A STUDY OF SOME KEY PROBLEMS OF HALL ACCELERATOR OPERATION OVER THE EXPENDED RANGE OF DISCHARGE VOLTAGE

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Hall accelerators (HA) (thruster) are effectively applied in space propulsion and as a source of ions for controlled fusion and another programs. For HA modernization (by expansion of a discharge voltage range) some key problems have been studied: the determination of potential drop in various zones of discharge interval; the calculation of HA integrated characteristics; the determination of influence of low-frequency azimuthally plasma heterogeneity on electron movement.

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1. THE RESEARCH AREA OF THE DISCHARGE INTERVAL INVESTIGATIONS

The following research area of HA physical processes are determined: 1) an experimental researching of azimuthal plasma heterogeneity in zone the cathode - edge of discharge chamber (DC) (DC entrance); 2) studying of electron movement regularity in the cathode - edge of DC zone in view of an electric field azimuthal component; 3) the calculation of potential drop in various zones of the discharge interval between anode and cathode.

1.1 RESEARCH OF PROCESSES IN ZONE I BY MATHEMATICAL MODELING METHOD

The features of an electron movement in zone I (Fig. 1) was studied by the Monte-Carlo method modelling.

The following boundary conditions were taken: potential drop in modeled area - 120 V, mass flow rate of Xe through the cathode 0.3 mg/s, temperature of electrons emitted by the cathode - T_e=1…2 eV. Performance distribution of magnetic and electric fields was taken by relative expressions obtained as a result of the data known from experimental researches.

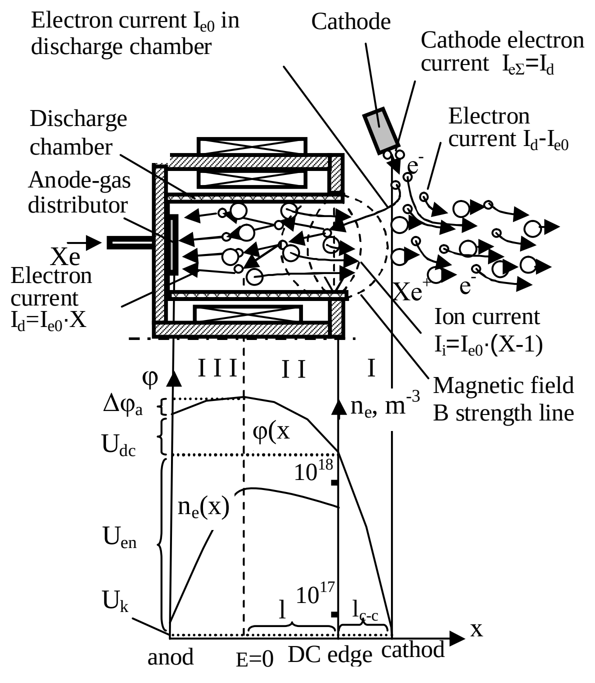

Fig. 1. HA scheme. Electron streams distribution. Distribution of potential drop in zone (I, II, III) of the discharge interval

The analysis of calculated results specifies the following: 1) distributions of electron concentration and energy at the DC entrance it is non-uniform with increase (more than twice) to the DC centerline. Such heterogeneity of electron concentration determines localization of ionization processes in DC near the median surface. 2) The mechanism of electron conductivity, caused by their dispersion in "magnetic mirror" and "transition" to the force line - closer to an DC entrance prevails outside of DC in the zone of a falling electric field (Fig. 2).

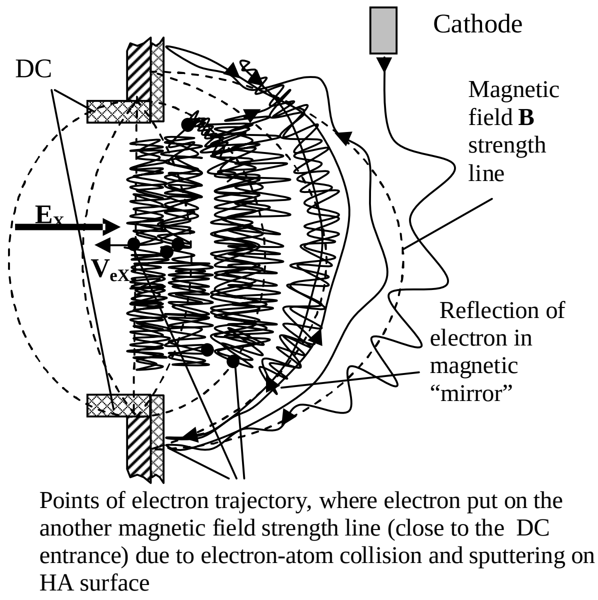

Fig. 2. Features of electron drift movement in the cathode – cut of discharge chamber (DC) area, was calculated by Monte-Carlo method

1.2. AN EXPERIMENTAL RESEARCH OF AZIMUTHAL PLASMA HETEROGENEITY IN ZONE I

Now existence of plasma potential azimuthal fluctuations with amplitude $\delta\varphi$ ~ T_e≈20 eV [1, 2] is established. The extent of these areas is estimated as $L\sim10^{-2}$ m, the intensity of the induced electric field $\delta E\approx\delta\varphi/L\approx2\cdot10^{3}$ V/m (Fig. 3). At the analysis of possible mechanisms of electrons conductivity these fluctuations should be taken into account as the additional factor which promotes increase of conductivity.

To determine possible mechanisms of electrons conductivity the plasma parameter fluctuations close to the DC edge are investigated on HA M-70 type operated in a nominal mode. The equipment allowing to fix a seen luminescence of plasma in expositions $\sim10^{-3}$ s was used. It is observed, that the plasma zone extends along DC with non-uniform brightness of a luminescence as is shown in Fig. 4.

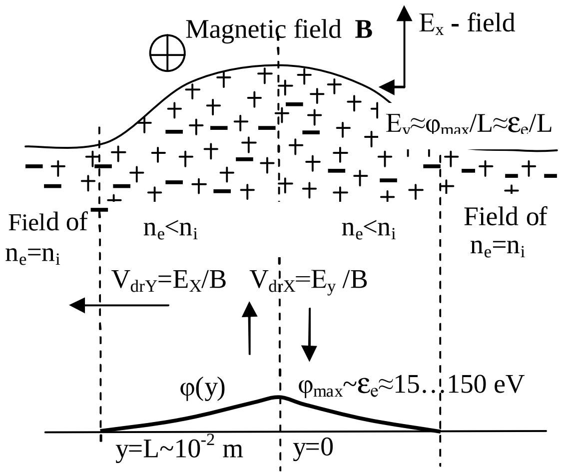

Fig.3. Possible polarization of plasma charges in the area of non-uniform atom concentration – seen as area of the increased intensity of plasma luminescence. There is a field $E_Y\sim10^3$ V/m in azimuthally direction, that can cause electron drift along E_X field in DC

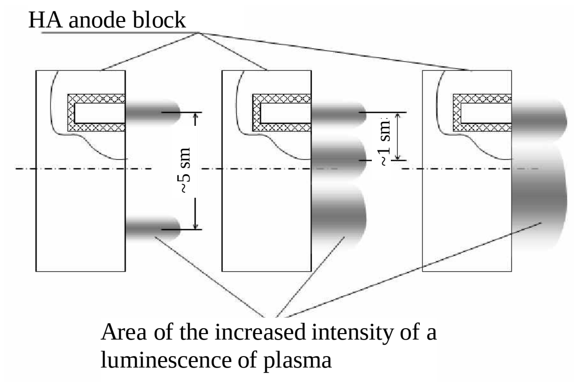

Fig. 4. Azimuthally heterogeneous luminescence of plasma

The picture of charges distribution, as well as the scheme of prospective process which results in occurrence of azimuthal electric field potential heterogeneity - process of polarization is resulted on Fig. 3. Results of the research of electron movement in view of azimuthal potential heterogeneity show, that electron conductivity changes insignificantly.

2. HYDRODYNAMIC MODEL FOR *HA* LOCAL AND INTEGRATED CHARACTERISTICS

2.1. FEATURES OF PROCESSES MODELING IN ZONE I

The probability P, that electron emitted by cathode have reached DC (mainly due to elastic collisions with atoms) $P=(P_c)^{N_{min}}$, where: $P_c=f(\varepsilon_e)$ – the probability of that electron with energy ε_e displaced on a height of a cycloid h_c will arrive to the DC entrance due to collision with atom; N_{min} - a minimum quantity of electron-atom collisions, necessary to reach DC at the $l_{c\text{-}c}$ distance from cathode $N_{min}=\int_0^{l_{c-c}}\frac{dx}{h_c}$. Allocating among all electron stream I_d/e (electrons emitted by cathode – total discharge current) stream I_{e0}/e (electrons reached DC), it was determined a ratio of these streams as

$$I_{e0}=I_d\cdot(P_c)^{N_{min}}. \quad (1)$$

2.2. FEATURES OF PROCESSES MODELING IN ZONE II

The coordinate system is located so, that at DC edge x=0, and strength E=0 at the x=l. The anode discharge current I_d represents avalanche-like increased in zone II electron current I_{e0} (at the DC entrance) so, that $I_d=I_{e0}\cdot X$,

$$X=\exp\left(\int_0^l \alpha(x)\cdot dx\right) \quad (2)$$

Where $\alpha(x)$ - number of ionization collisions per unit of length of electron run along an axis X. Voltage balance of the discharge interval (Fig. 1) $U_d=U_k+U_{en}+U_{dc}-\Delta\varphi_a$.

Cathode processes were not examined separately and cathode potential drop was determined as $U_k=20+(I_d-4)^2$. Thrust, specific impulse, thrust efficiency was determined at total cathode $\dot m_c$ and anode $\dot m_a$ mass flow rate as (M - mass of ion):

$$F_T=\int_0^l\left(\sqrt{\left(\int_0^x E_x(z)\cdot dz+U_{en}\right)\cdot\frac{2\cdot e}{M}}\right)\times \times\left\{\exp\left(\int_0^{x+dx}\alpha(z)\cdot dz\right)-\exp\left(\int_0^x\alpha(z)\cdot dy\right)\right\}\cdot\frac{I_{e0}}{e}\cdot dx/l \quad (3)$$

$$I_{sp}=\frac{F_T}{\dot m_c+\dot m_a},\quad \eta_T=\frac{F_T^{\,2}}{2\cdot U_d\cdot I_d\cdot(\dot m_c+\dot m_a)}. \quad (4)$$

2.3. FEATURES OF PROCESSES MODELING IN ZONE III

Diffusion movement of electrons to the anode in an electric field, which interferes with their moving, is determined by collisions with DC walls. Value $\Delta\varphi_a$, necessary for balance of discharge voltage, in view of $\Delta\varphi>>\varepsilon_{a.gener}$ – initial ion energy (equal to atom energy), is given by

$$\frac{V_{dra}^{3}}{V_{dr0}^{3}} = \frac{\left(V_{dr0}^{2} - \frac{\Delta\varphi_a \cdot 2 \cdot e}{m}\right)^{3/2}}{V_{dr0}^{3}} \cdot \left(\frac{B_0}{B_a}\right)^2 = \sqrt{\frac{\Delta\varphi_a}{\varepsilon_{a.gener}}}. \quad (5)$$

Where: $V_{dr0} \approx \sqrt{\frac{\varepsilon_{dr0}}{3} \cdot \frac{2 \cdot e}{m}}$, ε_{dr0} - electron drift velocity and total energy; B_a, B_0 – magnetic field at anode and in section where E=0.

Results of HA local and integrated characteristics calculation are show in Fig 5, 6, 7.

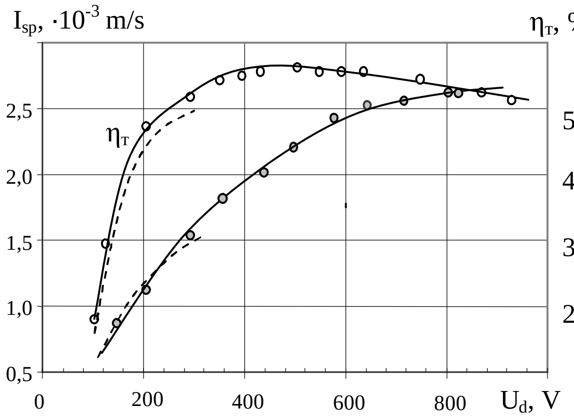

Fig. 5. Specific impulse I_{sp} and η_T:
— *Calculate data*
- - - *Experimental data*

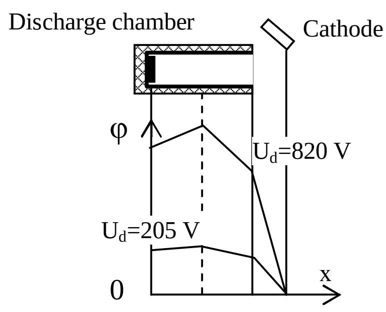

Fig. 6. Distribution of potential drop in discharge interval zone

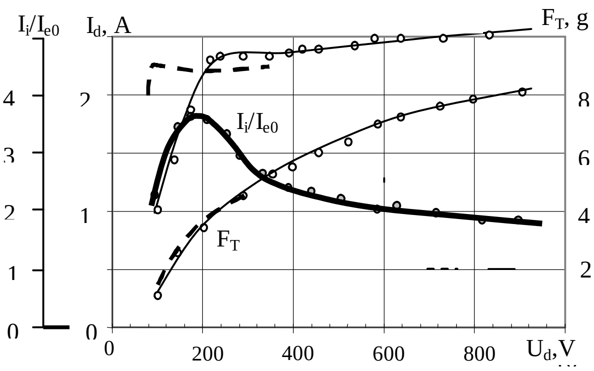

Fig. 7. V-A characteristic, thrust F_T, I_i/I_{e0} ratio of ion I_i and electron I_{e0} current dependences on discharge voltage U_d

CONCLUSIONS

For the first time the periodic azimuthally heterogeneous luminescence of plasma with duration of ~10^{-3} second it has been experimentally registered in area the cathode – the edge of DC, which demonstrates heterogeneity of plasma concentration and also - potential.

As is shown, using of Monte-Carlo method for electron motion modeling results in the following results: 1) electron reaches DC entrance mainly due to elastic electron-atom collision and dispersion on HA surfaces close to the DC entrance; 2) periodic azimuthal component E_y~10^3 V/m can effect on electron mobility cross magnetic field; 3) one of factors of an ion stream divergence increasing is non-uniform electron distribution already on the entrance in HA DC.

Largest potential drop can be concentrated outside of HA DC. Thrust efficiency decrease since 500 V up to 1000 V over the analyzed range of input parameters.

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ИЗУЧЕНИЕ НЕКОТОРЫХ КЛЮЧЕВЫХ ВОПРОСОВ РАБОТЫ УСКОРИТЕЛЯ ХОЛЛА В РАСШИРЕННОМ ДИАПАЗОНЕ РАЗРЯДНЫХ ХАРАКТЕРИСТИК

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В настоящее время ускоритель Холла (УХ) (двигатель) успешно применяется в составе космических двигательных установок, как источник ионов для проведения реакций ядерного синтеза и др. Для усовершенствования УХ (путём расширения диапазона разрядного напряжения) некоторые ключевые проблемы были выделены и изучены: рассчитаны перепады потенциала на различных участках разрядного промежутка; рассчитаны интегральные характеристики; исследовано влияние низкочастотных колебаний плазмы на движение электронов.

ВИВЧЕННЯ ДЕЯКИХ КЛЮЧОВИХ ПИТАНЬ РОБОТИ ПРИСКОРЮВАЧА ХОЛЛА У РОЗШИРЕНОМУ ДІАПАЗОНІ РОЗРЯДНИХ ХАРАКТЕРИСТИК

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На часі прискорювач Холла (ПХ) (рушій) успішно застосовується у складі космічних рушійних установок, як джерело іонів для проведення реакцій ядерного синтезу та ін. Для удосконалення ПХ (шляхом розширення діапазону розрядної напруги) деякі ключові проблеми було виділено й досліджено: розраховано перепади потенціалу на окремих зонах розрядного прошарку; розраховано інтегральні характеристики; досліджено вплив низькочастотних коливань плазми на рух електронів.