INVESTIGATION OF DIFFERENT SCHEMES OF GAS DISTRIBUTION IN SPT CHANNEL

Sergey A.Khartov, Alexander B.Perfiliev

Moscow Aviation Institute (State technical university) MAI
Electric Propulsion and Space Power Plants Department
4, Volokolamskoe sh., Moscow, 125971, Russia, k208@mai.ru

The software based on Monte-Carlo method and on direct simulation of particles motion was developed in order to investigate how neutral particles are distributed over near anode zone in the SPT channel. Neutral particles distribution in the SPT channel as a dependence on different variants of propellant feeding into the SPT channel and on different geometry (configuration) of the accelerating channel were obtained with the help of this software. Comparative analysis of the obtained results about neutral particles distribution over the SPT channel an their uniformity were carried out. The preliminary conclusions about preferable variant of propellant feeding and accelerating channel geometry were done. The work was sponsored by INTAS (project 99-1225).

1. Introduction

The experiments carried out earlier in MAI [1,2,3] show that a procedure of propellant feeding into discharge chamber influences greatly on to the SPT integral performances. Neutral particles distribution in the channel is a function of feeding procedure, accelerating channel and anode-gas distributor geometry. The best thruster performances was obtained in the case, when propellant feeding procedure was done such a way that the best uniformity of neutral concentration in the area of main ionization according qualitative attribute was secured. In this case propellant ionization rate is improved and energy expenses are decreased.

The aim of this work is to analyze how geometry factors can influence on neutral particles distribution in the SPT channel. The software simulating neutral motion and calculating neutral particles concentration in the accelerating channel was developed for examination. The Monte-Carlo method and method of direct simulation are used for calculations.

2. Theoretical background

In order to calculate neutral particles concentration in the near anode zone of the accelerating channel, it is necessary to know what factors neutral particle motion depends on, what factors influence on neutral particles distribution and what boundary conditions are?

In the kinetic theory gas is described with the help of Boltzmann equation:

$$[\frac{d}{dt}+\sum_{i=1}^{3}(\xi_i \cdot \frac{d}{dx_i}+(\frac{F_i \cdot d}{m \cdot \xi_i})]f = J(f), \tag{1}$$

where *J(f)* – the integral of direct and back collisions.

If there is no external force, Boltzmann equation is transformed into well-known Maxwell equation:

$$f_m = n \cdot (\frac{2 \cdot \pi \cdot k \cdot T}{m})^{-3/2} \cdot \exp\{-m \cdot [(\xi_x - \upsilon_x)^2 + (\xi_y - \upsilon_y)^2 + (\xi_z - \upsilon_z)^2]/2 \cdot k \cdot T\}. \tag{2}$$

Reducing Boltzmann equation to dimensionless view and choosing typical size of the body *L* as a scale value for coordinates, let us separate Knudsen index from obtained dimensionless equation $Kn = \frac{l_\infty}{L} = \frac{1}{\sqrt{2} \cdot n_\infty \cdot \sigma_\infty \cdot L}$. Taking into account that the pressure in the SPT channel is $P < 10^{-1}$ Pa and particles concentration $n < 10^{20}$ $1/m^3$. the simple estimations show that the length of molecule free motion is sufficiently greater than chamber's size L. And due to this fact neutral particles motion is collision free. Gas flow mode in the accelerating channel can be assumed as free molecular.

As far as flow mode in the accelerating channel is stationary one, Boltzmann equation can be rewritten as $\bar{\xi} \cdot \frac{df}{d\bar{r}} = 0$. In this case particle trajectory is a straight line.

Let us set the boundary conditions for incoming and reflected gas flows. The boundary conditions contain function f_∞ for gas, which is far from streamlining body on one boundary, and function f_r for reflected particles determining from lows of molecule interaction. Gas in incoming nondisturbed flow is characterized by Maxwell function. The function f_r is determined by mechanism of molecular interaction with solid body crystal grid atoms. After particle collision with the surface, the following events can happen: the particle can be reflected from the surface with (or without) internal energy change (the process of scattering); the particle can knock out particles from the surface (sputtering), the particle can be absorbed (physically or chemically) on the surface or it can penetrate into the surface material (capture). Spontaneous emission of dissolved gases particles back to the flow can happen. It is very difficult to take into account all micro parameters of interaction, so let use the simplified model describing the interaction between incoming flow and the surface. Let assume that particle diffusion reflection from the surface is taken place.

3. Procedure of calculation

It is known that for free-molecular flows, such as neutral particle flow in the accelerating channel, the gas parameters distribution follows the Maxwell law. But the direction of particle motion at the moment of its start from the surface can be assumed as equal-probable. The particles do not interact with each other and the mode of its motion is stationary. The particles move in straight lines until its interaction with the surface.

The following assumptions were used in the numerical model. The direction of particle motion at the moment of its start from the surface is equal-probable. The particles start from the surface of anode-gas distributor outlet. The process of calculation does not depend on time (stationary mode). Process of calculation is repeated until the moment when the particle flights out of acceleration channel. It is assumed during calculations that particles move in series as far as there is no interaction and mode of motion is stationary one. The task is 2D and the concentration is calculated as a number of particles in the surface round the mesh node.

Boundary conditions:

- Particles reflection is diffusion considering that particle velocity and energy is changed due to surface temperature influence. Incoming flow parameters correspond to parameters given on the start surface.
- It is assumed that particle moves with constant parameters until it collides with the surface. The direction of motion, energy, velocity and the distance covering at every step of the cycle are constant values. After interaction with the surface, the particle is characterized by new values of velocity, temperature, direction of motion and it displaces on different distance in the area of calculation.
- Total amount of particles examined during each simulation is $5 \cdot 10^4$.

Particle concentration distribution over mesh of concentration is output into text file, converting into MS EXEL where needed drawings are built.

4. Checking calculation

In order to check the model accuracy the process of gas flowing through ring coaxial channel [4] was calculated. This process is described as:

$$G = \frac{\Delta p}{\sqrt{2\pi \cdot \frac{1}{\mu} \cdot R_y \cdot T}} \pi \cdot r_2^2 \left(1 - \frac{r_1^2}{r_2^2}\right) W , \qquad (3)$$

where Δp - difference between pressures on channel's input and output; μ – gas molecular weight; R_y – universal gas constant; T – gas temperature; r_1 and r_2 - internal and external radiuses of the channel; W – Klauzing coefficient.

The difference between numerical and analytical results is 25-30%. Analyze shows that it is mainly due to model's 2D geometry.

5. Results of calculation

Propellant feeding scheme with different variants of channel and anode-gas distributor geometry and the results of calculations are represented in the following figures.

Fig.1

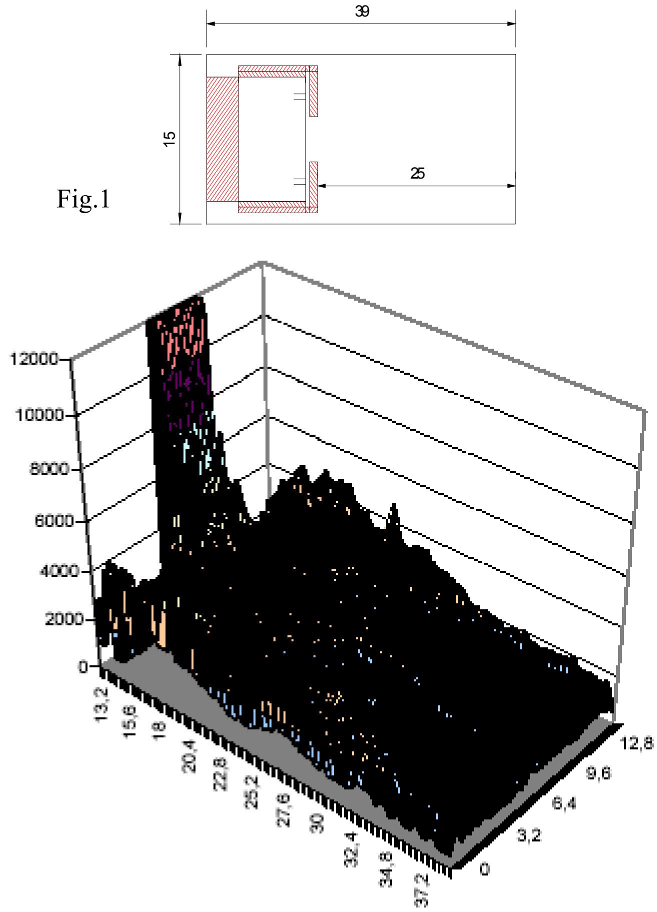


Fig.2

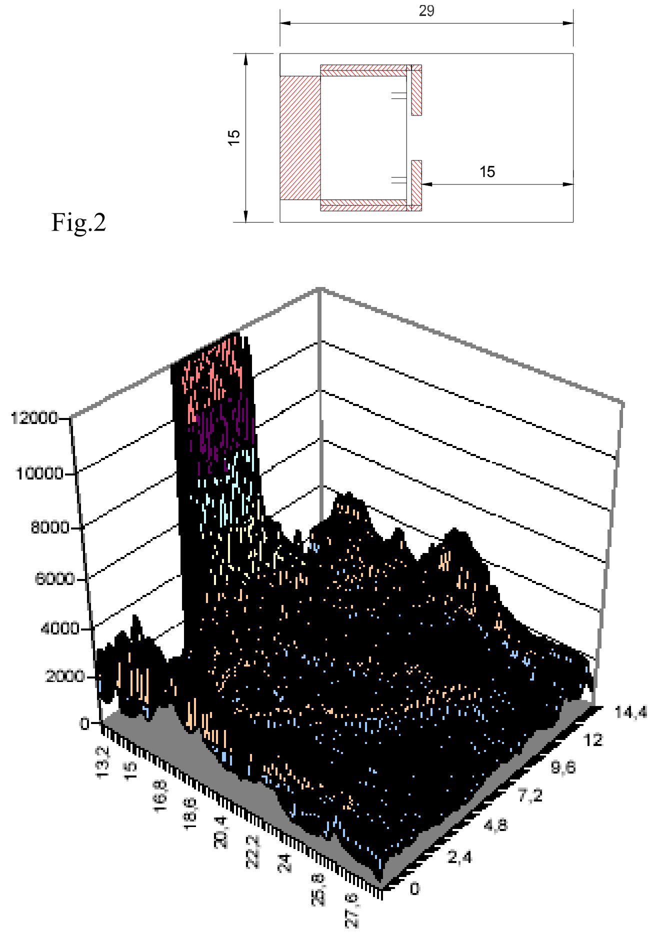


Fig.3

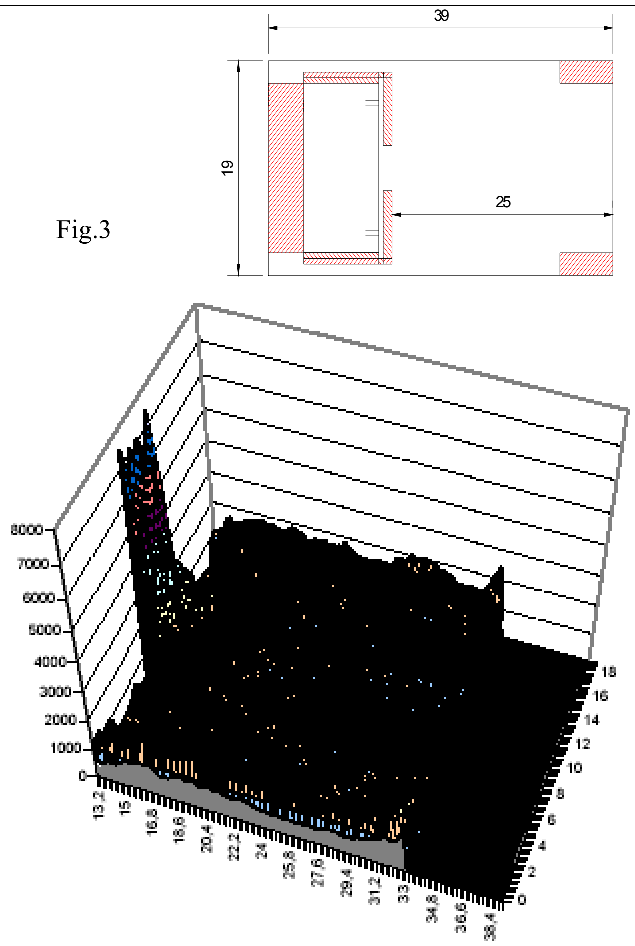
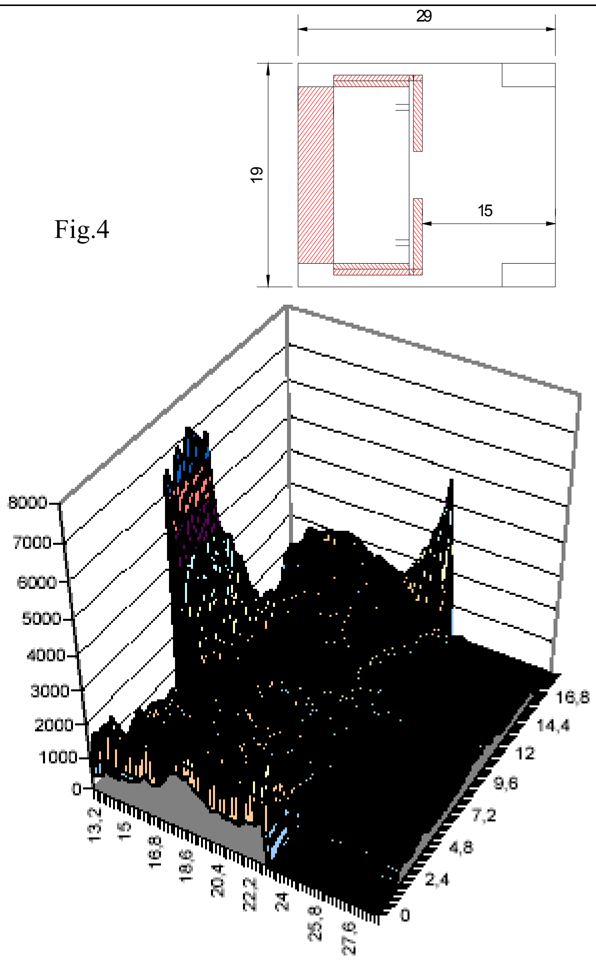
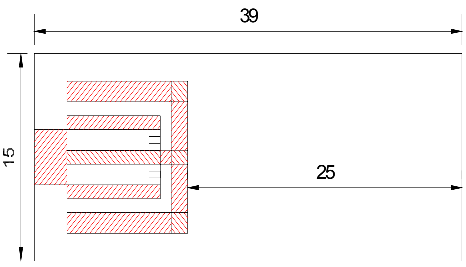


Fig.4





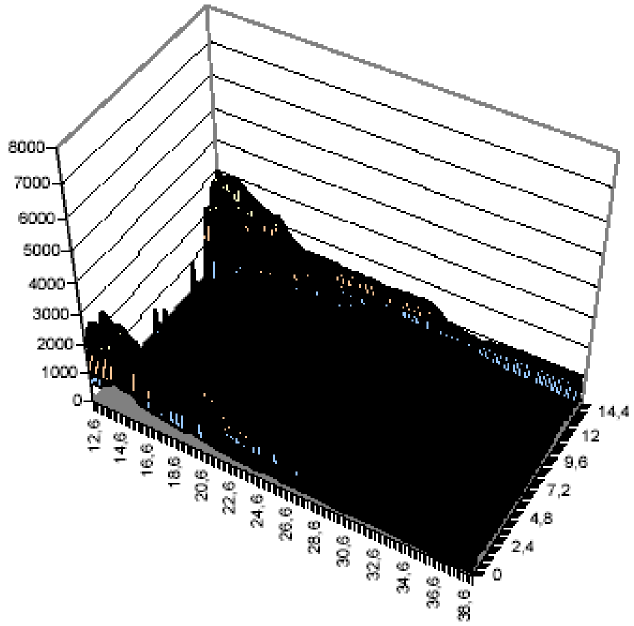
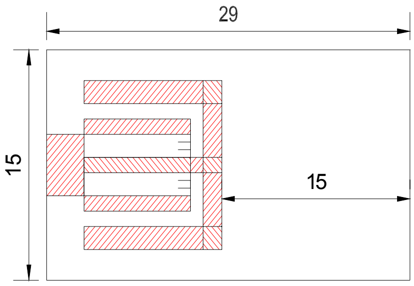


Fig.5



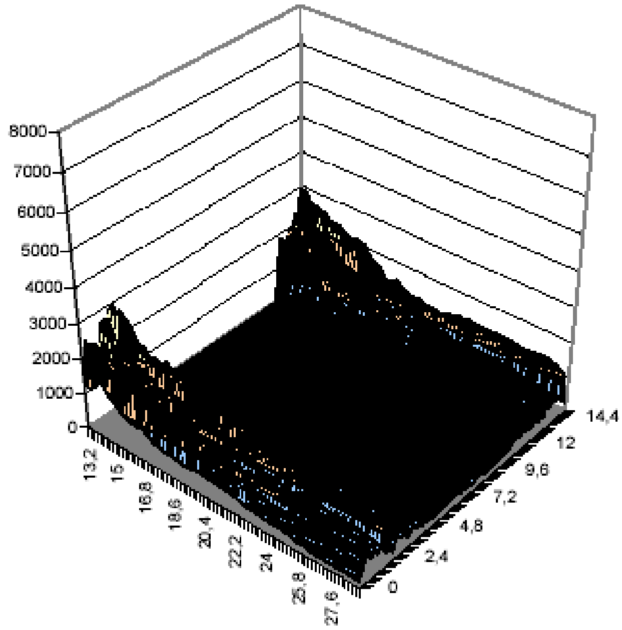
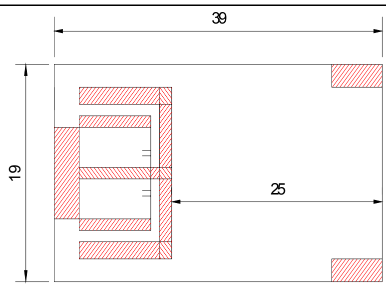


Fig.6



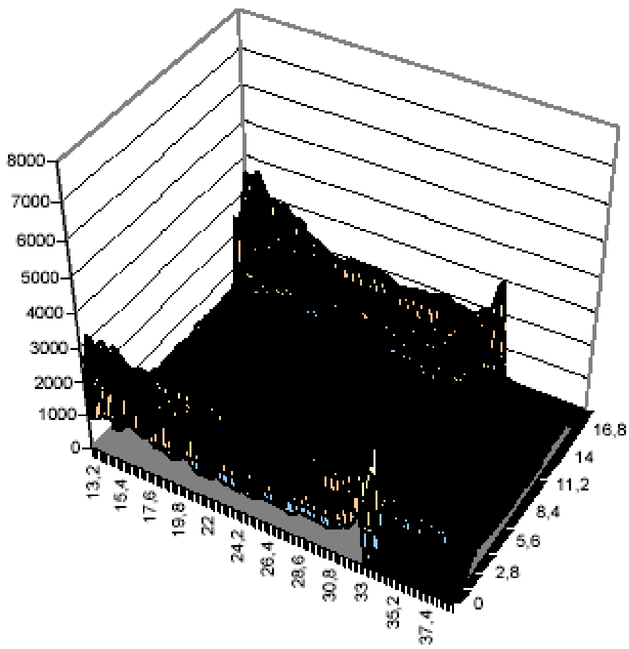
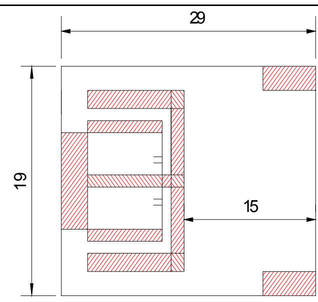


Fig.7



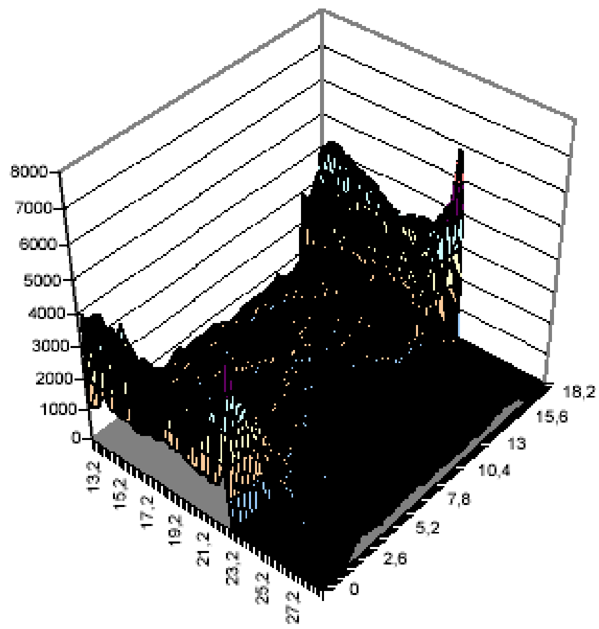


Fig.8

In this figures one can see particles distribution in:

- typical channel geometry and gas feeding procedure: fig.1 – standard, fig. 2 - shorting channel;
- channel with contraction at the exit: fig.3 – standard, fig. 4 - shorting channel;
- channel with gas feeding in back direction: fig.5 – standard, fig. 6 - shorting channel;
- channel with contraction at the exit and gas feeding in back direction fig.7 – standard, fig. 8 - shorting channel.

6. Conclusions

The results of simulation show that it is possible to obtain different distribution of neutral component on the input of the main ionization zone if one is changing channel wall geometry and gas feeding procedure.

The developed software permits to simulate atoms' motion in the SPT channel with admissible accuracy.

In all cases of simulation one can see that neutral particles flow disturbed mainly in the near anode zone of the accelerating channel.

In this case if propellant feeding is done according to standard scheme, more uniform concentration in the main zone of ionization is happened in longer channels. Channel extension in the near anode zone permits to increase atoms' concentration on the input of main ionization zone. Gas back feeding permits to increase atoms' concentration in the near wall zones of the channel. The obtained results confirm partially the hypothesis about channel wall geometry and gas feeding procedure influence on neutral particle distribution in SPT channel and therefore on thruster operation.

Bibliography:

1. A.Jakupov et.al. The possibility of nearanode process controlling for perspective SPT models. IEPC-95-48, 24 IEPC, Moscow, Russia, 1995.
2. Final report on the INTAS 96-2276 project "Physical study o f small hall thrusters used for satellite orbit control", CNES, 1998.
3. Final report on the INTAS-99-1225 project "Study, design and characterization of Hall thrusters optimized for being used with mixtures of Argon, Krypton and Xenon as propellant", CNES, 2002.
4. Yu.A. Koshmarov, Yu.A. Ryzov "Applied gas dynamic of rare medium". - Moscow, "Mashinostroenie", 1977 (in Russian).