Experimental study of heterogeneity in an azimuthal direction of Hall Thruster plasma flow

IEPC-2007-045

Presented at the 30th International Electric Propulsion Conference, Florence, Italy
September 17-20, 2007

Oghienko (Ogiienko) Sergii [*] , Bilokon Volodymyr[†] , Setrakova Yana[‡]
Zhukovsky National Aerospace University "Kharkov Aviation Iinstitute", Ukraine

Abstract: It is possible existence of quasi-stationary spatial heterogeneity of plasma potential, caused by features of Hall thruster (HT) design. Research of such heterogeneity in an azimuthal direction has been carried out using SPT models of M-70 and M-40 type in various modes of discharge voltage, values of a magnetic field and various designs of the anode - gas distributor. It was registered heterogeneities of plasma luminescence in azimuthal direction of ion flow of HT, operated in mode, close to the nominal. Registered plasma heterogeneities can be explained as consequence of gas ionization in the field nearby separate apertures in the anode –gas distributor.

I. Introduction

The mechanism of electron transport in the discharge interval of Hall thruster (HT) or stationary plasma thruster (SPT) is investigated for many years by various researchers[1, 2, 3], but full understanding of physical bases of transport process is not achieved. In particular, large attention is paid to studying of plasma fluctuations, which can play a significant role in transport of electrons through a discharge interval.

II. Experimental technique

It is well known that fluctuations in HT plasma flow can play a significant role in transport of electrons through a discharge interval and have been studied by many researches[4, 5]. Plasma fluctuations are spatial plasma heterogeneity, variables in time in each point. Besides, the existence of quasi-stationary spatial plasma heterogeneity caused by features of HT design is possible. Research of such quasi-stationary spatial plasma heterogeneity potential in an azimuthal direction has been carried out using SPT models of M-70 and M-40 type (where 70 and 40 are the values (mm) of outer diameters of discharge chamber) in various modes of discharge voltage, values of a magnetic field and using various designs of the anode – gas distributor.

For carrying out researches the installation (Fig. 1) has been created including: the device (1) for video-recording through a window (2) in the vacuum chamber (3) plasma luminescence of SPT (4) in a seen range during sufficiently short time of an exposition, a mirror (5) for simultaneous recording of a luminescence of SPT plasma from two positions and transparent glass (6) to protect a mirror against influence of the directed flow of accelerated plasma. While video-recoding, plasma luminescence brightness was suppresed by service program. Adequacy of fixation and display of the visual information was checked up by means of a gas-discharge lamp in 15 W of power (Fig. 2). While SPT operated in a nominal mode in the vacuum chamber, evacuated by the oil diffusion pump, pressure do not exceed $1.5 \cdot 10^{-4}$ torr.

---

* Senior Researcher, Department of thrusters and power plant of spacecraft, thrust@d4.khai.edu
† Senior Researcher, Department of thrusters and power plant of spacecraft, thrust@d4.khai.edu
‡ Master, Department of thrusters and power plant of spacecraft, yanaxai@mail.ru

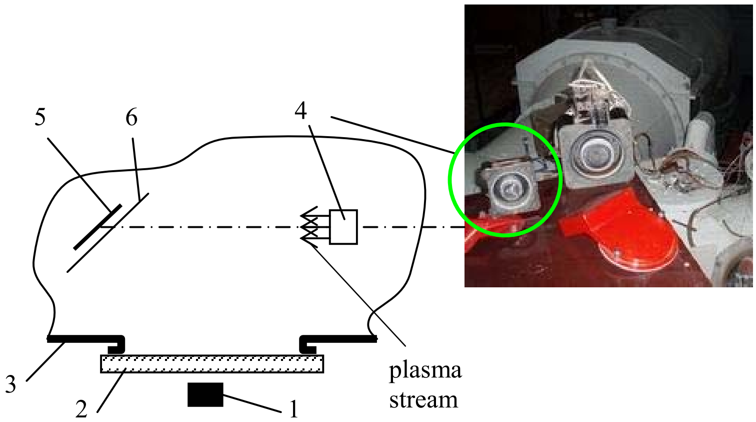

Figure 1. The scheme of installation for researches.

1 - device for video-recording,
2 – window,
3 - vacuum chamber,
4 – SPT,
5 – mirror,
6 – protect transparent glass.

Figure 2. Test photo of gas-discharge lamp, made by recording device.

III. Research equipment, results and hypothesis

The first series of experiments has been carried out using HT like SPT M-70 type while the anode mass flow rate 2.2 mg/s and cathode - 0.3 mg/s in a range of a discharge voltage from 70 V up to 250 V and at various values of a magnetic field (7 mTl, 15 mTl and 20 mTl) which were created by the separate power supply source. Design features of the anode – gas distributor, shown in Fig. 3, are the radial-directed apertures (with step of 10 mm) in the anode – gas distributor. Using such type of anode in SPT M-70 construction, pictures shown in Fig. 4 – 6, in which plasma luminescence heterogeneities are visible, were taken.

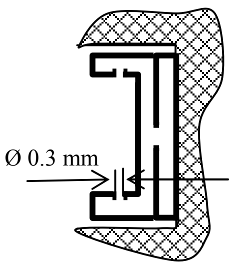

Figure 3. The scheme of the SPT anode – gas distributor with separate radial apertures.

Figure 4. Luminescence (suppresed) of plasma while SPT M-70 operated in mode: discharge voltage U_d=250 V, magnetic induction on discharge chamber edge B=16 mTl.

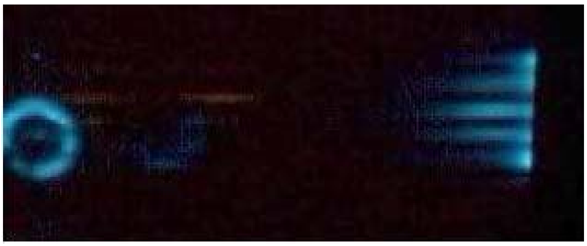

Figure 5. Luminescence (suppresed) of plasma while SPT M-70 operated in mode: discharge voltage U_d=200 V, magnetic induction on discharge chamber edge B=15 mTl.

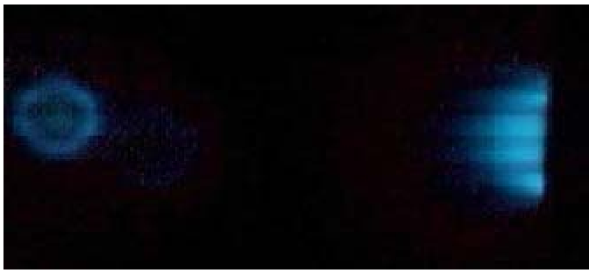

Figure 6. Luminescence (suppresed) of plasma while SPT M-70 operated in mode: discharge voltage U_d=70 V, magnetic induction on discharge chamber edge B=16 mTl.

Registered plasma luminescence heterogeneities can be explained in the following way. In the discharge chamber during all its extent a longitudinal electric field E_x of a constant sign, directed to the DC output exists. Electrons drift in azimuthal direction in crossed electric E_X and magnetic B fields with velocity $V_{drY}=E_X/B$. Nearby apertures in the anode – gas distributor there is an intensive ionization of the gas (Fig. 7) by electron impact. The ions given birth near to apertures flow out of the discharge chamber and form flows with increased charge concentration. Due to the existence of areas of charges heterogeneities in an azimuthal direction occurrence of opposite azimuthal components of an electric field E_y is possible.

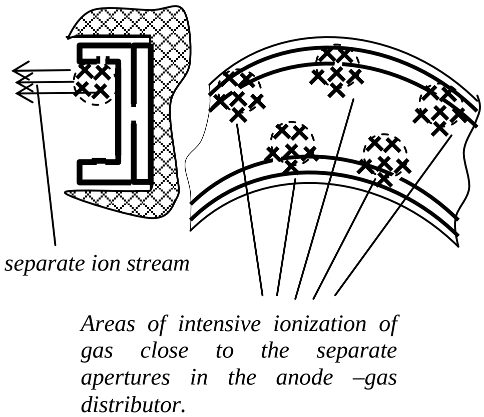

Figure 7. The way of the separate ion flows formation.

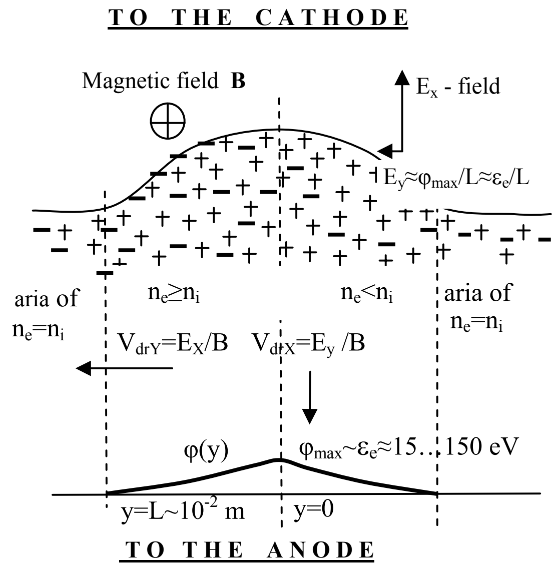

Figure 8. Possible polarization of plasma charges in the area of non-uniform concentration – seen as area of the increased intensity of plasma luminescence.

The extent of areas, in which charges concentration (n_e – of electrons, n_i – of ions) is increased, is estimated as visual distance of $L\sim10^{-2}$ m, amplitude of potential drop $\varphi_{max}\sim\varepsilon_e$ – electron energy, the intensity of the induced electric field in an azimuthal direction is $E_y\approx\varphi_{max}/L$. The picture of charges distribution, as well as the scheme of prospective process, is shown in Fig. 8, where there is a field $E_Y\sim10^3$ V/m in an azimuthal direction, that can cause electron drift along E_X field in discharge chamber. Analyzing of possible mechanism of electrons conductivity, these fluctuations should be taken into account as the additional factor, which increase electron conductivity longwise discharge interval due to drift V_{drX}.

Besides things spoken above, it is necessary to analyze next feature of experimental result (Fig. 4, 5, 6). As was shown in Fig. 4, 5, 6 - as the discharge voltage increase as separate ion flows became narrow. It is probable to formulate a hypothesis that in the low discharge voltage mode of SPT, electrons cannot bring high enough energy in the area nearby separate apertures in the anode – gas distributor. Therefore, there is not intensive ionization of gas nearby apertures and narrow ion flows are not formed (Fig. 6). Nevertheless, intensive ionization of gas occurs close to the anode (on the distance about 5-10 mm, where there are separate fields with increased atom concentration) and, as the consequence, we can see separate plasma flows from DC. During SPT operation in the high discharge voltage mode (more than 200 V), electrons bring high energy in the area nearby separate apertures in the anode – gas distributor, ionize gas and form narrow ion flows (Fig. 4, 5).

Similar researches were carried out using SPT M-40 type, in which the anode had another structure (Fig. 9), in which separate apertures were blocked. Pictures of plasma flown out of SPT with such anode are shown in Fig. 10, 11. There are not sharp-edged separated plasma flows (like in previous pictures). There are hardly visible heterogeneities of plasma luminescence in an azimuthal direction because of existence of the fields before deflector (nearby the orifices), where atom concentration and ionization little increased. It is possible to assume that the suggested hypothesis is confirmed by results (Fig. 10, 11).

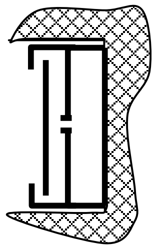

Figure 9. The scheme of the anode-gasdistributor with the separate apertures (10 mm distance) closed by deflector.

Figure 10. Luminescence (suppresed) of plasma while SPT M-40 operated in mode: discharge voltage U_d=190 V, magnetic induction on discharge chamber edge B=20 mTl.
Anode – gas distributor with the deflector (like Fig. 9).

Figure 11. Luminescence (suppresed) of plasma while SPT M-40 operated in mode: discharge voltage U_d=120 V, magnetic induction on discharge chamber edge B=18 mTl.
Anode – gas distributor with the deflector (like Fig. 9)..

IV. Conclusion

Results analysis allows formulating a next hypothesis. During experiment in HT operation mode close to nominal, using HT like SPT M-70 and M-40 (in which the major design features - magnetic screens and the anode – gas distributor with separate apertures are used), gas ionization and formation of ion flows (directed to the discharge chamber output) occurs in all volume of the discharge chamber (from the anode up to discharge chamber output). I.e., the operation mode when the ion stream is formed only in narrow area nearby the DC output is not realized. The area with negative potential drop near to the anode is not formed. It specifies separate jets of the ions given birth nearby apertures in the anode – gas distributor and accelerated in a longitudinal electric field in all an extent of the discharge chamber.

References

[1]Janes, G., and Lowder, R., "Anomalous electron diffusion and ion acceleration in a low-density plasma" Physics of Fluids, Vol. 9, No. 6, 1966, pp. 1115-1123.

[2]Fossum, E.C., King, L.B., Makela, J. "Mobility studies a pure electron plasma in Hall thruster fields" / 42nd AIAA Joint Propulsion Conf. and Exhibition, California, 2006.

[3]Meezan, N.B., William, A.Jr., Cappelli, M.A. Anomalous electron mobility in a coaxial Hall discharge plasma / Physical Review E, Volume 63, 026410 (2001).

[4]Lazurenko, A., Vial, V., Bouchoule, A., Prioul, M. and other. Characterization of microinstabilities in Hall thruster plasma: experimental and PIC code simulation results, physical interpretation and impact on transverse electron transport / Proc. of the 28th Int. Electric Propulsion Conf., France, IEPC-2003-0218.

[5]Baranov, V., Nazarenko, Yu., Petrosov, V., Vasin, A., Yashnov, Yu. New conception of oscillation mechanisms in the accelerators with closed drift of electrons / Proc. 24th Int. Electric Propulsion Conf., IEPC-1995-044.