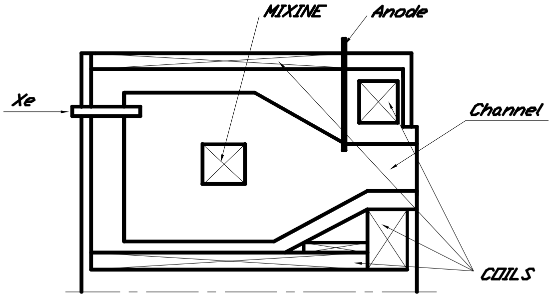


Figure 1. Design of the ion source MAG

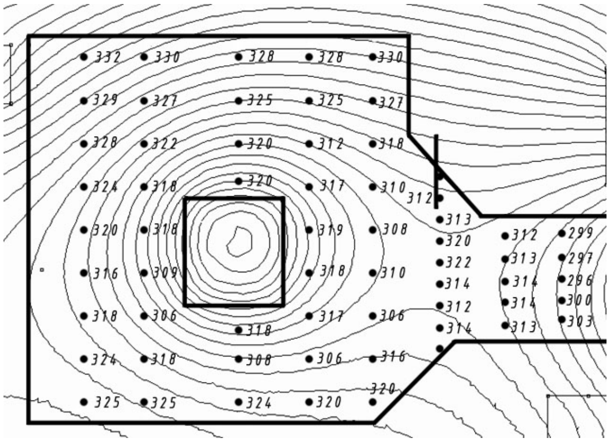


Figure 2a. Distribution of the space potential in the source MAG

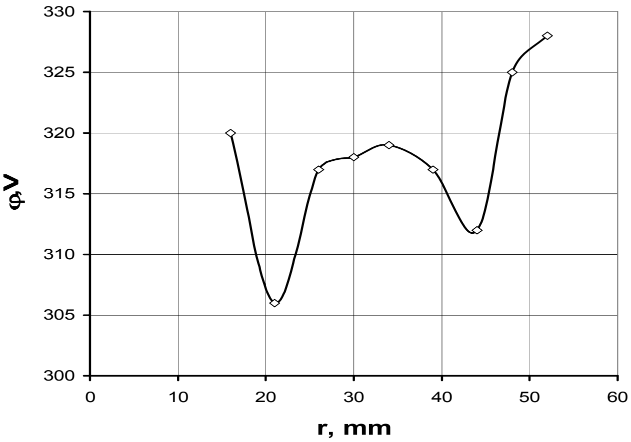
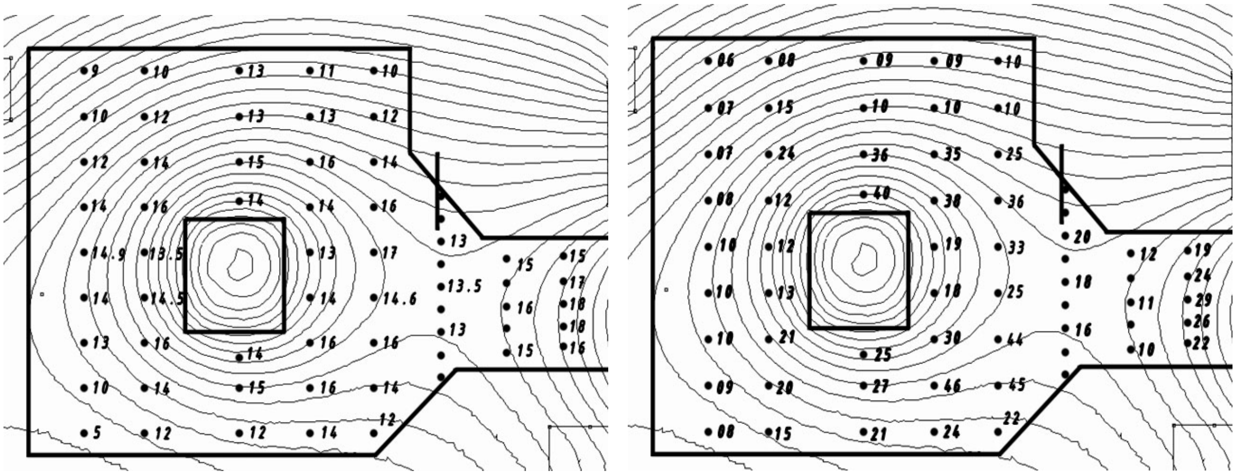


Figure 2b. Distribution of plasma potential in the cross-section Z=14mm from the anode in the buffer volume (m_a=2,0mg/s, U_d=300V, φmix=50V)

For this purpose flat probes with the area of collecting surface 0,07mm^2 and diameter of insulator ø=1,3mm were used. Such probe does not bring indignation in plasma and allows to get high-quality VAC. Measurings were carried out in five sections on Z on distances Z_1=7mm, Z_2=14mm, Z_3=23mm, Z_4=33mm, Z_5=41mm from the anode and in nine points in radial direction (every ~5 mm on r). VACs were measured in the optimal working mode of



a b

Figure 3. Distribution of electrone temperature (Te) and electron concentration (n_e, $10^{11}cm^{-3}$) in the source MAG.

thruster (Xe, U_d=300V; $\dot{m}_a$=2,0mg/s; $\dot{m}_K$=0,4mg/s; J_d=1,98A), according to the minimum value of the discharge current. Voltage between mixine and anode was 50V. On the fig. 2a distribution of magnetic force lines and value of potential in points of the VAC measurements are presented. It is seen, that minimum value of the plasma potential (306÷310)V takes place near-by separatrix. The value of potential increases at approaching to external and internal buffer walls and surface of mixine. The distribution of potential from the inner wall of buffer volume to the external wall is shown at fig.2b. The existence of potential pit with depth ~20V near by the separatrix is seen from these curves. The distribution of electron temperature and density of electrons are shown at fig. 3. It is seen, that the temperature of electrons changes in the range of values Te=(10÷16)eV and its maximal value corresponds to the separatrix position. The maximal values of the particle concentration (n_e~4,5*$10^{11}sm^{-3}$) are achieved in the output area of the first stage. The minimum values of particle density correspond to the areas near-by the walls of buffer volume. The obtained data allowed to expect the density of ion-birth $q=n_en_0 <\sigma V_e>$. Distributions of density of ion-birth are shown at fig.4. From fig.4 it is seen, that maximal ionization is along the separatrix and in area of the magnetic field zero.

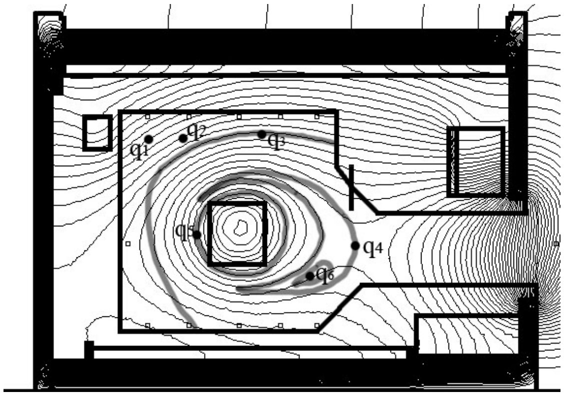


Figure 4. Lines of the constant ionization density
*q, *$10^{23}m^{-3}s^{-1}$ q_1=1.5, q_2=2, q_3=2.3, q_4=9, q_5=4, q_6=6*

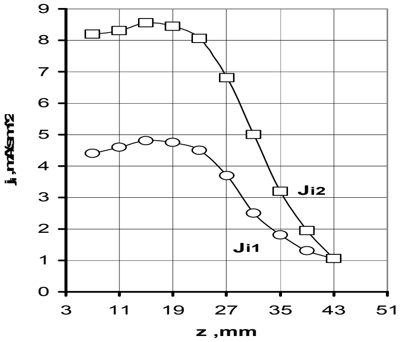


Figure 5. Distribution of density of ionic currents j_{i1} and j_{i2} along internal surfaces of a buffer volume.
m_a=2 mg/s; U_d=300V; φ_{mix}=50V.

The measuriements of the directed ion current density were carried out on the surface of th buffer volume with the purpose of determination of the working substance losses in the first stage. The method of double probe was used for measurements. The double probe had two plane-parallel collecting surfaces with the area S=0,07mm^2 per one. It allowed us to measure the ion currents on the surface and from the surface of the buffer volume wall. The directed ion current on the wall calculated from correlation: $j_{\perp i} = j_{i2} - j_{i1}$, where j_{i2} and j_{i1} are ion currents to the wall surface and out from it. At fig.5 The distributions of currents flowing from the surfaces J_{i1} and to the surfaces J_{i2} (external and internal) of the buffer volume walls are shown at fig.5. The similar curves were measured for all surfaces of buffer volume and mixine. The full ion current was calculated from these curves

$$J_i^N = \sum_{K=1}^{n} \left(j_{i2}^K - j_{i1}^K \right) \Delta S^K ,$$

where N- number of the buffer volume surface, k- number of breaking up of curves j_{i2} *(r)* and j_{i1} *(r).*

As a result, it was calculated that a maximal current falls out on-the-mixine surface and on the inner buffer wall. In addition, calculations showed, that the total ion current corresponds to 97% of the mass current in the volume of the first stage. It means that there is practically complete ionization of working substance in the first stage. Only one half from the total amount of the appeared ions enters in the accelerating channel. From the obtained data, it is possible to calculate the energy of ions falling on walls. This calculation shows that energy of ions, falling on walls is about 50eV. This energy can collect only on oscillations. For this purpose there must be oscillations of ionic current in the volume of buffer.

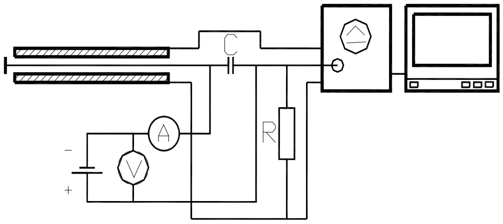


Figure 6. Principal chart of the probe measurements

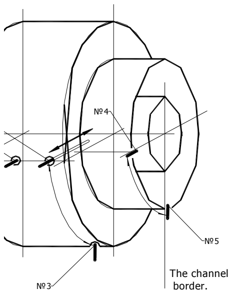
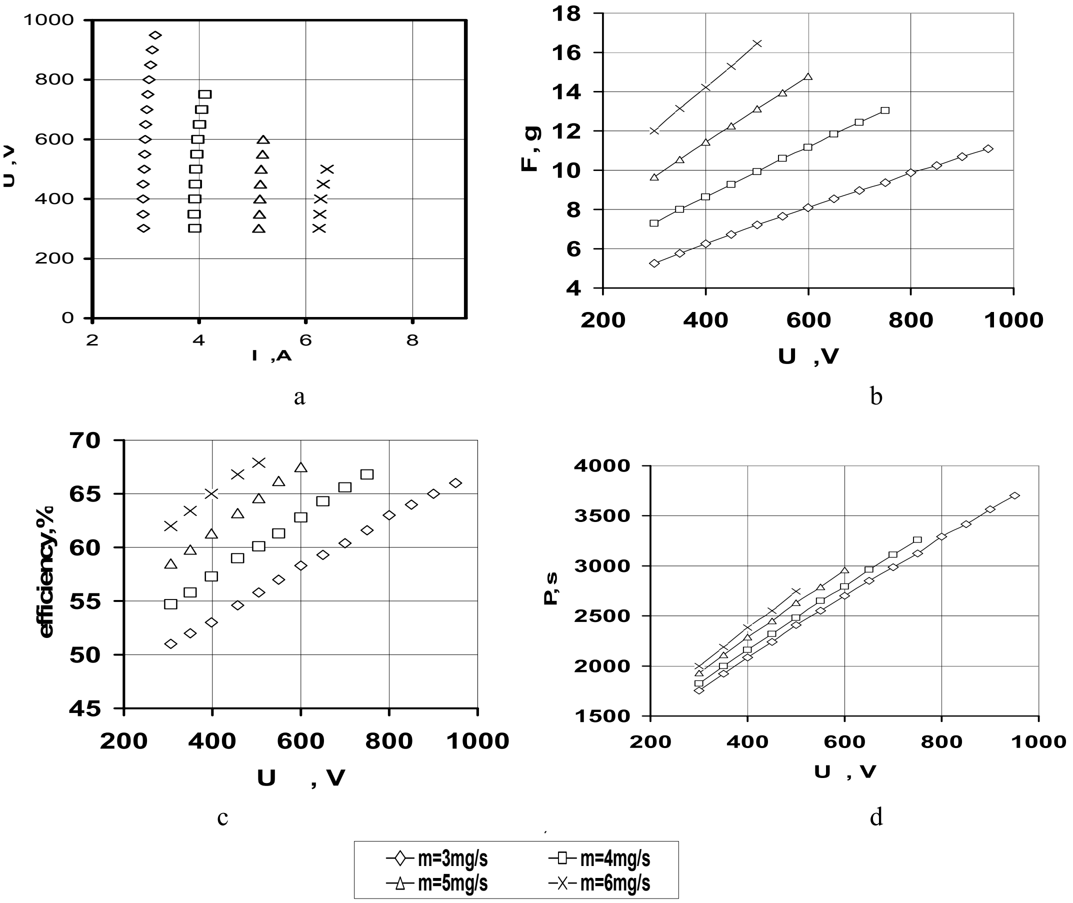


Figure 7 The displacements of the probes in the channel and in the buffer volume of the thruster MAG

The scheme of measurements of the ionic current oscillations is shown at fig.6. The structure of oscillations in the volume of the first stage and on a exit from the channel was studied with help of the butt-end flat near-wall probes. The location of probes is shown at fig.7. The negative displacement φ_{disp} relative to the floating potential was putted on each probe for the probe's activity in the area of ion satiation. The experiment showed that there are low-frequency oscillations with characteristic frequency f ~(15÷20)kHz in the spectrum of oscillation of ion current. They are synchronous in all near-wall area of the first stage, pass through the channel and synchronously show up at the cut of thruster. The change of situation takes place only in area located between mixine and zero of the magnetic field. Here is an azimuthal wave. The spectrum broadens up to 60kHz, but amplitude of oscillations is less, than at 20kHz. The difference of phases is fixed between probes,, for example, between 2nd and 3rd.

Thus there are two types of instabilities appears in the thruster, reason of origin of which can be the potential barrier in the near-anode area, impedimental flowing of current on the anode. In this case, only an alternating current flows on an anode.

As a result of the resulted works «quasi-linear» growth of basic integral characteristics of source without the effect of satiation (fig.8) was obtained. As it is seen from pictures, the maximal specific impulse is I=3700s at U_d=900V, $\dot{m}_a$=3mg/s . Thus maximal value of the thrust is F=16,5g (U_d=500V, $\dot{m}_a$=6mg/s), and anode efficiency of the thruster achieves a value η=67%. The rate of the discharge current not higher then (5÷7)%, and a half-angle of the divergence is α/2≤(8÷10)°. It is necessary to mention that the obtained results are identical both for a diffusive and for cryogenic vacuum.



a b

c d

Figure 8.VAC (a), thrust (b), anode efficiency (c) and specific impulse (d) of the ion source MAG.

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Periodicals

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