The Distinction between the EP Plume Expansion in Space and in Vacuum Chamber.

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Abstract: The paper contains the results of the research into the influence of external conditions on the plasma plume characteristics. This research is carried out trough a comparison between the SPT-100 plume characteristics, measured in an evacuated chamber, and the data obtained onboard "*Express*" satellite. In particular, it is shown that the plasma plume is dilated more intensively under space conditions than under ground conditions. It causes denser fluxes of particles, impulse and energy at the periphery of a plasma flow.

Nomenclature

$a=a(x)$	= transverse dimension of a plume
$A_{0,1,2}$, $B_{0,1,2}$	= constants
$\mathbf{B}$	= magnetic induction
e	= electron charge
$\mathbf{E}$	= electric field
J	= total current
j	= current density
fi	= potential drop
M	= torque
$\dot{N}$	= total ion rate
n	= concentration
S	=area
t	= time
T	= temperature
R,φ	= spherical coordinates
x, y, z	= Cartesian coordinates
ε	= ion energy
λ	= mean free path
θ	= angle of rotation
" $_i$ "," $_e$ "	= ion and electron components

I. Introduction

The characteristics of the SPT-100 and the force impact of exhausted plume on the spacecraft's (SC) elements were investigated on the geostationary satellites "*Express-A2*" and "*Express-A3*" [1, 2]. The primary analysis of these experiments is carried out in Ref. [1] We have done a complex analysis of experimental results using the original data from Ref. [2] and compared these data with theoretical models including the self-similar model (SSM) developed at TSNIIMASH [3].

The following factors determine a difference between the electric propulsion's (EP) plume characteristics in a vacuum chamber and in space:

- Influence of plasma and gas background on the plasma plume expansion;
- Influence of conductive walls on the distribution of electrical fields and currents in a EP plume;
- Losses and transformation of thermal energy of the plasma plume electrons;

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- Influence of the geomagnetic field on electrodynamic processes in a plume.

It is fundamentally impossible to simulate a real plume inside a vacuum chamber even for geostationary conditions where the influence of the Earth' magnetic field on an expansion of plasma flow is negligible. It is stipulated by the fact that in a metal chamber the electric field $\vec{E}$ of a flow is distorted by conductive walls, rather dense plasma background and reduced electron temperature T_e (approximately $\vec{E}\ \sim T_e$) as well. Moreover, to evaluate a possible negative influence of plasma plume on spacecraft elements and onboard system it is necessary to know well such plasma parameters as ion current density and ion energy near to solar panels, radio antennas and other sensitive equipment. It will allow to increase a reliability and an efficiency of a operation of electric propelled space vehicles.

II. Basis data

The general view of SC "*Express*", direction of the rotation of the solar panels θ, location of thrust modules, ion current density and ion energy sensors on the hull are presented on Figure 1. Axis *X* is directed away from the Earth, axis *Z* is directed along the solar panels.

On the satellites "*Express-A*" №2,3 the following experiments were carried out:

1. The distributions of ion current density were measured in two cross-sections at distances $x_1 = 3.75\ m$ and $x_2 = 8.8\ m$ by means of the sensors DRT1and DRT3 correspondingly, which were mounted on the frame of solar panel, and at distance $\sim 1m$ (practically in the thruster exit plane) by the sensor DRT3-1,2 located on SC hull .

2. The energy distributions of ion flow were measured in the same points.

3. The thrust of all four pairs of thrusters was measured. The noticeable decreasing of their thrust in comparison with the magnitudes which were measured in a vacuum chamber during ground tests was fixed. Besides, the dependence of thrust magnitude versus rotation of solar panels was registered for those thrusters whose plumes flow around the solar panel.

4. Three components of torque arising at plasma flow around the solar panels were measured.

5. The electric intensity near to SC surface was measured.

During the measurements the solar panels were at varied angles relative to the vector of flow velocity. So, due to a revolution (turn) of the sensors the angular distributions of mentioned above parameters were received.

A set of flight data, together with experimental data, obtained at ground tests of SPT-100 [4], allows to verify theoretical models very well.

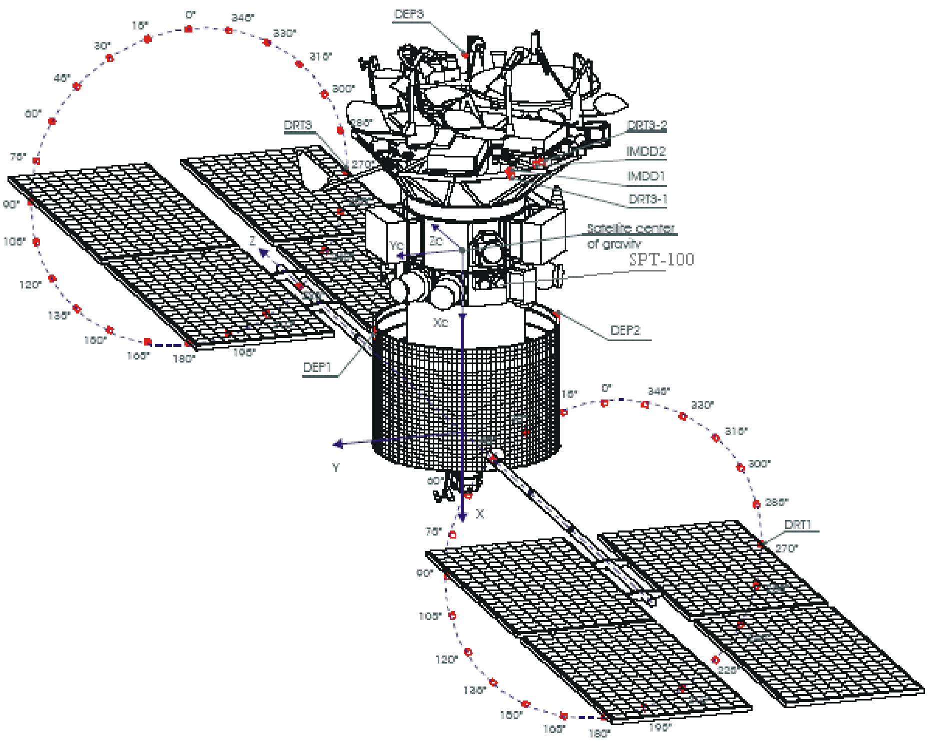

Figure 1 General view of "*Express*" satellite and dislocation of the SPT-100 thrusters and DRT sensors.

A. Distribution of ion current density.

The experimental data registered by DRT sensors are contained in the reports [2]. However, not all of them are authentic. We have done the preparatory selection of data proceeding from the following reasons:

Firstly, an investigation of telemetry results of dependencies $j(\theta)$ shows that in a channel "sensor–onboard evaluation – telemetry" a transient processes, $j = j(t)$, which are associated with a change of an angle of SP-turn, $\theta = \theta(t)$, are being registered obviously incorrect. It is shown that often, at a change of θ magnitude, the j magnitude stays constant and equal to previous value (appropriate to the previous value θ of an angle). And at the same time the fidelity of telemetry reproduction has the 5 to 6 significant (nonzero) digits. Then, after 12 to 60 minutes, the value of current density changes itself, but the value of the angle θ stays constant. Sometimes, a value of the current density, which corresponds to the initial value of the angle θ, stays constant during one or more hours, at the same time the angle is changed twice or three times. Such effects are typical particularly for large magnitudes of the angle $\theta \sim 90^\circ \div 180^\circ$, when the sensor is most distanced from the flow axis and, consequently, the expected values of the current density are minimal.

This defect of the registration system can be conditionally called as "freezing" effect on the analogy of a defect of a lab-equipment.

At screening the j data, which are invalid due to "freezing" effect, two criteria was used:

- All measured data of a current density $j(\theta)$, which stayed constant at changing of $\theta(t)$ value, were rejected;
- To exclude an inaccuracy at transient processes only those data of $j(\theta)$ which stayed constant during three or more measurement period (with a duration $\Delta t \cong 6$ min) were used.

Secondly, the analysis of the DRT sensor design given in Ref. [2] and their displacement on the SP-frame (see Figure 2) demonstrates a necessity to add the correction factors for values $j(\theta)$ given in Ref. [1,2].

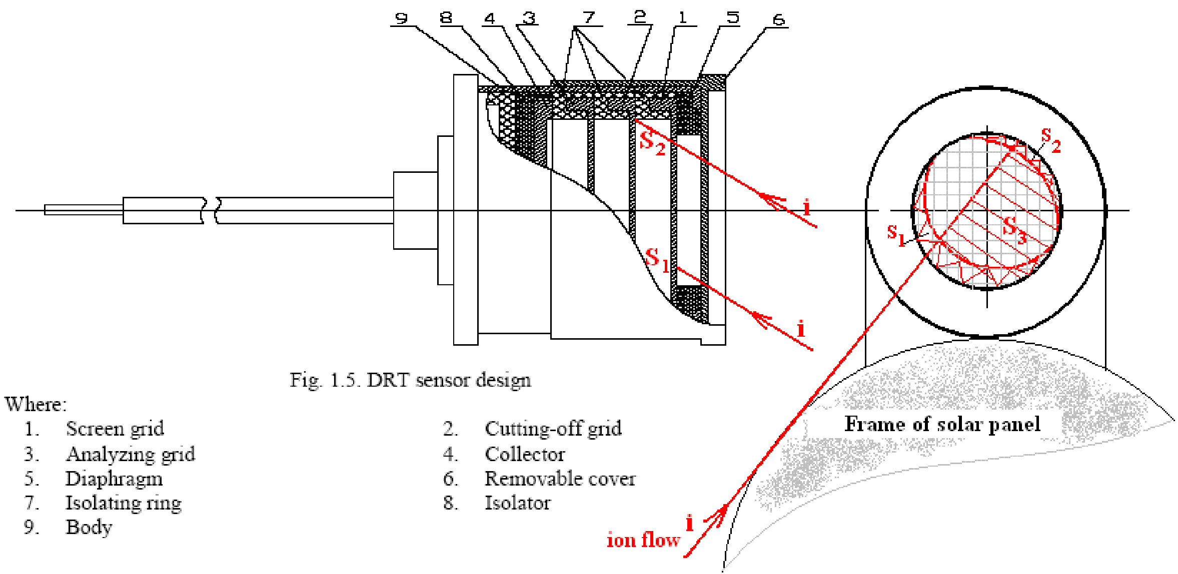

Figure 2 DRT sensor design and the shape of shading (S_1, S_2, S_3) of grides by structure elements of the sensor and the frame

The plane of the screen grid of sensors DRT1,3 is perpendicular to the axis of a solar panel rotation (axis *Z*). The axes of interchangeable thrusters T3 and RT3 (direction «– *Z*») and T4 and RT4 (direction « +*Z*») are also turned on the angle $\alpha = \pm 5^\circ 40'$ relative to the axis «*Z*».

At the initial angular position of solar panels, $\theta \approx 0$, the sensors DRT-1,3 are near to the SPT plume axis, and the ion flow **i** falls on the DRT inlet almost along a normal to the surface (with an accuracy α, i.e. $\cos\alpha \approx 1$). At the angle $\theta > 10^\circ$ the ion flow gets to the inlet with an incidence. Therefore, it is necessary to take into account the appearance of a shadow, which significantly cuts the effective area of the inlet (see Figure 2).

First type of a shadow, S_1, appears from the diaphragm 5 placed before the screen grid.

Second type of a shadow corresponds to that part of ion flow which passed (together with electrons) the screen grid having the zero potential and recombined on the inner lateral surface 7 between first and second grids (second grid has a negative potential and cuts off electrons).

Third type of a shadow appears at rather large angle θ , when the frame shuts partly the DRT inlet from the primary ion flow **i .** The frame shields completely the inlet of the sensors DRT-1 and DRT-3 at critical angles in range $\theta_{cr} \cong 90$ to 105° (It is related to the working (*T*) and reserve (*RT*) thrusters).

When the solar panel is turned on an angle more than θ_{cr} , the sensors DRT are whole in the shadow from the primary ion flow, although they fix nonzero values of a current density j . It is obviously the fluxes of scattered ions, and they are unsuitable for an analysis of primary flow generated by SPT. Therefore we did not use the array of experimental data of $j(\theta)$ measured at angles $\theta > \theta_{cr}$. For angles $\theta < \theta_{cr}$ the areas of first and second type shadow were calculated and correction factors for decreasing the effective area of the DRT-1,3 inlet were used.

The array of experimental data $j(x_1,\theta)$ and $j(x_2,\theta)$ represents a broad swarm of points. The "freezing" effect gives the points, which lie above the true dependence $j(\theta)$. A shading of the sensors gives the points below the true values. Such experimental data can confirm any theoretical model.

So, using the mentioned above criteria a great deal of experimental points was culled especially on a flow periphery. Nevertheless, a great number of measured data allows to determine the true dependence $j(\theta)$. Practically all of points of this dependence reproduce themselves 4 to 10 times (during separate sessions of SPTs switching "on" which were in different data distanced up one to several months).

The angular dependence $j(\theta)$ relating to the pair of *T*4 and *RT*4 thrusters is presented on Figure 3. A variation of values, $\Delta j / j \leq 15\%$, corresponds well to the accuracy of the DRT measurement that was depended during ground tests [2].

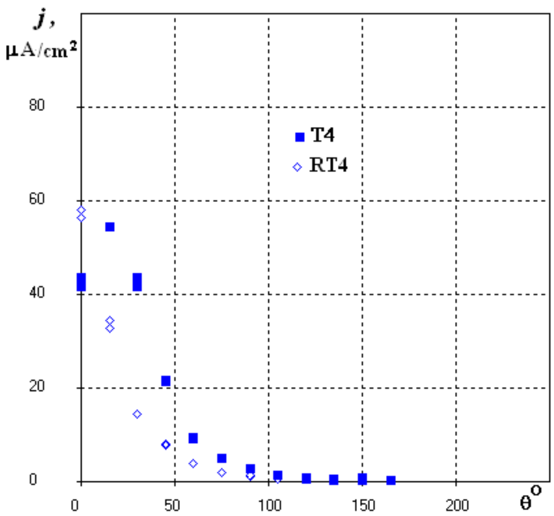

Figure 3 Dependence of ion current density *j* versus solar panel rotation θ. Data are measured by DRT1 at operation of T4 and RT4 thrusters

During an investigations of both features of plasma plume and effects of plasma plume / spacecraft interaction the many researchers assume that the ion flow exhausted from electric thruster expand itself under a conical similarity. I.e. it is assumed that the parameters of axis-symmetrical flow are described in spherical coordinates (R,φ) by a dependence as following

$$j_R = \frac{J}{\pi R^2} \cdot f(\varphi) \tag{1}$$

Here the center point is at the intersection of thruster exit plane and flow axis; *R*- radius-vector, φ - angle between axis and radius-vector *R*.

Based on on this hypothesis an approach was developed to evaluate the vital effects of force and erosion impacts of exhausted plume on a spacecraft. It is rather logical. Inside a vacuum chamber the sensors move along the arc with radius R_o equal to $R_o = 1m$ and measure a current density in radial direction. At that an experimental dependence is determined:

$$j_R = j_o(R_o,\varphi) = j_o(R_o) \cdot f(\varphi) \tag{2}$$

At practical calculations for all range of R, φ the trivial dependence (for conical flow) is used :

$$j_R = j_o(R_o,\varphi) \cdot \frac{R_o^{\ 2}}{R^2} \tag{3}$$

Just this hypotheses and this approach the authors of Ref.[1] try to confirm using the swarm of experimental points $j = j(R,\varphi)$.

At EDB «Fakel», the leading producer of electric thrusters of SPT-type, investigations of SPT-70,100 plumes executed on own test facility and in other labs are extended. In terms of this extension the approximation of a mathematical plume model was developed in a next view:

$$j = \frac{R_0}{R}\left(A_0 + \frac{A_1}{\varphi^2 + A_2}\right); \qquad \varepsilon = B_0 + \frac{B_1}{\varphi^2 + B_2}, \tag{4}$$

A set of constants of $A_{0,1,2}$, $B_{0,1,2}$ is determined relative to the SPT-70 and SPT-100.

At estimations of plume effects on spacecraft elements these expressions allow to get approximate values. But they are not adequate for quantitative calculations. This sentence follows from a comparison of angular dependencies (4) with ground and flight data.

First of all, experimental data [2, 4, 5] don't confirm square dependence from distance of plasma parameters, i.e. don't confirm the expressions (4). Figure 4 demonstrates the results of measurements of SPT-100 current density which were done at distances R_1=0.5m and R_2=1m [4] and normalized to R_0=1m with use of the expressions (4). If the expansion of plasma plume is under this law, experimental data should be coincided completely. But the Figure 4 shows that even at a flow beginning there are the differences from law (4).

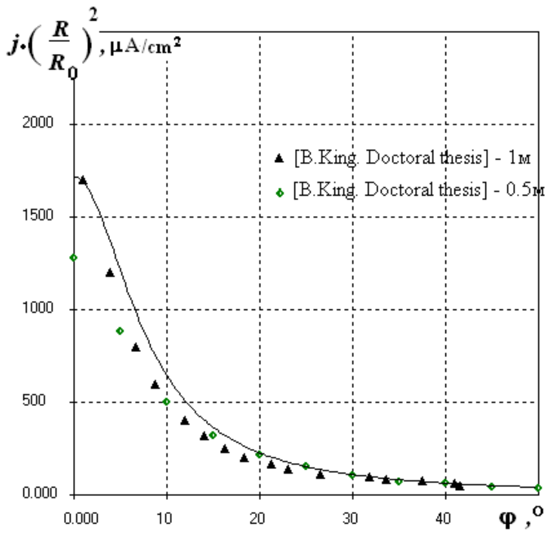

Figure 4 Experimental [4] and theoretical (4) angular dependencies of ion current density of the SPT-100 plume

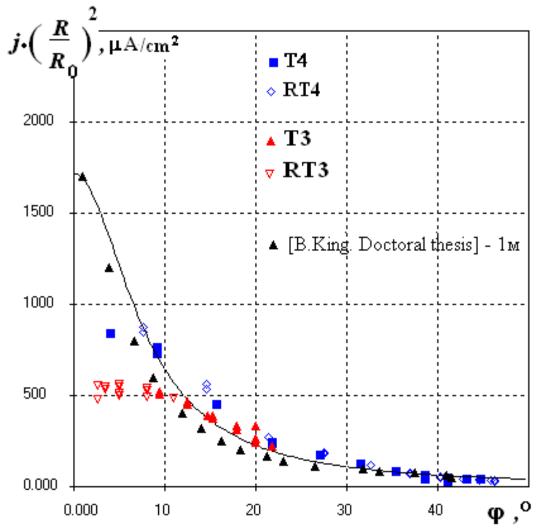

Figure 5. Angular dependence of current density. Theoretical model (4) - solid curve. Experimental data –symbols- are normalized to 1*m* with use of conical approach (4)

To verify mathematical models describing the SPT plume like conical flow we used the corrected experimental dependence $j(x,r)$ received on "*Express-A*". Here x and r ($r^2=y^2+z^2$)- the cylindrical coordinates associated with a plume. Experimental data were translated in spherical coordinates with use of the next relations

$$j_{Ro} = j_R(R,\varphi)\cdot\frac{R^2}{R_o^{\,2}}, \; R^2 = x^2 + r^2, \; \varphi = arctg\frac{r}{x}, \; j_R = j_x\frac{1}{\cos\varphi\cdot\cos\alpha},$$

Comparison of angular dependence (4) with ground and translated flight data is presented on Figure 5.

On Figure 5 the difference between the theoretical (conical) curve and experimental data is more appreciably.

The *SSM* model describes the distribution of ion current density in next view:

$$j_x = \frac{e\dot{N}}{\pi a^2} f\left(\frac{r^2}{a}\right); \; j_r = j_x\frac{r}{a}a'; \; j_x = \frac{j_э}{\cos\alpha} \tag{5}$$

Here x, r cylindrical coordinates, $\dot{N}$ - total ion flow rate, the values of $a = a(x)$ and $f = f\left(\frac{r}{a}\right)$ are calculated with use of a set of non-linear differential equations describing a hypersonic, narrow flow of low-temperature plasma.

To verify the *SSM* model the same experimental data are presented on Figure 6 as the dependence

$$j = j_э(x,r)\cdot\frac{a^2}{a_o^{\,2}}\cdot f\left(\frac{r}{a}\right).$$

The dependence of $a = a(x)$ is calculated by use of the flow parameters that were measured in a vacuum chamber [4]. Here it is taken into account that the electron temperature should be higher under space conditions than under conditions in ground vacuum chambers.

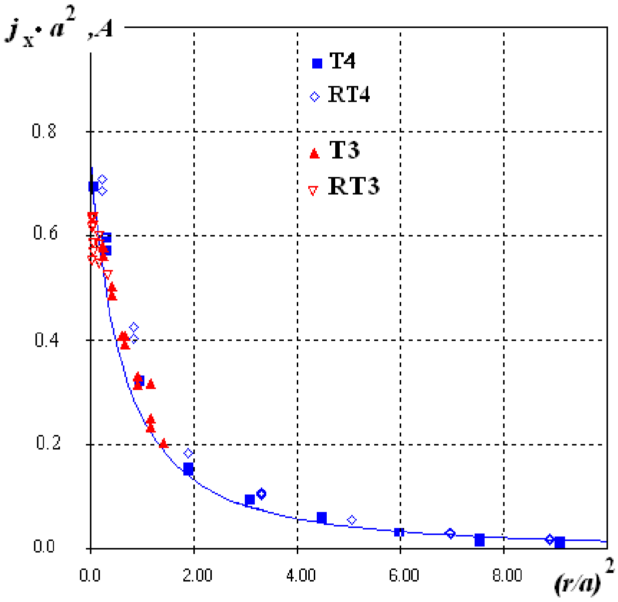

Figure 6 Angular dependence of current density. *SSM* model - solid curve. Experimental data –symbols- are normalized to 1*m* with use the *SSM* model

Figure 7 illustrates how much the difference between experimental data which were measured under space conditions and predicted data is significant. The sensors were mounted on the frame of solar array of "*Express*" satellite at the distances 3.8*m* and 8.8*m* from the thruster exit plane (as it is mentioned above). During a rotation of the solar panel these distances were being changed. After a complete revolution of the solar panel the sensors were able to register the characteristics of that plasma volume which is shown on Figure 7 as red ovals. The black thick curve corresponds to the transverse dimension *a(x)* of the SPT-100 plume calculated with use of expression (4). The arc with radius 1*m* is displayed black too. Note, such arc was chosen previously as basic to estimate downstream plume parameters with conical approach. The blue lines relate to the *SSM* model: lines of ion current in the plume (dotted curve); the transverse dimension of the plume (solid thick curve).

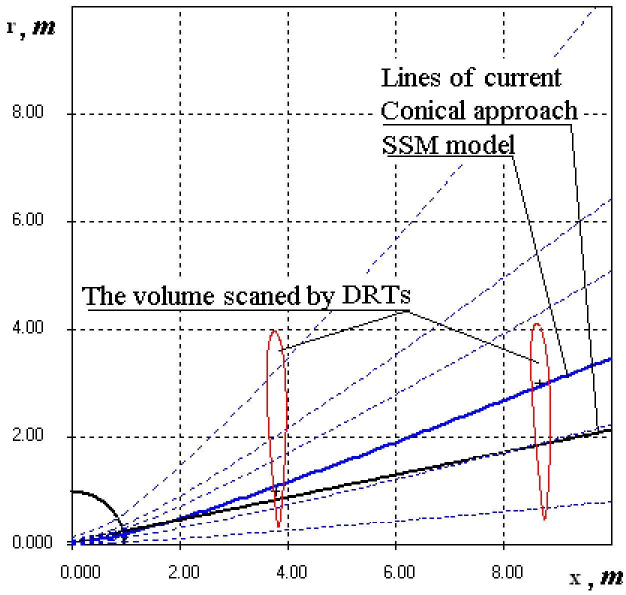

Figure 7 Comparison between a conical approach and *SSM* model with reference to the plume of SPT-100 on "*Express*" satellite

One can see how the lines of current diverge if that or other model is used. With reference to an evaluation of effects of plasma plume on a spacecraft such difference results in different magnitudes: the values are lower at use of conical approach.

B. Velocity distribution of ions.

A preview analysis of braking characteristics measured on "*Express*" allows to conclude the following.

With reference to the thrusters *T*3 and *RT*3 with cathode *C*1 the braking characteristics are presented in Ref.[2] only for the initial stage of work during period up 06.07.2000 to 07.09.2000. Corresponding sensor is placed at distance x_1=8,71*m* and moves with respect to the plume in angular range θ=0 to15°. Software was developed to process the braking characteristics. Output data are the magnitudes of average ion energy ε(θ) and energy distribution expressed through ion temperature *T*(θ). For the initial stage the following characteristics of the plume are typical:

1. Distribution of average ion energy ε(θ) weakly changes across the plume.
2. Energy spread is not great. Temperature increases up T_i=0.3*eV* at the flow axis to T_i=2*eV* at θ=15°.
3. Magnitudes of energy received with use of braking characteristics are less a little than received in a vacuum chamber (and incorporated in the "Fakel"'s-model (4)).

With reference to the thrusters *T*4 and *RT*4 with cathode *C*1 the braking characteristics are presented in Ref.[2] for more wide range of angles θ=0-40° and for period from July 2000 to January 2001. Their analysis allows to conclude:

1. At the initial stage of SPT work (June-September 2000) the parameter distributions in the *T*4 and *RT*4 plumes at distance *x*=3,8*m* are similar to parameter distributions of *T*3,*RT*3 plumes at distance *x*=8,7*m*. The average ion energy ε(θ) decreases weakly, and temperature *T*(θ) increases across the plume. Energy spread is relatively low, ion temperature is equal to an order of units of *eV*.
2. By December 2000, when a total operating time of each of SPT assumed several tens of hours, the average ion energy decreased noticeable, ion temperature increased.
3. By January 2001 a significant decreasing of ion energy occurred up to ε<200*eV* at θ=0 and a significant increasing of energy spread up to $T_i \sim 10eV$ at θ=40° was as well.
4. These changes of plume characteristics coincide well with measurements of SPT thrust; the thrust decreased significantly during this time.
5. The transverse ion distribution measured in flight experiment differs noticeably from the one measured at ground tests and then accumulated in the "Fakel"-model of SPT-100 plume. So, ion energy in the flow periphery is greater in space than in a vacuum chamber.

The examples of braking characteristics and the results of their processing are also presented on Figure 8 and Figure 9.

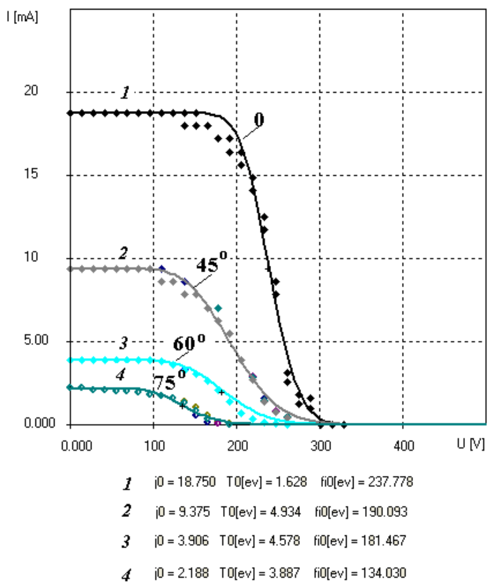

Figure 8 Change of braking characteristics with reference to angular position of the sensor

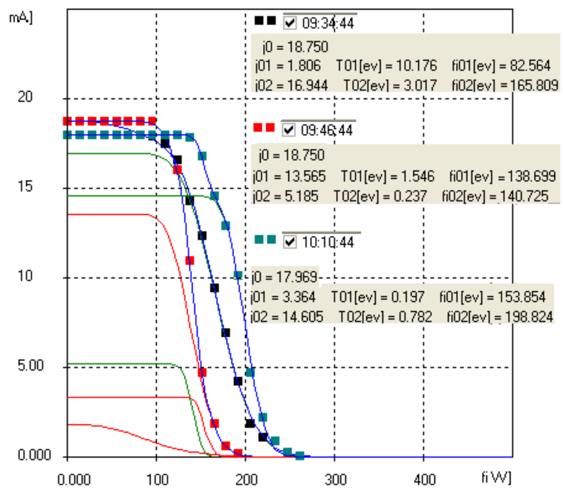

Figure 9 Braking characteristics of two-component flow

The curve ***1*** corresponds to the initial stage of SPT operation when the average ion energy is great enough and the ion temperature T_i is relatively low. The curves ***2-4*** correspond to braking characteristics with reference to the same thruster at change of angular position of sensor 45°, 60° и 75°, correspondingly. One can see that even ion flows on the periphery are described well at the initial stage of thruster operation by an approach of a monoenergetic beam.

Figure 9 illustrates braking characteristics of the same thruster at the same angular position relative to the sensor (0°) which were measured after several tens of hours of operating time. Even during one operating session the braking characteristic changes noticeably. Ion flow ceases to be mono-energetic; it is described well now as a two-component flow and energy of each ion component is lower than applied voltage (~300*V*).

C. Parasitic torque

The parasitic torques which appear at SPT operation were measured subject to a solar panel rotation. Two pairs of SPT generate plumes in (YOZ) plane at the angles of θ = ±5°40′ to OZ-axis (this is the axis of solar panel rotation). The vectors of a thrust from one pair (*T*3 and *RT*3) pass though the gravity center of the spacecraft, from other pair (*T*4 and *RT*4) the vectors do not pass through the gravity center.

Figure 10 and Figure 11 show the calculated results of all three torque components *Mx, My, Mz,* which appear on SC *Express* when the SPT operates. In the figures hollow dots relate to experimental values of torque of working thrusters (*T*3 and *T*4). Filled dots relate to reserve thrusters (*RT*3 and *RT*4). One can see that calculations of torque created by all of four thrusters coincide quantitative with flight data.

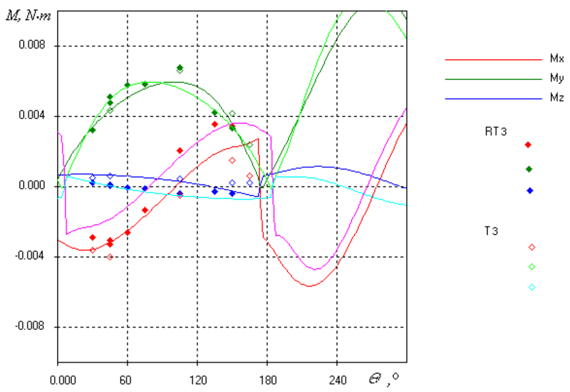

Figure 10 Comparison of calculated torque with *Express* data for *T*3, *RT*3

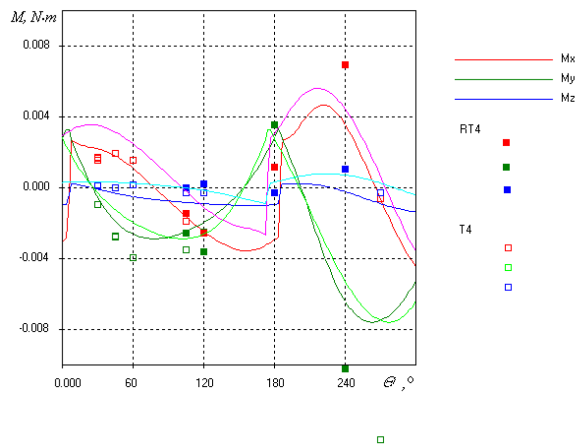

Figure 11 Comparison of calculated torque with *Express* data for *T*4, *RT*4

So, unique results of flight experiment on *"Express"* satellite refute clearly all mathematical models on base of conical approach and confirm the *SSM*- model which quantitatively describes a flow as non-conical in principle. Note, this model on united positions describes both the local plume parameters (*T, n,j*) and the integral effects of a plume on a spacecraft. An analysis of received data allows to conclude that a divergence of exhausted plasma flow will be greater under space conditions that it is determined at a ground test. It results in greater ion currents coming to nearby structure elements than it follows from a conical approach. An increasing of ion current coming to solar array, for example, results in , firstly, an increasing of surface erosion, secondly, an increasing of parasitic torque and, thirdly, a decreasing of effective thrust of an plasma propulsion. It should be very interesting and very profitable from practical point of view to extract a maximal information from unique experiment conducted on "*Express*" satellite. In particular, it is necessary to investigate a correlation of time-base changes of both integral propulsion characteristics of SPT and local distributions of physical values in a plume. It will allow not only to determine a real mechanism of SPT degradation under space conditions, but also to give vital information about physical behavior of electric discharges in plasma thrusters.

III. Physical processes governing a different characteristics of EP plume in space and in vacuum chamber.

A. Influence of a dense neutral background inside a vacuum chamber .

The accelerated and concentrated in a thruster ion flow $\dot{N}$ is re-charged on background neutrals having a density n_n at near-field of a plume. A length of this part of a plume is in order of free pass length of an ion in background gas $\Delta x \sim \lambda_e = \frac{1}{n_n q_e}$. Except a charge-exchange, at distance of $\Delta x \sim 0{,}2\ m$ from an exit nozzle of thrusters like SPT-100 or D-55 a background neutrals are ionized partly. An ionization of neutrals by electron impact occurs in discharge gap of a thruster and in a near-field ("hot") zone of a plume as well where a electron temperature is great enough, $T_e \sim 10$ *eV*.

As a result of the two mentioned above processes a secondary plasma appears near to a thruster and scatters in a radial direction and partly backwards [6]. The flow rate of primary ions decreases $\dot{N} = \dot{N} \exp\left(-\frac{x}{\lambda_e}\right)$. Secondary ions accelerate in a self-consistent electric field of a plume and get an energy of $\varepsilon \sim 20 \div 30$ *eV*.

As distinct from vacuum chamber a secondary plasma is less dense in space. Its sources are only the non-ionized in a gap propellant – Xenon (a share of neutral xenon is too little 0,01-0,05) and rather rarefied gas of a spacecraft outer atmosphere (the pressure in *"Express"* outer atmosphere was $P \sim 10^{-8}$ *mm Hg* [1,2]).

Secondary plasma influences on processes of an interaction between a plume and walls of vacuum chamber or nearby structure elements of a spacecraft. Obviously, such effect is much greater under vacuum chamber conditions.

B. Influence of conductive walls on a distribution of electric fields, currents and dynamic characteristics of a plume as well.

Inside the plasma plume there is a potential drop Δfi in radial and axial direction regarding to a flow velocity [8]. Its magnitude is $\Delta fi \sim 30V$ with reference to the kilowatt-class thrusters [7]. Under influence of this electric field appearing between a plasma plume and conductive surfaces (walls of vacuum chamber or structure elements of a spacecraft) a electric current leaks through a secondary plasma.

Under vacuum chamber conditions "hot" electrons go to walls from a near-field zone, and ions from narrow accelerated beam encloses this current trough a far-field zone. As a result along the plume an electric current leaks and encloses over vacuum chamber hull.

At EP operation in space where a secondary plasma is less dense in several order of magnitude and a plume almost does not touch conductive surfaces, these currents are much less.

The technique of estimation of an intensity of these processes and also examples of calculation of shorting current under ground and space conditions are given in Ref. [8].

C. Losses and transformation of thermal energy of electrons in a plume

Inside a vacuum chamber and at EP operation on orbit there is an electron flow from a plume to walls, first of all it relates to "fast" electrons from a high-energetic tail of their distribution function. However, inside a vacuum chamber, where there is a dense secondary plasma and all plume is bounded by metal, this process occurs more intensive than it is in space, near to a spacecraft. These electron flow to walls are regulated by a potential jump, Δfi_E , in a thin Debye layer close to hull surface (of a vacuum chamber or spacecraft). A potential jump in turn is assigned by a balance of flows of electrons and ions all over a surface. For example, during a ground test of SPT-100 or D-55 thrusters a magnitude of potential jump is equal to $\Delta fi_E \cong 10B$. The earlier calculations of potential jump with reference to SPT-100 operation on geostationary orbit [8] gave the magnitude $\Delta fi_E \cong 13$ to $20V$ in dependence on thruster design.

An experimental study of a distribution of electron temperature in the D-80 plume has shown [7] that the heat transfer by electrons is difficult in an accelerated plasma flow. Besides, a retarding field close to spacecraft surface is higher than it is in a chamber. That is why under space conditions, where the flow of "fast" electrons to walls is not so intensive, the electron temperature in a plume should be higher that it is registered under ground conditions. Measurements made in vacuum chambers by many authors [9] give a same value $T_e \sim 1 \div 2$ *eV* at distance $\Delta x > 1m$ from SPT' exit nozzle. The analysis of "*Express*" flight data [10] shows that at flow downstream $\Delta x \sim 3 \div 8$ *m* the electron temperature is higher and it is equal to $T_e \sim 3 \div 4$ *eV*.

IV. Conclusion

1. Field experience of electric thrusters on a geostationary satellite shows that at initial phase of an operation many working characteristics of a thruster in space differ from ones at ground tests; i.e. in the space the thrust of thrusters is less, the divergence of a plume is more, the ion density on a periphery is higher, energy spread of ions is less, electron temperature is higher.

2. By an increase of a total operating time a thrust and an average energy of ion flow decreases, an energy spread of ions and a flow divergence increases.

3. Calculations made using ground experimental results as input data and *SSM* model of a plume allow both to predict correct characteristics of thruster plume and to estimate expected impacts on spacecraft taking into account mentioned below electro-dynamical and thermal-physical effects:

- A divergence of a plasma flow is more intensive than it is in conical flow. It is a consequence of influence of self-consistent electric field $\vec{E}$ on a dynamics of plasma flow. This field is directed predominantly in radial direction of a flow $E_r >> E_x$.

- An flow expansion along the geomagnetic field $\vec{B}$ occurs more intensively than one can wait on basis of measurements in a vacuum chamber, an expansion across a field $\vec{B}$ is significantly slower.
- Negative electric potential which appears over a surface of a geostationary satellite at the SPT-100 operation achieves the value of $13 \div 20V$. An accelerating voltage in a discharge decreases on the same value. As a result the thrust of thrusters becomes less than expected.

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