HYBRID MODEL OF THE PLASMA ACCELERATOR WITH OPEN WALLS AND CLOSED ELECTRON DRIFT

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The original approach to use Hall-type plasma accelerators with closed electron drift and open walls for production converging towards axis accelerating ion beam describes here. The two-dimensional theoretical hybrid model was created. The performed computer modeling showed that in high-current mode the potential drop forms at the axis. This effect can be used for self consistent accelerating the ions moving toward the system center and then along the axis in both directions.

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INTRODUCTION

The Hall-type plasma accelerator with closed electron drift is one of the kinds of the electric rocket engines and devices for ion-plasma treatment of the surface material. However the accelerators with closed electron drift and open (gas) walls were not research sufficiently for now in contrast to the well known and widely used plasma accelerators with anode layer [1] and with dielectric walls of accelerator channel [2]. But this type accelerator has some advantages, since the wall absence leads to exclusion of the wall material inclusions into the ion beam and to exclusion of the secondary electrons formation due to emission and thus to conservation of the plasma electrons dynamics. It could be interested for manipulating high-current flow of charge particle as well as can be attractive for many different high-tech applications for potential devises of low cost and compact thrusters.

In our previous works [3-5] we firstly described the model of accelerator with closed electron drift and open (gas) walls and based on the idea of continuity of total current transferring in the system, we obtained exact analytical solutions describing potential distribution in the acceleration gap. The one-dimensional hybrid model was created and a comparison of its results with hydrodynamic model showed good agreement. Here we consider a two-dimensional model. The performed computer modeling showed that in high-current mode the ions moving to the system center and then along the axis in both directions. In the center of system they are able to create space charge, similar to lens with positive space cloud [6]. The potential drop forms at the axis that can be used for ion beam accelerating.

1. EXPERIMENTAL SETUP AND RESULTS

The sample of plasma accelerator with closed electron drift and open walls is shown in the Fig. 1. This sample of cylindrical Hall-type plasma ion source that produced ion plasma flow converging towards the axis system was created for the properties exploration [3, 4]. The discharge in the system is burning up due to ionization of the working gas by the electrons. Electrons are magnetized and form stable negative space charge. The created ions are accelerated from ionization zone toward the cathode. As follows from discharge geometry, an accumulation of ion space charge occurs as it is in the positive space charge lens [6].

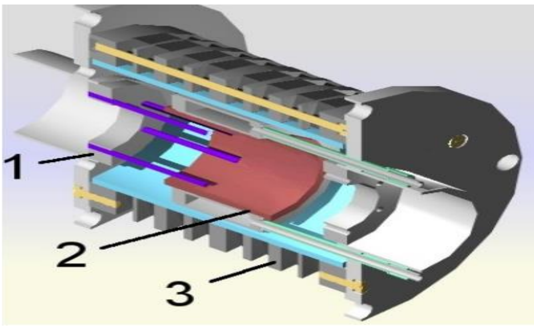
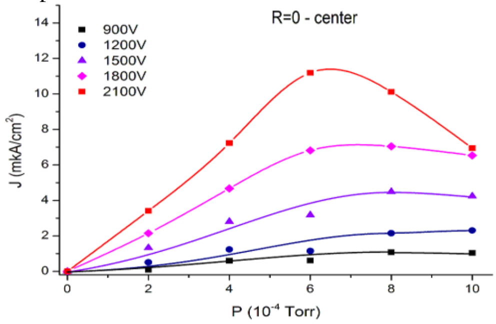


Fig. 1. Experimental setup: 1 – cathode (Ø = 3.2 cm); 2 – anode (Ø = 6.7 cm); 3 – permanent magnets system (H = 650...750 Oe)

As show experiment [3, 4] the accelerator has two operating modes: low-current one with narrow anode layer and clear-cut plasma flow and high-current one when plasma fills the entire volume of the accelerator. The transfer to the high-current mode occurs under influence of two parameters: work gas pressure and applied voltage. In high-current quasi neutral plasma mode of accelerator operation, plasma jet is observed [3]. The preliminary results show that potential drop along the jet axis arises which can be used for ion beam accelerating. The study of plasma flow along the system axis depends on pressure under different voltage showed significant increasing of the current density on the axis (Fig. 2,a). It may indicate on ion plasma acceleration in that direction. One can see the existence of a maximum of the uncompensated current density from accelerator volume at a pressure of $6 \cdot 10^{-6}$ Torr. The Fig. 2,b shows ion current density radial distribution on the edges of accelerator for different anode potential.



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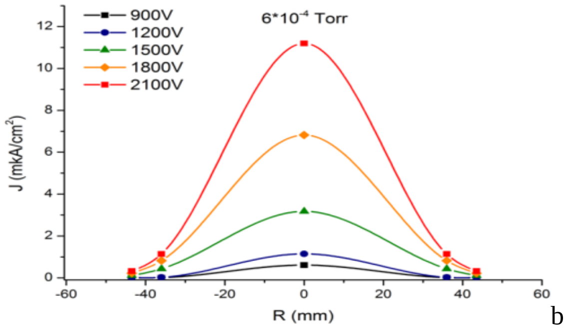

Fig. 2. Ion current density at different anode voltage dependence: a – on pressure; b – radial distribution

2. COMPUTER MODEL DESCRIPTION AND RESULTS

We will consider cylindrical geometry, where the anode is a cylinder with diameter 6.7 cm and applied potential about 1…2.5 kV, and cathode consist from 2 cylinders with diameter 4.5 cm, placed on some distance from each other. For ions and neutrals description we use Boltzmann kinetic equation:

$$\frac{\partial f_{i,n}}{\partial t} + \vec{v}_{i,n}\frac{\partial f_{i,n}}{\partial \vec{r}} + \frac{e}{M}(E + \frac{1}{c}[v \times B])\frac{\partial f_i}{\partial v_i} = St\{f_{i,n}\} \quad (1)$$

We solved this equation by splitting on the Vlasov equation for finding ions and neutrals trajectories:

$$\frac{\partial f_{i,n}}{\partial t} + \vec{v}_{i,n}\frac{\partial f_{i,n}}{\partial \vec{r}} + \frac{e}{M}(E + \frac{1}{c}[v \times B])\frac{\partial f_i}{\partial v_i} = 0 \quad (2)$$

and for correction of the determined trajectories we considered the collision integral, for which we took into account the processes of ionization and elastic and inelastic collisions:

$$\frac{Df_{i,n}}{Dt} = St\{f_{i,n}\} \quad . \quad (3)$$

The Vlasov equations were solved by the method of characteristics:

$$\frac{d\vec{v}_k}{dt} = \frac{q_k}{M}(\vec{E} + \frac{1}{c}[v_k \times B]), \quad \frac{d\vec{r}_k}{dt} = \vec{v}_k . \quad (4)$$

To solve these equations the PIC method [7] with Boris scheme [8] was used to avoid singularities at the axis. For initial electric field distribution was taken electric field in the plasma absence:

$$E(r) = \frac{U_a}{r\ln(r_c/r_a)} . \quad (5)$$

The Monte-Carlo method was used for modeling of ionization in this field. The probability of a collision of a particle with energy ε_j during time Δt was found from expression [9]:

$$P_j = 1 - \exp(-v_j \Delta t \sigma(\varepsilon_j) n_j(\vec{r}_j)), \quad (6)$$

here $\sigma(\varepsilon)$ – collision cross-section (elastic, ionization or excitation), nj – density of similar particles at the point rj. To determine the probability of collision, a random number β is chosen from interval [0,1] by means of a random number generator. If β<Pj, then it is assumed that collision has occurred. It is determined by the ratio of the cross-sections with the random number generator, which collision has occurred – elastic, excitation or ionization one. Depending on that, either particle parameters changes or new ion is added in computational box. The emerging ions begin to move toward the system axis. The evolution of all particles that are in the modeling region is traced at each time step. For that purpose, motion equations were solved and new velocities and positions of the particles were found. Particles that move out the modeling box boundaries are excluded from consideration. After sufficiently long time particle density distribution was found. The ion charge density and current density are calculated from coordinates and velocities particles according to formulas:

$$\rho(r,t) = \frac{1}{V}\sum_j q_j R(\vec{r},\vec{r}_j(t)) \quad j(r,t) = \sum_j q_j v_j(t) R(\vec{r},\vec{r}_j(t)), \quad (7)$$

where $R(r,r_j)$ – usual standard PIC – core, that characterizes particle size and shape and charge distribution in it. After that the Poisson equation was solved and new electric field distribution was found. Since electrons are magnetized we consider their movement in radial plane only, thus we can solve for electrons one-dimensional hydrodynamic equations on each layer at z separately. By solving it we find electron density, calculate electric field on each layer and correct particle trajectories. After that the procedure is repeated again. Modeling time is large enough to establish ion multiplication process. The formation of the sufficient number of ions is possible due to magnetic field presence, which isolates anode from the cathode. Ions practically don't feel the magnetic field action and move from anode to the axis, where create a space charge, first in the center of the system. In Fig. 3 is shown ion distribution along the radius in accelerator, obtained as a result of modeling.

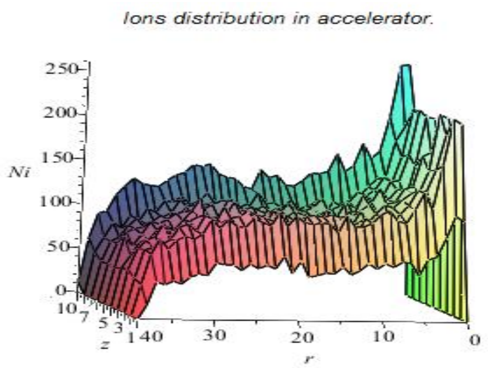

Fig. 3. Ion distribution along radius in accelerator

Electrons move along the magnetic field line, but due to collisions with neutrals, they start to move across the magnetic field. An internal electric field is formed which slows down the ions and pushes out them from the volume along system axis. In Fig. 4 is shown ion space charge distribution for different time step. One can see that ions create space charge in center of the system at first, but then under electric field action they leave center and move along z-axis in both directions.

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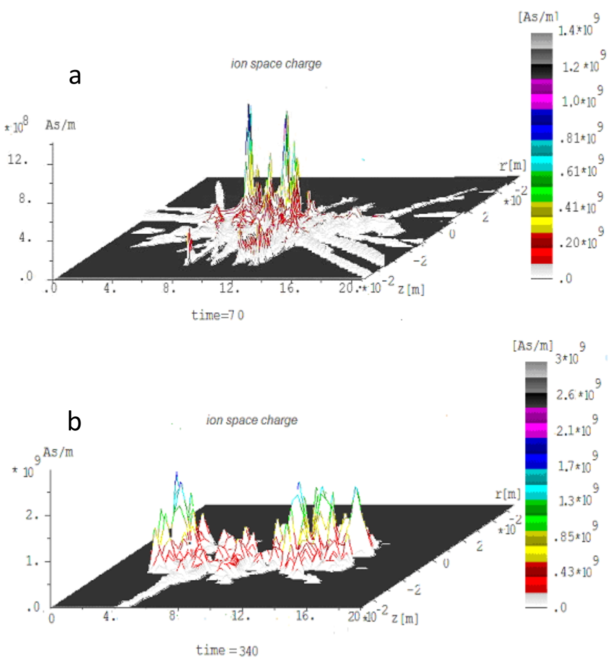

Fig. 4. Ion space charge for time step: a – 70; b – 340

CONCLUSIONS

Experimental model of accelerator that formed ion flow converging towards the axis system was created. In high-current mode of accelerator operation is observed plasma jet. It is shown at the jet axis forms potential drop that could be used for ion beam accelerating.

Two-dimensional model for accelerator was created for which a kinetic approximation was used for ions description and a hydrodynamic – for electrons. The performed simulation showed that in high-current mode the ions moving to the system center and then along the axis in both directions. In the center of system they are able to create space charge.

Note also that the presented plasma device is attractive for many different high-tech practical applications, for example, like plasma lens with positive space cloud for focusing negative intense charge particles beams (electrons and negative ions) and for potential devises small rocket engines.

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ГИБРИДНАЯ МОДЕЛЬ ПЛАЗМЕННОГО УСКОРИТЕЛЯ С ГАЗОВЫМИ СТЕНКАМИ И ЗАМКНУТЫМ ДРЕЙФОМ ЭЛЕКТРОНОВ

И. Литовко, А. Гончаров, А. Добровольский, И. Найко, Л. Найко

Описан оригинальный подход к использованию плазменного ускорителя с открытыми стенками и замкнутым дрейфом электронов для создания эффективного устройства, которое может быть использовано в современных технологиях, в частности для модификации поверхностей, управления пучками заряженных частиц, а также как прототип малогабаритного ракетного двигателя. Приведены результаты экспериментальных исследований. Построена двумерная гибридная модель и представлены результаты численного моделирования.

ГІБРИДНА МОДЕЛЬ ПЛАЗМОВОГО ПРИСКОРЮВАЧА З ГАЗОВИМИ СТІНКАМИ ТА ЗАМКНУТИМ ДРЕЙФОМ ЕЛЕКТРОНІВ

І. Літовко, О. Гончаров, А. Добровольський, І. Найко, Л. Найко

Описано оригінальний підхід к використанню плазмового прискорювача з відкритими стінками та замкнутим дрейфом електронів для створення ефективних пристроїв задля застосування в сучасних технологіях, таких як модифікація поверхонь, керування пучками заряджених частинок та як прототип маневрових космічних іонних двигунів. Наведено результати експериментальних досліджень. Побудовано двовимірну гібридну модель і представлено результати чисельного моделювання.