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Computer Simulation of Ion and Electron Beam Extraction and Transport

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The simulation of the extraction of charge particle beam from a vacuum arc based source has been used for investigation of the beam quality and optimization for specific application possibilities. A few examples are used to demonstrate the capabilities and limits of these simulations. The simulation can provide the basis for optimizing the extraction system and acceleration gap for source and for decrease of losses of the extracted beam.

Introduction

Computer modeling of charge particle beam is important part in investigation of processes that take place in different electro-physical equipments and has been used for about 50 years [1]. The aim of these simulations is always to investigate the charge particle beam quality, which makes optimization for a specific application possible. As a rule, the applied numerical method is based on solving the Poisson equation with the unknown space charge term. The result is used for the solution of motion equations for charge particles. A repeated iteration allows achieve self-consistent solution.

In this work for investigation high current charge particle beams was used 3D computer code Kobra [2]. 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.

Ion beam extraction and transport

For calculations the ion source of the MEVVA type has been used [3]. The beam is extracted from plasma by applying a potential difference between the plasma and the beam line. The plasma is assumed as collision less, fully ionized and the ions confined in the plasma have different charge states. The calculation has been made for phosphorus ions beam with different ion charge state (45% P^{+1}, 45%P^{+2}, 10%P^{+3} on current fraction). 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 [4]. The space charge inside the plasma is compensated by electrons with Boltzmann density distribution. For transport high-current ion beam we need take into account in addition to the external fields the importance the space charge of the particles and the magnetic self-field that may influence the particles themselves.

The evaluations have been made for different geometry of extraction system. 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, thus on picture first left electrode is plasma electrode, second – screening and third – ground.

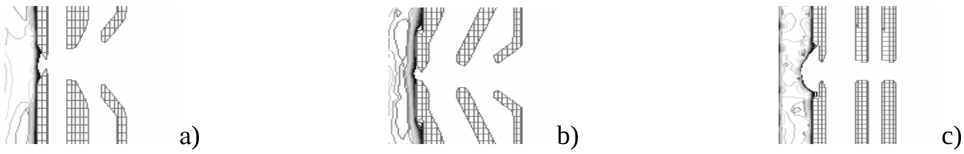


Fig. 1. Emission boundaries for different type of construction of extraction system.

The position of plasma emission boundary determine 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 be focused, but beam density and space charge will increase and will lead to increase of diverging force. Such we have two opposite processes and there is optimal condition that provide minimal divergence for the extracted ion beam. Fig. 2 shows trajectory plots corresponding to constructions in Fig.1.

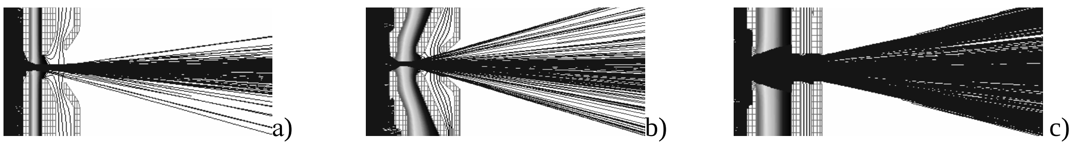
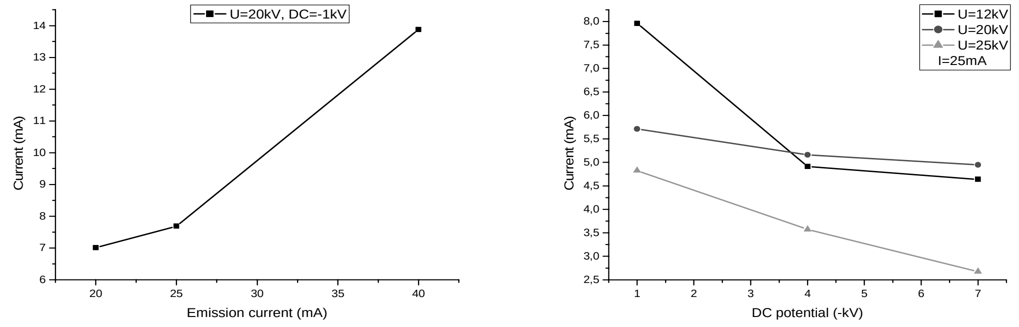


Fig.2. Trajectory plots for different extraction system geometry (the cross-section presented in Fig. 1).

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 other can provide biggest beam intensity (c).

From summary results, which present on Fig.3 we can see that beam divergence decrease with increasing of current and acceleration voltage, but intensities of the ion beam grows with current increasing and decreases with grows potential on screening electrode. It is in agreement with experimental results [6].



a) b)

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

The results of calculation confirm that geometry extraction system, shape of apertures and its diameter plays very essential role in beam formation and its intensity.

Electron beam extraction and transport

Simulations have been made for plasma electron source with hollow-cathode, based on electron emission from gas discharge plasma. The schema of plasma electron source is shown on Fig.4. The discharge with hollow-cathode 1 is using for plasma generation in system. Electrons are emitted from the plasma along system axe through central hole in anode 3. Electrons are accelerated by dc-voltage applied between anode and accelerate electrode 4, behind them there is magnetic focused system 5.

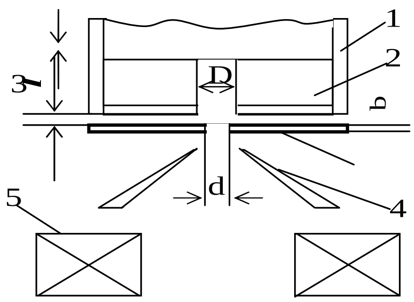


Fig. 4. Electrodes scheme of plasma electron sources:
1 – hollow cathode, 2 – cathode insertion, 3 – anode, 4 – accelerating electrode, 5 – focused system .

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

Fig. 5 shows the cross-sections and emission boundaries for different electrode systems:

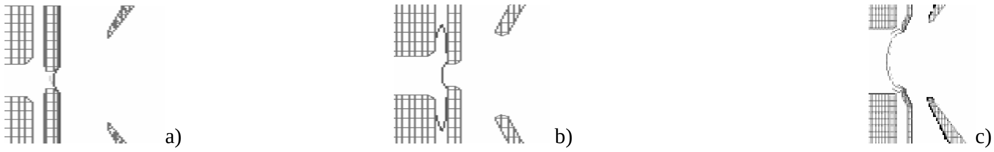


Fig. 5. Emission boundaries for different electrode configurations: a) cylindrical hole (Ø=1.5mm), b)cylindrical with smaller diameter (Ø=1mm), c) conic hole.

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

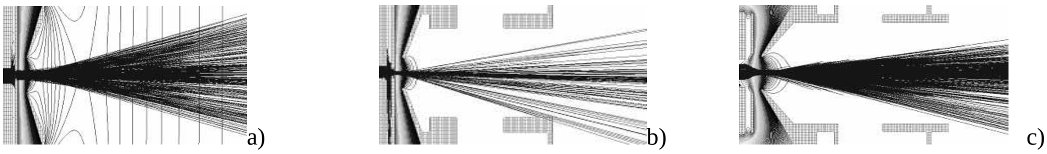


Fig. 6. Trajectory plots corresponding to electrode system configuration present in Fig.5.

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). The calculation confirms that exist optimal aperture size. Emission current increase with increasing of hole diameter, but if diameter is too big (ø>1.8mm) 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 also. The simulation shows that configuration 5c) provide minimal beam loses and biggest beam intensity at the exit of system.

Conclusion

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 [5, 6] and can provide the basis for optimizing plasma source construction and its parameters for beam generation.

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