Simulation of Work Processes in Low Power Hall Thruster

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Abstract: The problem state of the simulation of three dimensional plasma flow in low power hall thruster is provided. The plasma flow in low power Hall effect thruster channel simulation method is proposed. The simulation process separation on two phases is proposed. The frequency of impact of neutrals with walls of channel and distribution of thermal flow on walls of channel for outer and inner surfaces respectively are shown. Results of simulation not contradicted to experimental data. The future development of the proposed method is described.

Nomenclature

C	=	the central point of an element of border
$I_{i,j,k}$	=	ions concentration which was experimentally measured along channel centerline
M_{in}	=	weight of the gas which has inlet in calculation area
M_{out}	=	weight of the gas which has outlet from calculation area
m	=	particle mass
$N_{i,j,k}$	=	calculated concentration of neutrals
$\vec{N}$	-	a normal to the border element directed into the computational area
$P_{i,j,k}$	=	probability of ionisation of a particle
R	=	the casual point belonging to an element of border
V	=	speed at inlet to cell
V_T	=	thermal speed of gas with temperature of an element of border
V'	=	new speed
$\Delta\varphi$	=	potential between cells

I. Introduction

It is known that developers of Hall Effect Thrusters (HET) were confronted with significant decreasing of its characteristics according to power consumption decreasing. Decreasing of its characteristics appears more rapidly than it can be supposed. There is statistical treatment of published data of HET efficiency with power consumption from 20 W to 10 kW on fig. 1. Data approximation for thrusters with power consumption more than 300 W gives forecast for small HET efficiency around 40%. However efficiency of known low power HET is about 20%.

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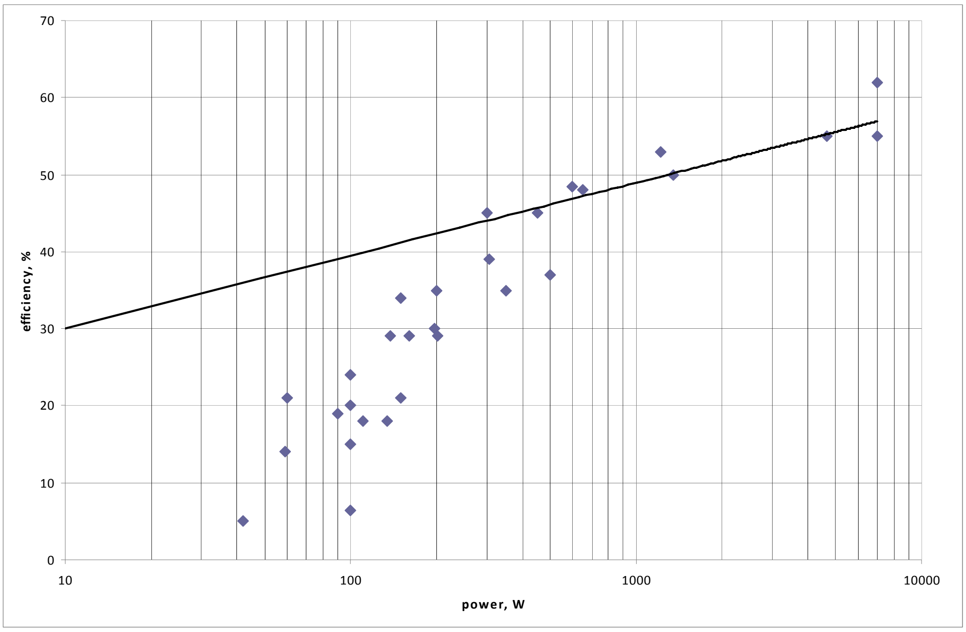

Figure 1. Dependence of HET efficiency vs. consumption power.

Thus the problem of optimisation of low power HET (LPHET) for today facing especially sharply. Carrying out of full-scale experiments for research of influence of modification of parametres on thruster performance data is connected with essential material and time expenses. The capability of an estimation of planned changes before full-scale experiments by means of simulation model essentially reduces cost of workings out and time of issue of new modification. The model for simulation of flow of plasma in LPHET channel is offered in article.

The purpose of activity is to calculate distribution of concentration of neutral gas and ions in LPHET channel. It is considered that gas steady input with constant mass flow rate. The gas outflow implements in vacuum. Consider for calculations that temperature of walls of the thruster is a constant and consider that for reflection of gas from walls of working area.

II. Simulation model of plasma flow

Channel of the thruster is divided by a rectangular grid into cells according to a method of calculation of gas flow in HET [2]. Calculation of gas flow implements with use of a method of “hard” spheres. There are following basic ideas of application of this method:

1. Particles are blown into working area with random directed thermal speed through special areas of injection. These areas represent the thin tubes divided by reflecting planes. Each plane reflects in one direction and passes particles in other. Planes are intended for creation of the directed motion and acceleration of calculation process.

2. On an exit from injection area the modelling particle falls in working area of calculations – HET channel.

3. HET channel represents triangulated three-dimensional model. Particles are reflected from a surface by two ways: mirror and diffuse as it is described in [3].

4. For acceleration of calculations the working area is divided into cells by a rectangular grid. The rectangular grid is chosen taking into account that use of borders of the grid parallel to co-ordinate planes reduces quantity of the operations connected with calculation of key parametres of flow simulation (the moment of time of border crossing, change of speed of a particle under the influence of an electrical field) in three times. Grid parametres are calculated, as is described in [2].

It is necessary to consider not only motion neutral, but also the charged particles during calculation of plasma flow. Gas in the thruster channel inlet neutrally and further is ionised. For modelling of process of ionisation it is offered to enter parameter of probability of ionisation of a particle at an entry into a cell - $P_{i,j,k}$. Considering necessity of calculation of this parameter, modelling process is offered to be divided into two stages:

1. Flow of neutral gas only.

2. Flow of neutral and ionised gas.

At calculation of flow of neutral gas it is possible to achieve distribution of neutrals concentration of plasma [3]. Further the probability of ionisation of a particle is calculated by equation:

$$P_{i,j,k} = \frac{I_{i,j,k}}{N_{i,j,k}} \qquad (1)$$

$I_{i,j,k}$ - Xe^{+} ions concentration which was experimentally measured along channel centerline;

$N_{i,j,k}$ - calculated concentration of neutrals.

It is necessary to define criterion of transition between stages for division of calculations into stages. In the offered method of calculation transition from the first stage to the second implements when steady-state at calculation of neutral gas flow is achieved. Steady-state is considered a condition for which the following condition is satisfied:

$$\frac{M_{in}}{M_{out}} \cdot 100\% > 95\% \qquad (2)$$

M_{in} - weight of the gas which has inlet in calculation area;

M_{out} - weight of the gas which has outlet from calculation area.

The condition (2) is checked up on each step of the collecting and processing of the statistical information on a flow [4].

At the second stage of activity of algorithm when particle entry in a cell the random number from 0 to 1 undertakes. If the received number is less than probability of ionisation the particle becomes an ion; if it is more - calculation of its motion implements according to algorithm activity at the first stage.

Calculation of ions motion implements separately from neutral particles considering high speeds of its motion in HET channel. It is considered only a capability of ion collision with walls of working area. Collision of an ion with other particles of working area is not considered. Change of trajectory leaded by electrical field implements with use of distribution of electrical potential in the channel.

At collision with a wall the ion becomes a neutral particle and is diffuse released with such speed:

$$\vec{V} = \frac{\left(\vec{N} + \overrightarrow{(R - C)}\right)}{\left|\left(\vec{N} + \overrightarrow{(R - C)}\right)\right|} V_T \qquad (3)$$

$\vec{N}$ - a normal to the border element directed into the computational area;

R - the casual point belonging to an element of border;

C - the central point of an element of border;

V_T - thermal speed of gas with temperature of an element of border.

Ions speed varies at each crossing wall of a computational grid during motion in the channel [4]. Considering rectangular grid and parallelism of walls to coordinate planes, will change only one component of speed: V_x - at crossing of a vertical wall, V_y - horizontal and V_z - walls in a screen plane. New speed is calculated by equation:

$$V' = V + \frac{\Delta\varphi q}{m} \qquad (4)$$

V' - new speed;

V - speed at inlet to cell;

$\Delta\varphi$ - potential between cells;

m - particle mass.

Distribution of electrical potential was built using calculated distribution of an electrical field and experimental data of potential in various points of the channel are used. Electrical field calculations are proceeded with use of final element analysis (fig. 2).

For building of electrical potential distribution the following algorithm is used:

1. Determination of colour value of the distribution diagramme in points of potential measurements;

2. Interpolation of the received values;

3. Building of three-dimensional distribution of potential in the channel. Determination of potential value in points is fulfilled by received interpolation functions. Linear interpolation was used for check of an offered method in view of a considerable quantity of experimental points.

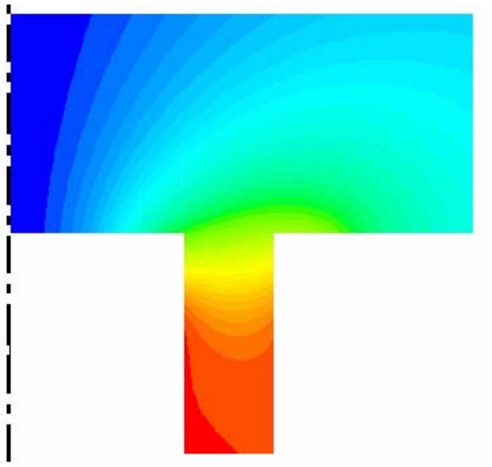

Figure 2. Electrical potential distribution in HET channel.

III. Simulation results

The program complex of simulation of ionised gas flow in HET channel is developed on the basis of the offered model. The software allows varying of discharge chamber dimensions, corners of gas injection and configuration of magnetic elements of system and its thermal condition.

There are main results of simulations:

1. The basic integral thruster characteristics - thrust, efficiency, specific impulse and angle of divergence of ion beam.

2. Distribution of heat flows on discharge chamber walls.

3. Function of distribution of ions.

4. Estimated lifetime of the thruster.

5. Comparison of simulation and experimental data.

Results of simulation do not contradict to experimentally received data.

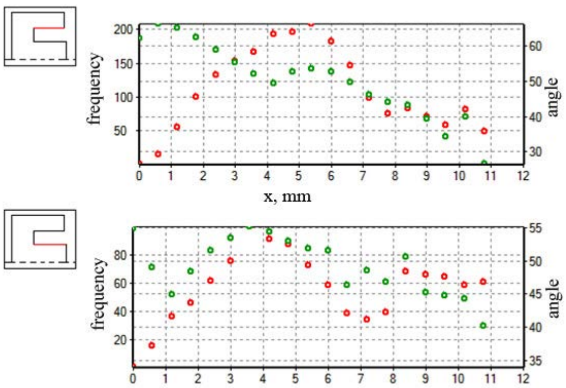

Figure 3. Frequency of neutrals interactions with walls of discharge chamber.

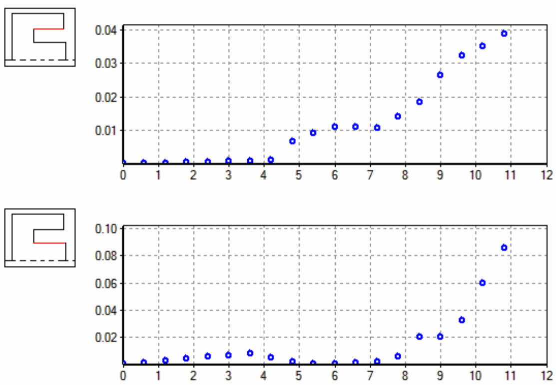

Figure 4. Distribution of thermal flow on walls of discharge chamber for inner and outer surfaces correspondingly.

IV. Perspectives

Further it is planned to take in account not only electrical but a magnetic component of field for electrons motion modelling considering practical utility of the received results of simulation.

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