The gear of a working gas flow in the SPT discharge chamber

Sergey A.Oghienko, Anatoliy I. Oranskiy

Scientific and Technological Center of Space Power and Engines at Kharkov Aviation Institute

Address: 17, Chkalova St. Kharkov, 61070, Ukraine.

E-mail: s_oghienko@hotbox.ru, Oranskiy@yahoo.com, thrust@d4.khai.edu

Introduction

SPT is used for a space vehicle orbit keeping, and also can be used as the main engine for inter-orbital overflies of space vehicle. Reliability of SPT activity in a structure of a space vehicle power plant confirms by exploitation of this engine during the term more than 30 years.

Due to affirmed reliability SPT prolongs to be perfected by efforts of scientific different countries. One of directions of researches - analysis of ionization processes of plasma-making gas (PG) in the SPT discharge chamber (DC) with the purpose of thrust and thrust efficiency increasing. More full knowledge of these processes can be obtained on the basis of researches of PG atom motion in DC, when the discharge does not burn.

The role is of interest, which one is played by different types of atom collision during motion in DC. The findings of investigation can be utilized for mining the practical guidelines at designing of the anode-gasdistributor unit.

Abstract

The experimentally-analytical investigation are conducted to define the way of PG flow formation in the SPT DC in conditions, when the discharge does not burn.

The contribution of different collision components to process of PG motion in the DC is determined. The researches are carried out at different PG mass flows through an anode-gasdistributor and at different DC surface temperatures. Are determined: a mean general collision number of atom during his motion in the DC before departure from a channel, number of interatomic collisions, number of collisions with walls of a DC channel, number of collisions with an anode surface, axial velocity of PG in the DC. The problem is decided by a method of probabilistic simulation (Monte-Carlo method), which one allows to realize actual probabilistic process of interatomic interferences and probabilistic process of atom dissipation on a DC canal surface.

1. The experimental research of plasma-making gas distribution in DC, when discharge does not burn.

In an experimental part of activity the distribution of PG atom concentration in DC is studied when the discharge does not burn. Gas pressure in a volume DC was determined with usage the ionization sensator as the pressure transducer, and then the concentration was calculated.

The experimental activities are conducted on a vacuum bench with a volume of 2.5 m^3. The value of dynamic pressure did not surpass $2*10^{-4}$ bars. The measurement accuracy of PG mass flow was provided not worse than 5 %.

The scheme of the experimental equipment is shown in fig. 1. The measurements were conducted with usage of SPT model M-70 established on a flange near to a wall of an evacuated chamber - 6. SPT had standard DC - 1 with the anode-gasdistributor - 2. Tonometries is conducted with usage of the longitudinal-directional probe 3 (on a median canal surface) and radially - directional probes 4 (on a DC wall).

All probes incorporated with one ionization sensator - 8 through gas pipelines - 5 identical lengths, which one could be overlapped by valves - 7. Accuracy of the longitudinal-directional probe positioning is of ±0.5 mm. With the purpose to lower influencing of probes on PG flow in DC, the probe with a minor diameter of 3 mm is selected. At tonometry the effect of measuring probes on PG motion was unsignificant (in detection limits of the device). The settling time of pressure ≈1 minute, that is reasonable to experiment. The measurements are conducted for xenon mass flow 2.3 mg/s. The surface temperature at experiment corresponded to ambient temperature $T=18^0$ C.

Experimentally was established, that the values of pressure measured by longitudinally-oriented probe twice are exceeded with pressure, measured by radially-oriented probe. This difference - development of

idiosyncrasy of PG motion (close to a molecular mode) in a SPT channel, where a part of PG atoms takes off from a channel without interferences with walls.

The calculation of PG atom concentration $n_à$ on value of pressure (obtained at experimental measurements) is executed under the formula $n_à=P/k*T_a$, where P - measured pressure in Pa, k - Boltzmann constant, T_a - temperature of gas in absolute degrees. Values thus are counted: concentrations n_{axial} (the conforming pressure P is gauged by longitudinally-oriented probe, see fig. 1); reduced pressures $p_{rad}=P/k*T_a$ (the conforming pressure P is gauged by radially-oriented probe on a DC wall, see fig. 1). From them only n_{axial} can be interpreted as PG concentration.

Using the obtained data about the PG concentration n_{axial} on the DC cut, it is possible to calculate mean axial velocity of the PG efflux for the DC cut – V_{cut} on a ratio $m_a=S*M*n_{axis}*V_{cut}$, where S - sectional area of a channel, M - weight of Xe atom. It is necessary to mark, that the calculation of concentration n_{axial} is qualitative. The outcomes of experimental definition of concentration are adduced in a fig. 3 and 4, where the range of value of PG concentration absolute error is retained also.

2. Numerical modeling of PG atom motion in a DC accelerating channel.

In conditions, when the idealized methods come across on difficulties in connection with transient nature of a gas flow regime in DC, and the natural experiments are labor-consuming or are in essence impossible (it is impossible to determine quantity of particle collisions with DC walls or among themselves), numerical methods - alone analyses method of considered process. For the solution of a problem it is represented optimum to use a “method of particles”, as he allows to trace the contribution of a coupling effect of particles among themselves in a general picture of the PG atom motion process in DC.

It is necessary also to compare outcomes of mathematical modeling of PG atom concentration in DC to experimental outcomes.

2.1 Mathematical modeling of PG atom motion in DC.

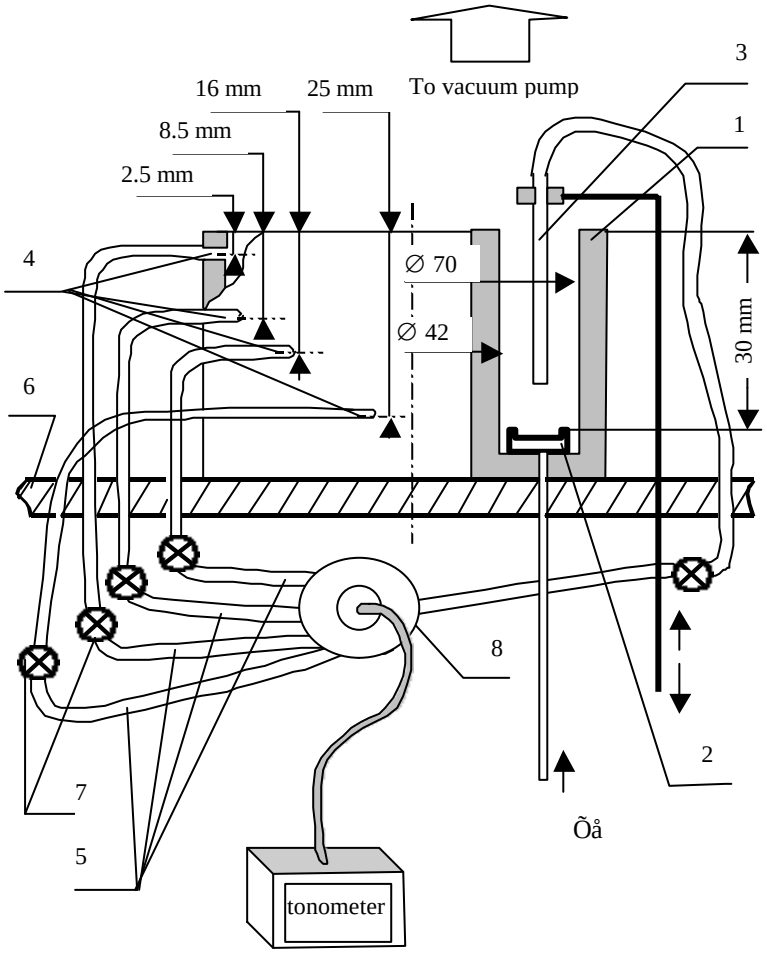

Fig. 1 The scheme of the experimental equipment for tonometry (along the DC channel) in axial and radial directions.

The two-dimensional model is esteemed. For the description of atom interplay the model of firm spheres will be used. The gradient of concentrations (along a channel) atoms is allowed.

The interplay with a surface is described by a diffuse law of reflection - law “cos”; the full energy accommodation of dropping atom is necessary; to atom the speed equal V_{int} (interquartile) is assigned, which one is determined by a surface temperature, on which one the atoms are dispersed.

At computation on mathematical model the motion of PG with mass flow $m_à$ is modeled by series passing 1000 particles through DC during time t=1 second. The pathway of PG atom motion in a DC volume is watched. The initial velocities of atom are determined at: interplay of particles with a DC surface; interference of atoms; input of PG in DC through foramens in the anode-gasdistributor.

For implementation of the gear of interatomic collisions at computation, on the basis of a Monte-Carlo method, the probability of free roll by atom of spacing interval λ under the formula $P\left(\frac{l}{l_s}\right)=\exp\left(-\frac{l}{l_s}\right)$ was determined. Thus, the mean free length λ_S is

determined under the formula $l_s = \frac{l_a}{1 + \frac{T}{l / T_a}}$, where: $l_a = \frac{1}{\sqrt{2} * \pi * n_a * d_0^2}$, T_λ=252 - Sazerland constant for Xe, d_0- gas-kinetic diameter of atom Xe, n_a - concentration of atoms.

The probabilistic selection of a atom traffic current after collision is determined with the count of distinction of PG concentration lengthwise axis DC apart λ_S from a place of collision. The normalization conditions were set by the formula $P_2 = 1 - P_1 = \frac{n_2}{n_1 + n_2}$, where $P_1 = n_1 / (n_1 + n_2)$ - probability of impact on a considered atom on the part of an anode, P_2 - probability of impact on the part of DC cut, n_1 and n_2 - to concentration on the part of an anode and on the part of DC cut apart λ_S from a place of atom collision.

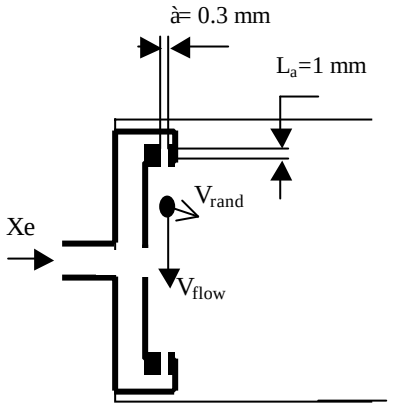

Fig. 2 Input plasmamaking gas (Xe) in DC through the anode-gasdistributor

It is necessary, that the flow of PG through a foramen in the anode-gasdistributor goes in DC in a radial direction with speed V_{flow} determined under the formula $V_{flow} \sim \frac{m_a * T_a}{S_{for} * N_{for} * M * P_2}$, where S_{for}- the area of a foramen in the anode-gasdistributor, N_{for} - number of foramens in a membrane of the anode-gasdistributor, M - weight of Xe atom, T_a and P_2 - temperature and gas pressure in a cavity of an anode, m_a - PG mass flow. The ratio $(m_a * T_a) / P_2$ sets under the experimental data and it is considered as a constant.

The dilating of a PG spray at input in DC through the anode-gasdistributor descends as a result of interatomic collisions (see fig. 2). We suppose, that the atoms which are taking off from a foramen, have isotropic distribution of random component of speed vector - V_{rand} and PG flow velocity vector from a foramen - V_{flow} (in a radial direction), as shown in a fig. 2. Thus the random component of scattering atom speed is determined as $V_{rand} \sim V_{int}$, where V_{int} - most interquartile particles speed at Maxwell distribution with temperature of the anode-gasdistributor - T_a.

We suppose, that the atoms, which have departed from DC, do not return back.

Concentrations n_{axis} PG in DC was calculated with usage of a ratio $n_{axis} = m_a / (S * M * V_{cut})$. The value V_{cut} of axial flow velocity component for the given DC cross-section was determined at computation on mathematical model by average of speeds of all atoms passing through considered cross-section.

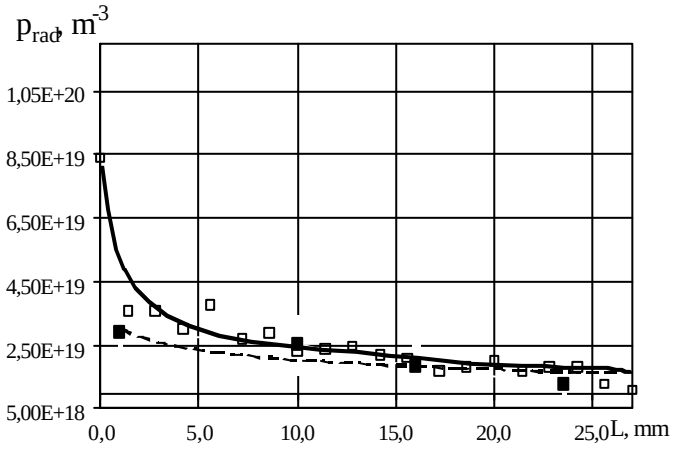

Fig. 3 Experimental and computational distribution curves of value p_{rad} in DC.

calculated curve, experimental curve.

The computation on mathematical model of value p_{rad}, as well as at experimentally-analytical definition p_{rad}, was conducted with usage of the formula $p_{rad} = P / k * T_a$. The value P was calculated on change of normal component of an atom impulse at dispersion for a DC surface.

2.2 Outcomes of numerical calculation on mathematical model and matching them with experimental data.

To evaluate value of a fixed error of computation of PG flow parameters, it is necessary to compare outcomes of computation on mathematical model and outcomes of experimental definition of PG flow parameters, which one are shown in a fig. 3 and fig. 4. In these figures the absolute error value of PG concentration definition (by results of experimental researches) is rotined also.

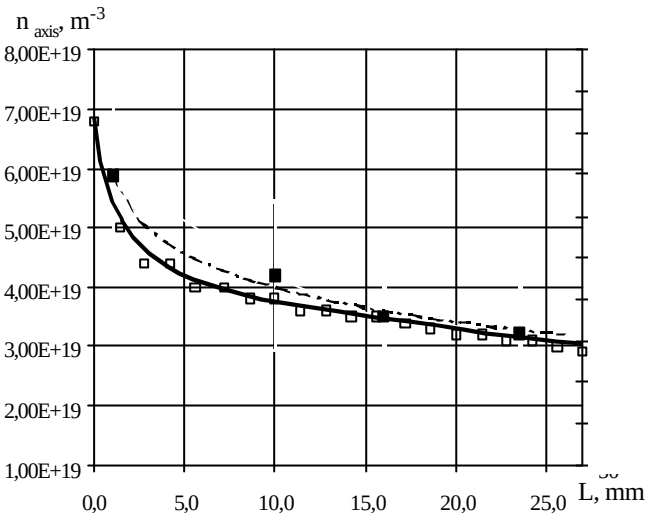

Fig. 4. Experimental and computational distribution curves of PG concentration n_{axis}.

calculated curve, experimental curve.

The values of PG atoms concentration obtained as a result of computation on mathematical model lie within the limits of an error band of experimental outcomes. Exception - area near to an anode, where by probe measurements it was impossible to investigate space with heightened PG concentration near to foramens in the anode-gasdistributor, since the sizes of the probe are commensurable with length of investigated area.

Difference of values p_{rad} and n_{axis} (see fig. 3. and 4.), counted with the help of mathematical model, mirrors that fact, that the considerable number of PG atoms, not having experienced interference with a DC walls, leaves area of a DC channel. Observed sharp horse racings of concentration in area near to an anode (on a stretch ≈4…5 mm) - development by reference for the given design of the anode-gasdistributor (see fig. 2) feature of input of PG in DC (through foramens of small diameter). It creates local areas near to foramens, with heightened concentration of PG atoms.

Besides at a mathematical modeling of PG motion the following flow parameters of PG (were counted at miscellaneous surface temperatures and miscellaneous mass flows of PG) was calculated: distribution of an axial speed of PG flow; a general collision number of atom during his motion in DC - $N_{general}$, collision number of atom with a surface of the anode-gasdistributor, collision number of atom with a DC canal surface - N_{wall}, collision number of atoms among themselves – $N_{atom\text{-}atom}$.

Directly to evaluate influencing of an interatomic collision on PG atom motion in DC the computation with the help of mathematical model was executed, at which one the interatomic collisions were leave outed. The outcomes of this calculation for temperatures $T_a=T_{serf}=290$ K and for xenon mass flow $m_a=2.3$ mg/s, introduced in a fig. 5, are compared to outcomes of calculation for same temperature and value m_a with the count of interatomic collisions.

The comparative analysis (see fig. 5) distribution of concentration and speed demonstrates, that during 2/3 lengths of a channel (from an anode) the values V_{axis}, counted with the count of interatomic collisions and without this count, essentially differ. Therefore, the motion of PG atoms on this segment of a channel is largely determined by interatomic collisions. On an output segment of a channel, ≈1/3 lengths of a channel, prevail influencing collisions with a DC walls.

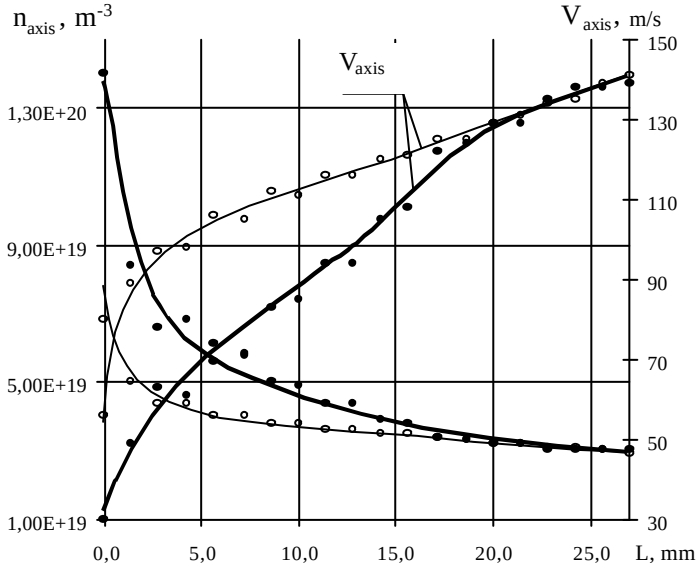

Fig.5 Distribution of concentration and flow velocity of PG:
○ - at the count of interatomic collisions,
● - without the count of interatomic collisions.
$T_a=T_{wall}=290$ K, $m_a=2.3$ mg/s.

The outcomes of computation, introduced in a fig. 6, allow to evaluate the contribution to PG flow formation of a different gears of atom collisions at their motion in DC. The data analysis, introduced in a fig.6, indicates that the collisions with a DC surface prevail among all type of collisions in DC. Collision with DC walls N_{wall}, which one surpasses a collision number with an anode twice and more is determined as $N_{general}$ -$N_{atom\text{-}atom}$- N_{wall}. The observed decrease of value $N_{general}$, in process of growth of value m_a, can be explained following: in process of growth of mass

flow the concentration gradient grows in a direction from an anode to DC cut, that sets (already near to an anode) flow of atoms, which one move to DC cut and to take off from DC without collision. When the PG mass flow corresponds to nominal for SPT such as M-70 (2.3 mg/s), the contribution of a collision number with an anode makes ≈1/3 from $N_{general}$.

Conclusions.

1. As a result of an experimental research of PG flow parameters distribution is established following. Pressure of PG in axial and radial directions essentially differ (twice for DC cut). It testifies to the conforming excess of a flow lengthwise axis DC above a radial flow of PG on DC walls. Thus, the feature of PG atom motion in DC - considerable number of atoms shows escapes a DC channel without collision with a walls.

2. As a result of computation on the probabilistic model of PG atom motion in DC is established following. During motion in DC, the atom, on the average, tests 4-5 collisions. From these collisions a number of collisions with DC walls take ≈2/3, number of collisions with an anode take ≈1/3, and interatomic collisions take only ≈1/40 from a total number of collisions. However, the gear of interatomic collisions, owing to a gradient of concentration, largely determines motion of PG on a segment (on the part of an anode) lengthy ≈2/3 lengths of a channel. Near to DC escaping PG flow parameters are determined by atom collision with DC walls.

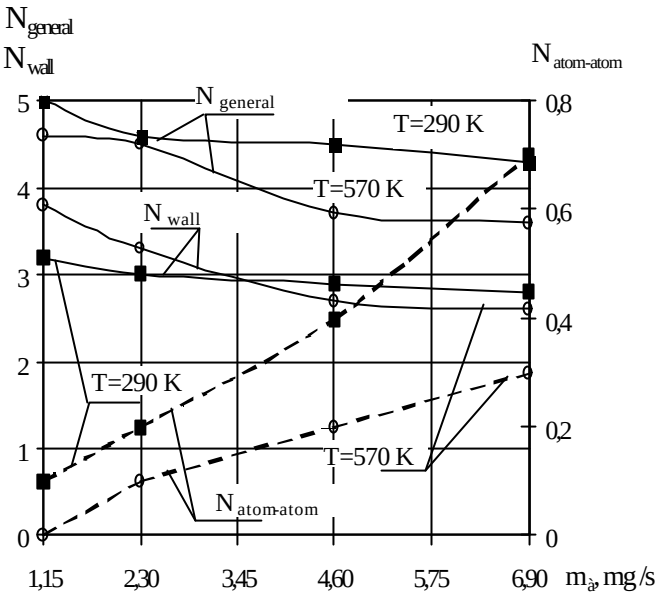

Fig. 6 Calculations of a atom collision number at motion in DC. $N_{general}$ – general number of collisions, N_{wall} – number of collisions with the DC wall, $N_{atom-atom}$ – number of interatomic collisions.

3. Matching outcomes of an experimental research of outcomes of computation on mathematical model demonstrates, that the built mathematical model of PG atom motion adequately mirrors features of PG motion in DC.