# 3D NUMERICAL SIMULATION OF EXTRACTION OF A LARGE-POWER NEGATIVE ION SOURCE

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*Abstract*

A driver of the RF negative ion source has been finished at Huazhong University of Science and Technology (HUST) last year, and then the extraction system of negative ion source will be finished in the next stage. The extraction system has important influence on the extraction beam. This paper presents a 3D numerical modelling to simulate the extraction system, considering the space charge effect. The electric field is calculated by solving Poisson equation with finite difference method (FDM). The particle transport process is simulated with particle-in-cell (PIC) method, considering the electrodes field, the electron deflection magnetic field, as well as the field of the space charge. The influences of the shape of electrodes and the electron deflection magnetic field on the quality of extraction beam are studied. These results provide useful guidance for the design of a negative ion source.

## INTRODUCTION

The radio frequency (RF) driven negative hydrogen ion source is the reference source for the ITER neutral beam injection (NBI) system [1,2]. RF driven negative hydrogen ion source can be divided into three parts: driver, exp-ansion region and extraction system (see Fig. 1)[3,4].

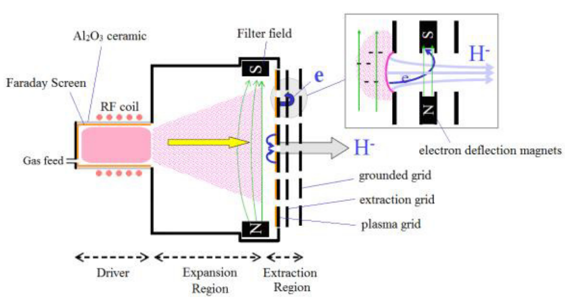


Figure 1: Schematic view of negative ion source.

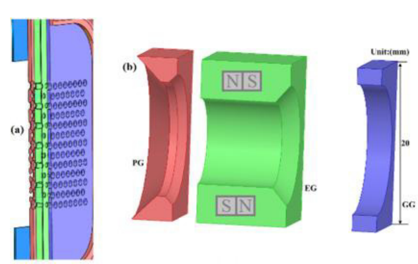


Figure 2: Schematic view of extraction system.

This paper presents a 3D numerical modelling to simulate the extraction system. As shown in Fig. 2, the extraction system consists of three grids: the plasma grid (PG), which separates the plasma from the beam region; the extraction grid (EG), where the co-extracted electrons are filtered out of the beam by the fields from the permanent magnets embedded in the extraction grid; and the grounded grid (GG)[5, 6]. The extraction system of the test facility BATMAN [7] (a test facility at IPP, Carching) is used as an example in this paper.

## SIMULATION MODEL

### *Model Description*

The simulation domain is restricted to a single extraction aperture of the grids due to the periodicity of the structure, as shown in Fig. 3. The particles can only move in the space without grids, as shown in Fig. 4.

The CoSm permanent magnets are embedded in EG to deflect the co-extracted electrons out of the beam.

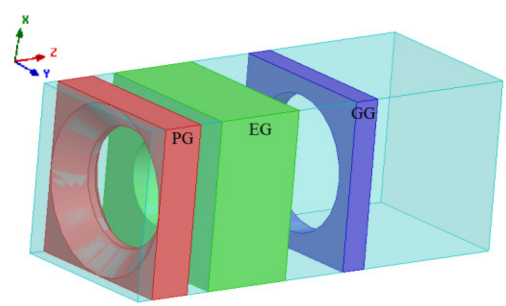


Figure 3: Computational domain.

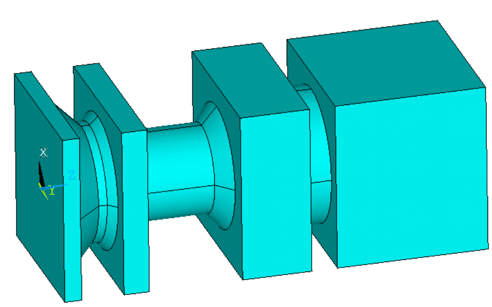

Figure 4: Domain without electrodes.

The plane $z$=$z_{min}$ with the plasma potential (approximately equal to potential of PG) is the emitting surface that a prescribed number of particles are injected every time step from this plane uniformly in $x$ and $y$

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directions. The plane $z=z_{max}$ satisfies the natural boundary conditions. And the periodical boundary conditions are used in the $x$ and $y$ directions.

### *Flow Chart of Simulation Code*

The general flow of simulation is shown in Fig. 5:

(1) Initialize: input the electron density ne, the electron temperature Te, the ion density ni and the ion temperature Te; define the type of the particle location and velocity distributions; import the data of the reflecting magnetic field.

(2) Calculate emitting surface: this is a complex step including the interaction between plasma and electromagnetic field, the collisions of the particles. We have not complete this step up to now, so in this paper, the location and velocity of electrons and ions are assumed in uniform distribution.

(3) Calculate electric field: the finite difference method is used to solve Poisson equation.

(4) Calculate particle trajectories: tracking the particle trajectories from their starting points to their leaving points of the calculate domain.

(5) Calculate charge density: the space charge density is calculated on the grid based on the ray-traced trajectories, the charge deposition is based on the method used in the more established PIC codes, where the space charge is assigned to the grid from particles at each time step.

(6) Convergence criterion: the evolution of the transverse rms emittance has been chosen to be used for estimating the convergence.

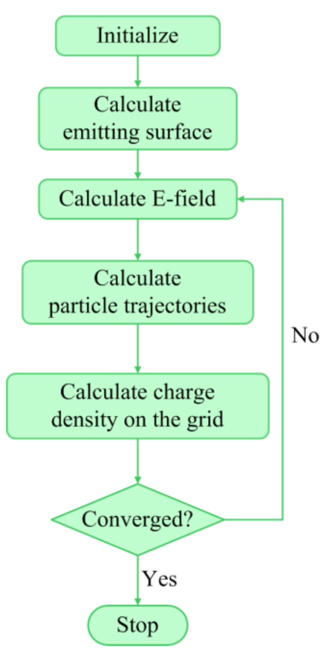


Figure 5: General flow chart of the simulation.

## RESULTS AND DISCUSSION

This paper calculated two different extraction systems of BATMAN (CEA and LAG), as shown in Fig. 6. The size of computational domain is shown in Table 1.

Every step in Fig. 5 has been finished except for the calculation of emitting surface. This paper presents the preliminary results, which is agree well with the IPP results, electrons are almost filtered out of the beam.

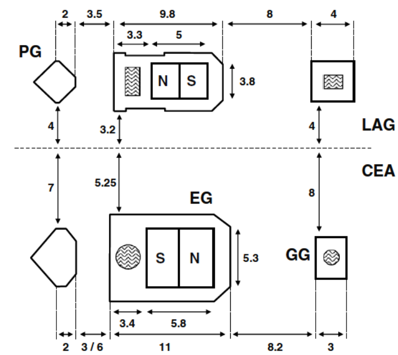


Figure 6: Geometry of the two different extraction systems (unit: mm).

Table 1: Size of CEA and LAG

| | LAG | CEA |
|---|---|---|
| $X_{min}$(mm) | 0 | 0 |
| $X_{max}$(mm) | 12 | 20 |
| $Y_{min}$(mm) | 0 | 0 |
| $Y_{max}$(mm) | 11.5 | 20 |
| $Z_{min}$(mm) | 0 | 0 |
| $Z_{max}$(mm) | 45 | 50 |
| PG(kV) | -26.4 | -26.4 |
| EG(kV) | -16.8 | -16.8 |
| GG(kV) | 0 | 0 |

The equipotential lines for the two different extraction system is shown in Fig. 7 and Fig. 8. The potential of grids is PG: -26.4kV, EG: -19.2kV, GG: 0V.

The vertical magnetic field strength Bx of the electron deflection field along the aperture center is shown in Fig.9 and Fig. 10. The samarium cobalt magnet is used, the relative permeability is 1.07, and residual magnetism is 1.1T.

The negative ion (in blue) and electron (in red) trajectories for the two different extraction systems is shown in Fig. 11 and Fig. 12. The initial temperature of electron and negative ion are both 9eV.

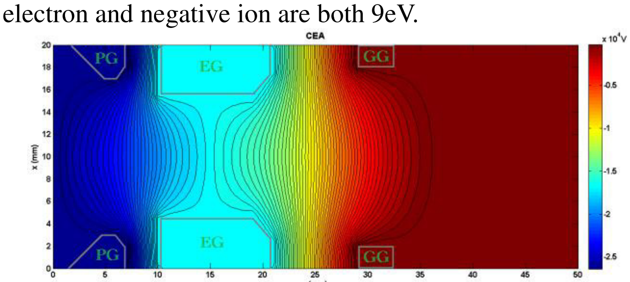


Figure 7: Equipotential lines of the extraction system CEA.



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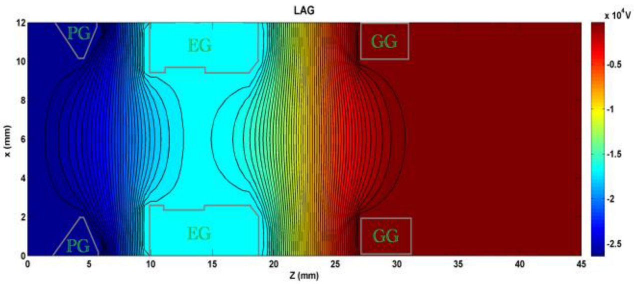


Figure 8: Equipotential lines of the extraction system LAG.

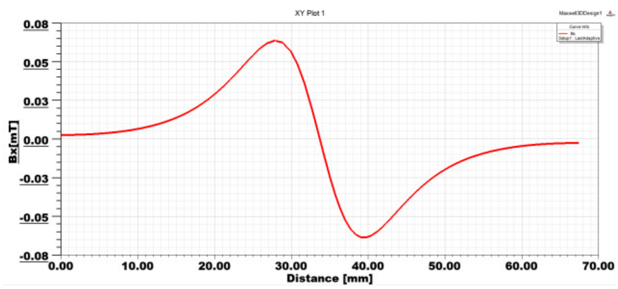


Figure 9: Vertical magnetic field strength Bx of the electron deflection field (CEA).

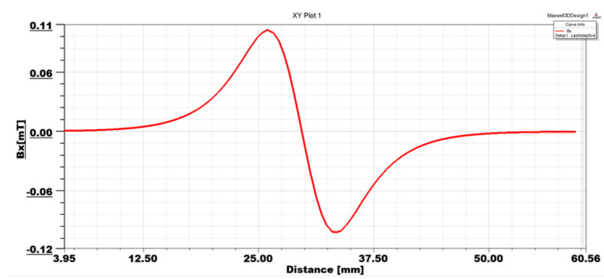


Figure 10: Vertical magnetic field strength Bx of the electron deflection field (LAG).

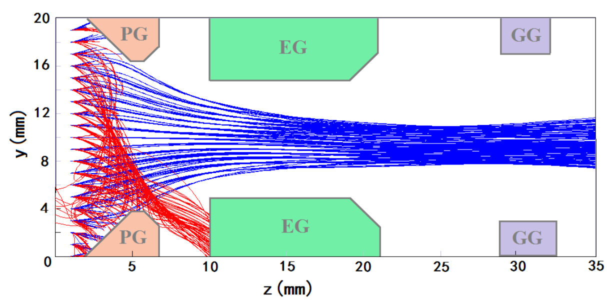


Figure 11: Negative ion (in blue) and electron (in red) trajectories for the extraction system CEA.

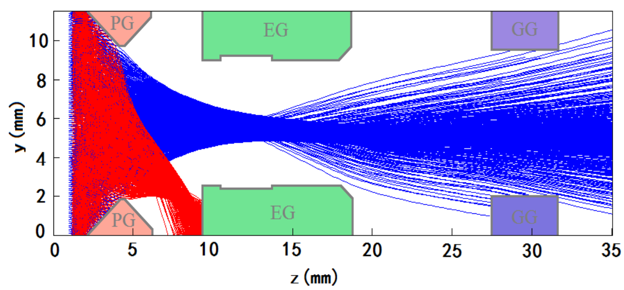


Figure 12: Negative ion (in blue) and electron (in red) trajectories for the extraction system LAG.

## CONCLUSION

This paper presents a 3D numerical modelling to simulate the extraction system of negative ion source based on finite difference method. CEA and LAG (two different extraction systems of BATMAN have been used to check this numerical modelling. The results prove a very good agreement with the IPP results. In the future work, the calculation of the emitting surface will be finished, the simulation model and the code will be improved to get the more realistic results.

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