COMPUTER MODELING OF CHARGE PARTICLE BEAM EXTRACTION AND TRANSPORT

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The computer simulation of the extraction of high current charge particle beam from a plasma source and its transport has been used for investigation of the beam quality and its dependence from plasma parameters. The calculation has been made for different geometry extraction system as well as acceleration gap for purpose system optimization in attempt to generate the steady beam and to study the behavior and influence of different factors on beam parameters. The results indicate that the geometry extraction system, aperture shape and its diameter play an important role in beam formation process. Simulation shows that acceleration voltage and emission current essential influent on beam quality, intensity and beam divergence. The simulations are in a good agreement with experimental results and can provide the basis for optimizing of plasma source construction and its parameters for beam generation.
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1. ION BEAM EXTRACTION

3D computer code Kobra [1] is intended for solving stationary problems of forming charged particle beams in external and self-consistent electric and magnetic fields in vacuum and gas-filled systems. It allows translate the geometry information into mesh information and take into account plasma source geometry and acceleration gap geometry as well as physical condition for beam formation. The finite difference method (FDM) is used for the discretisation of equations. For solution of the set of algebraic equations an iterative point-to-point over relaxation method (SOR) is applied. The first step is solution of the Laplace equation with using seven point differential schemes. Equation of motion is solving by exact integration. By repeated solving of Poisson equation, motion equations for particles and re-determination of the space charge distribution a self-consistent solution can be found. The existing boundaries between regions with space charge and region with plasma condition are taken into account.

The ion source of the MEVVA type [2] has been used as ion extracted system for calculations. The beam is extracted from plasma by applying a potential difference between the plasma and the beam line. The plasma is looking as collision less, fully ionized and the ions confined in the plasma are of different charge states. Inside the plasma a homogeneous ion density distribution is assumed. The starting energy is given by a direct ion drift energy which is determined by the physics of plasma formation and the ion temperature. Corresponding data for plasma source have been taken from experiment [3]. The space charge inside the plasma is compensated by electrons with next density distribution:

$$n_e = n_{e0} \exp\left(-\frac{q\,\delta\varphi}{kT_e}\right), \qquad (1)$$

where n_{e0} –the electron density in undisturbed plasma, T_e – electron temperature, q- charge, $\delta\varphi=\varphi_{pl}-\varphi$ is difference between plasma potential and local potential. This function describes the electron density term for the solution of Poisson's equation. The motion of particle is written by equation:

$$\frac{dv_i}{dt} = \frac{Q_i}{M_i}\left(E + [v_i \times B]\right)\cdot \qquad (2)$$

In these equations E – the electric field, B- the magnetic induction, v_i – the velocity of the particle with charge Q_i and mass -M_i. For transport high-current ion beam we need take into account the importance the space charge of the particles in addition to the external fields:

$$\rho = \sum_{i=1}^{N} \frac{j_i}{v_i}, \qquad (3)$$

(here j is current density and N is maximum charge of ions in the beam) and the magnetic self-field that may influence the particles themselves:

$$B = \mu_0 \mu_r \frac{j}{r}, \qquad (4)$$

where B is the magnetic flux density, μ_0 μ_r -the permeability and r is the perpendicular distance to the trajectory.

The evaluations have been made for different geometry of extraction system for purpose optimizing of the construction. Fig.1 shows the cross-sectional view and character plasma boundaries. The ac-dc system is used for saving the space charge compensation of the extracted ion beam. Fig.1 shows the cross-section view and character of plasma boundary for three different type of extraction system. On picture first left electrode is plasma electrode, second – screening and third – ground.

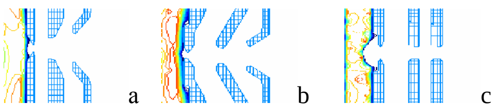


Fig. 1. Emission boundaries for different type of construction of extraction system

The position of plasma emission boundary is determined by interaction of accelerating electric field with plasma discharge. If plasma parameters (ion density and electron temperature) are constant then current density is constant also and plasma boundary position is determined by acceleration voltage. The ions will run from plasma normal to plasma surface. Thus, velocity vector has component directed to axe beam and beam will focused, but beam density and space charge will increase and will lead to increase of diverging force. Such we have two opposite process and there is optimal condition that provides minimal divergence for the extracted ion beam. Fig. 2 shows the trajectory plots that can be received for upper shown constructions.

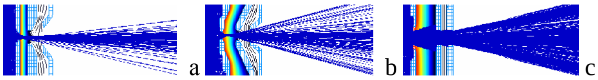
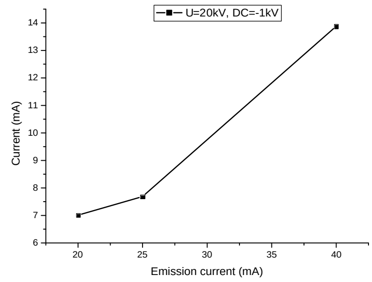


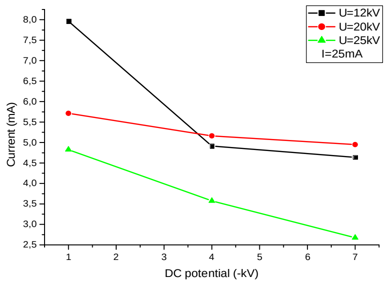
Fig.2. Trajectory plots for different extraction system geometry (the cross-section present on Fig. 1)

We can find from comparing different geometry that one is more suitable for delivering an ion beam with the minimum divergence of the extracted ion beam (a), but the other can provide biggest beam intensity (c).

From summary results, which present on Fig.3 we can see that beam divergence decreases with increase of current and acceleration voltage, but intensities of the ion beam grow with increase of emission current and decreases with increasing screening electrode potential. It is in agreement with experimental results [3].



a



b

Fig. 3. Intensity of the ion beam at the end of section as function of the: a) emission current, b) dc- voltage

2. ELECTRON BEAM EXTRACTION

Simulations have been made for plasma electron source with hollow-cathode, based on electron emission from the gas discharge plasma. The schema of plasma electron source is shown on Fig.4.

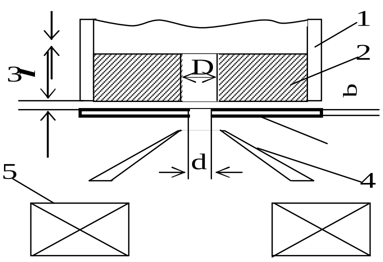


Fig. 4. Electrodes scheme of plasma electron sources: 1 – hollow cathode, 2 – cathode insertion, 3 – anode, 4 – accelerating electrode, 5 – focused system

The discharge with hollow-cathode 1 is using for plasma generation in system. Electrons are emitted from the plasma along system axes through central hole in anode 3. Electrons are accelerated by dc-voltage applied between anode and accelerating electrode 4, behind them there is magnetic focusing system 5.

Presence of gas in beam formation region provides space charge beam compensation by ions, which is generated by ionization of residual gases. It reduces divergence forces in electron beam and provides increasing beam density and thus can change electric field configuration in acceleration gap that influences on electron trajectories and beam quality. Gas ionization in acceleration gap provides occurrence of ions back streaming to plasma and therefore changing plasma boundary position because the plasma density increases. All this will influence on beam configuration and quality.

The calculations have been made for different size and aperture shape of emission electrode with the aim to determine the behavior and influences of different factors on geometrical parameters of the electron beam. Fig. 5 shows the cross-sections and emission boundaries for different kind of electrode systems.

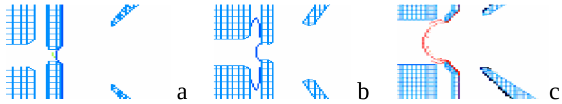


Fig. 5. Emission boundary for different kind of electrode: cylindrical hole a)Ø=1.5mm, b) Ø=1mm, c) conic hole

Fig. 6 present resulting corresponding trajectory plots (without external magnetic field).

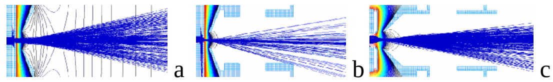
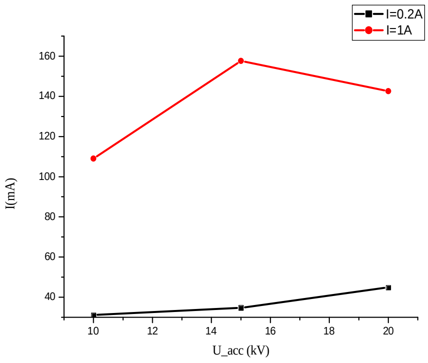


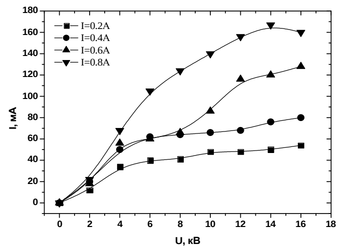
Fig. 6. Trajectory plots corresponding to electrode system configuration present on Fig. 5

The comparison of electron beam parameters at the exit of system for these cases shows maximal beam current for case a) and minimal beam divergence for case c). Emission current increases with increasing of hole diameter, but if diameter is too big (ø>1.8 mm) the beam will not form, because of the plasma penetration from discharge region to acceleration gap. The aperture shape plays important role in beam formation, too. The simulation shows that configuration 5c) provides minimal beam loses and biggest beam intensity at the exit of the system.

The important task is influence of acceleration voltage on quality and geometry of electron beam. Fig. 7 shows summary results for dependence of beam intensity from acceleration voltage. We can see that beam divergence is decreasing and beam intensity increase with increasing of acceleration voltage for emission current less than 0.5 A. For emission current bigger than 0.6 A there is optimal voltage that allows get maximal beam intensity and minimal divergence when electron beam pass through drift space. Increasing of accelerating voltage displace plasma boundary and it become more flat. Opposite it – with emission current increasing will increase plasma density and because it reduces distance between plasma and accelerate electrode that will lead to increasing curvature of the plasma surface. Thus there is optimal acceleration voltage and emission current that provide minimal divergence of the beam. The calculation is with agreement with experimental results [4, 5].



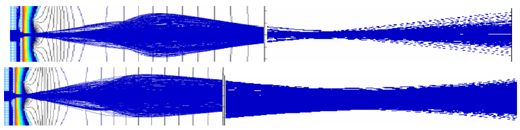
a



b

Fig.7. Intensity electron beam as a function of acceleration voltage a) simulation, b) experimental result

The great interest for technological purpose has sharp focused electron beams, which used at least for two fields of employment: electronic beam welding and fusion. For such beam formation important role plays external magnetic field. Calculation confirms that location the focusing system influence on beam convergence and important for delivering beam for the distance required by technological process. Fig. 8 demonstrates resulting trajectory plots for different location of focusing system.



a

b

Fig. 8. The center of focusing system locates from anode on distance: a) 60mm, b) 80mm

Fig. 9 shows experimental and simulation results for dependence beam diameter on accelerating voltage for distance 15 cm from focusing system for different emission currents. One can see that experimental and calculate dependence have the same tendency decreasing with beam divergence increase of acceleration voltage.

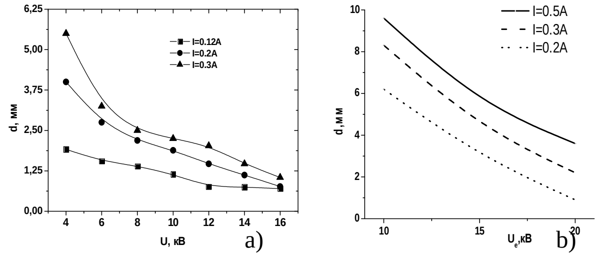


Fig. 9. Dependence beam diameter on acceleration voltage: a) experimental result, b) calculation

CONCLUSIONS

The computer models for charge particle beams have been building and characteristics beam extracted from plasma sources were investigate. The results indicate that the geometry extraction system, aperture shape and its diameter play an important role in beam formation process. Simulation shows that acceleration voltage and emission current essential influent on beam quality, intensity and beam divergence. The electron beam focusing are improve with accelerate voltage increasing There is optimal emission current, that give maximal beam intensity and minimal beam divergence. The simulations are in a good agreement with experimental results.

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КОМПЬЮТЕРНОЕ МОДЕЛИРОВАНИЕ ИЗВЛЕЧЕНИЯ И ТРАНСПОРТИРОВКИ ПУЧКА ЗАРЯЖЕННЫХ ЧАСТИЦ

И.В. Литовко, Е.М. Окс

Проведено численное моделирование формирования пучков заряженных частиц из плазменных источников, а также расчеты транспортировки пучка в дрейфовом пространстве с учетом пространственной компенсации заряда. На основе полученных данных можно оптимизировать конструкцию извлекающей и ускоряющей систем плазменных источников, а также оптимизировать параметры источников и получить пучки заряженных частиц с заданными параметрами.

КОМП'ЮТЕРНЕ МОДЕЛЮВАННЯ ФОРМУВАННЯ ТА ТРАНСПОРТУ ПУЧКА ЗАРЯДЖЕНИХ ЧАСТОК

І.В. Літовко, Є.М. Окс

Проведено чисельне моделювання формування пучків заряджених часток з плазмових джерел. Також було зроблено чисельні розрахунки транспортування пучка в дрейфовому просторі з урахуванням просторової компенсації заряду. На основі одержаних результатів можна здійснити оптимізацію конструкцій екстракціонної та прискорювальної систем плазмових джерел, а також оптимізувати параметри джерел та отримати пучки заряджених часток з заданими параметрами.