Vacuum 83 (2009) S256–S259

Contents lists available at ScienceDirect

Vacuum

journal homepage: www.elsevier.com/locate/vacuum

Simulations of negative ion extraction from a multi-aperture ion source in the presence of the magnetic filter

M. Turek [a,*], J. Sielanko [b]

[a] Institute of Physics, Maria Curie-Skłodowska University, Pl. Marii Curie-Skłodowskiej 1, 20-031 Lublin, Poland
[b] Institute of Computer Science, Maria Curie-Skłodowska University, Pl. Marii Curie-Skłodowskiej 1, 20-031 Lublin, Poland

ARTICLE INFO

Article history:
Received 16 June 2008
Received in revised form
21 December 2008
Accepted 30 January 2009

Keywords:
Plasma simulation
Ion sources
Particle-in-cell
Ion beams

ABSTRACT

The particle-in-cell method based numerical model of negative ion beam extraction from a large volume multi-aperture ion source is briefly described. The model takes into account the influence of the transversal magnetic field and diffusion of electrons across the field. The current-voltage curves for H^- ions and electrons are presented. The results are compared for the three cases: without filter field; with the field but without diffusion; and with the field and electron diffusion. The presence of the magnetic filter field increases H^- yields significantly (by 200%). A random-walk electron diffusion model enables electrons to travel through the magnetic field, which reduces a nonphysical effect of excessive electron aggregation in the filter region. The changes of filter width do not alter H^- current more than 10%.

1. Introduction

Neutral beam injection (NBI) is one of the most promising candidates for the plasma heating technique in future fusion devices. The development of NBI systems based on a negative ion beam (due to more efficient ion neutralization for higher beam energy compared to positive ion beams) requires detailed knowledge about negative ion production and transport phenomena, as well as beam extraction and formation. The computer simulations help to understand the above mentioned processes and support design and optimization of powerful plasma ion sources.

It was experimentally shown that weak transversal magnetic field improves negative ion extraction [1] by stopping electrons and increasing negative ion flow into the extraction area. This is due to the plasma tendency to maintain its neutrality. Such an effect was also confirmed by two- [2,3] and three-dimensional [4] particle-in-cell (PIC) simulations. The magnetic field also helps to get rid of unwanted electrons from the extracted negative ion beam We have used PIC based, 3D code TRQR which follows the trajectories of charged particles in the self-consistently calculated electric field and the static magnetic field in order to investigate extraction of H^- ions from large RF source by the multi-aperture grid system resembling those tested at IPP Garching [5,6]. The transversal (with respect to the extraction direction) magnetic filter (MF) field was applied in the extraction region, as in Ref. [4]. Its aim is to hinder unwanted electron flow and to increase extracted H^- current. The simple random-walk electron diffusion model, similar to that presented in Ref. [7], has been also implemented. The electron diffusion enables electrons to travel across magnetic field and suppress their tendency [4] to create nonphysical aggregations in the area of the MF peak.

In the paper a brief description of the simulation model is presented. The evolution of plasma potential inside the plasma chamber, as well as its spatial profiles for different simulation regimes (i.e. without MF; with MF but without electron diffusion taken into account; and including both MF and electron diffusion), are discussed. The current-voltage curves are compared for the three above mentioned cases both for negative ions and electrons. The influence of MF strength on H^- current is under investigation. The results are compared for the cases with and without electron diffusion taken into account. The influence of MF profile width is also studied.

1.1. Numerical model

The TRQR code [8–10] is based on the particle-in-cell (PIC) method for computing the trajectories of charged particles in the electromagnetic field [11]. Having the total charge density calculated, the electrostatic potential is determined by solving the Poisson equation using the successive over-relaxation method [12]. The single particle equations of motion are numerically solved by

* Corresponding author.
E-mail address: mturek@kft.umcs.lublin.pl (M. Turek).

0042-207X/$ – see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.vacuum.2009.01.076

means of the 4-th order Runge–Kutta method. The whole procedure repeats in a self-consistent manner.

The simulation area is very similar to that presented in Ref. [4]. The plasma grid is unbiased, the acceleration grid has the potential $U_a = 18$ kV while the extraction grid potential U_e is changed up to 10 kV. The simulation area is divided into the $100 \times 100 \times 100$ spatial grid of $\Delta x0 = .1$ mm and $\Delta y = \Delta z = 0.75$ mm. The plasma in the source chamber consists of H^+ ions (50%), electrons (40%) and H^- ions (10%). The plasma density is set to 10^{16} m^{-3}. In all simulations 10^7 macro-particles are employed. Particles are randomly created inside the chamber with randomly directed initial velocities. The initial particle velocities correspond to 1 eV. Once the particle leaves the chamber or is destroyed, e.g. while hitting the obstacle, a new particle of the same kind is created inside the chamber in order to keep the plasma quasi-neutrality.

The transversal MF field applied in the extraction area is of the Gaussian shape:

$$B_z(x,y,z) = B_0 \exp\left\{ -\left(\frac{x - x_0}{l}\right)^2 \right\} \tag{1}$$

The values of x_0 and l are 50 mm and 20 mm, respectively, unless it is clearly said that other values are used. All other components of the MF vector vanished. The electron diffusion through the magnetic field is simulated as a random-walk process, similarly to Ref. [7]. Electrons are shifted in the x direction with an additional step estimated by the formula:

$$\delta x = \sqrt{2D\Delta t} \cdot \mathrm{RND} \tag{2}$$

where RND is the normal random number. The diffusion coefficient could be estimated as $D = r_L^2 \nu$, where r_L is the Larmor radius and ν is the electron-neutral and electron-ion collision frequency [13]. The code records plasma component charge densities and plasma potential distribution, as well as extracted currents for ions and electrons.

1.2. Simulation results

At the first step the plasma potential behaviour and current-voltage characteristics were under investigation. The U_e was increased up to 10 kV whilst U_a was kept invariant (18 kV). The time step was $\Delta t = 0.5 \times 10^{-10}$ s, simulations were stopped after 3500 time steps. The initially strong potential oscillations are damped and a steady state is achieved after approximately 2000 main loop iterations. The potential inside the chamber oscillates near the mean value of 17 V ($B_z = 0$, no diffusion). As shown in Fig. 1 the initial potential profile is very steep – it resembles the potential distribution in the case of an empty chamber. After the steady state is achieved the potential becomes flat – the electric field inside the chamber disappears, due to the screening properties of plasma. Note that the mean plasma potential in the presence of magnetic filter and electron diffusion is much higher compared to the 'no field' case. This is possibly due to the fact that electrons travel toward the extraction grid faster if the simple model of diffusion is included. This is also the reason for the low potential near the plasma grid. On the other hand in the 'no diffusion' case one can observe small bump of the potential profile in the region of MF maximal strength. This could be due to the fact that electrons are trapped by MF [4]. Consequently, electron aggregations attract positive ions, which also gather in the region of maximal MF strength. One may expect charge density and potential oscillations especially well pronounced in that region.

The extracted currents were determined by counting particle passing the extraction grid. Fig. 2 shows the extracted H^- currents (part a) and electron currents (part b) for different values of

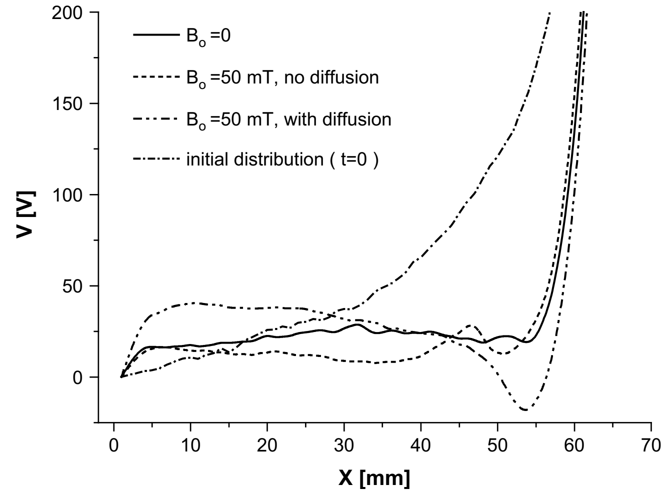

Fig. 1. Potential profiles along the test line in the three considered cases (no MF; with MF; MF plus diffusion). The results for $U_e = 4.5$ kV.

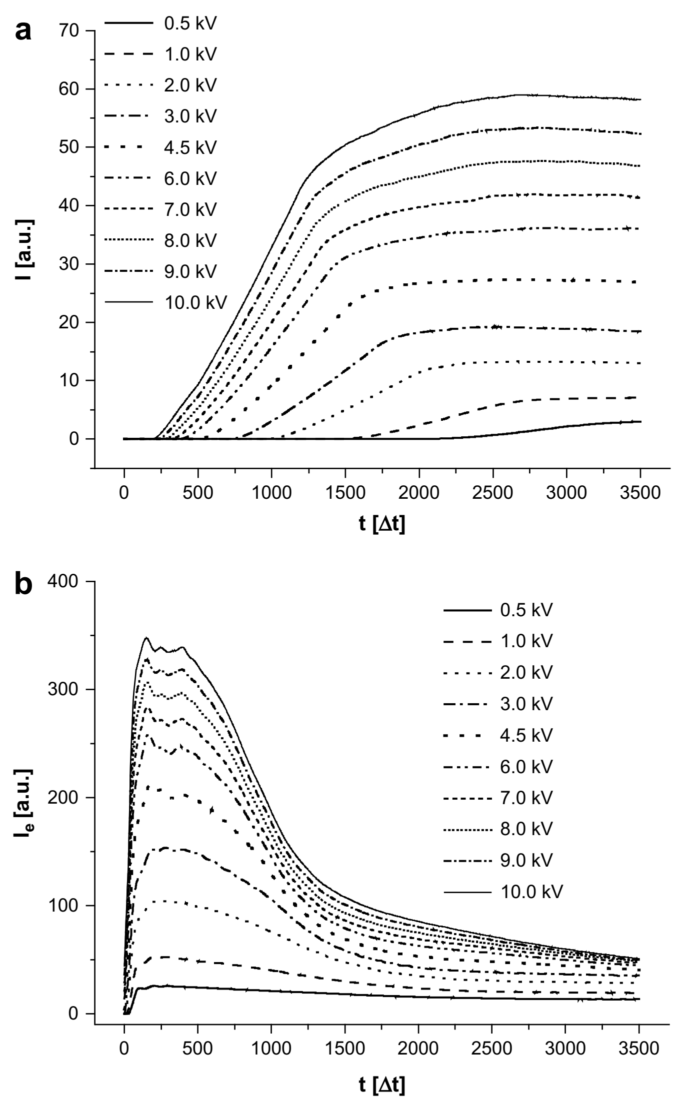

Fig. 2. The evolution of the extracted currents in the 'no field' for the H^- ions (a) and the electrons (b). All results for $U_e = 4.5$ kV. Similar calculations were also done in the case of the MF and diffusion.