Optics of ion beams for the neutral beam injection system on HL-2A Tokomak

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The ion beam optics for the neutral beam injection system on HL-2A Tokomak is studied by two-dimensional numerical simulation program firstly, where the emitting surface is taken at 100 Debye lengths from the plasma electrode. The mathematical formulation, computation techniques are described. Typical ion orbits, equipotential contours, and emittance diagram are shown. For a fixed geometry electrode, the effect of plasma density, plasma potential and plasma electron temperature on ion beam optics is examined, and the calculation reliability is confirmed by experimental results. In order to improve ion beam optics, the application of a small pre-acceleration voltage (~100 V) between the plasma electrode and the arc discharge anode is reasonable, and a lower plasma electron temperature is desired. The results allow optimization of the ion beam optics in the neutral beam injection system on HL-2A Tokomak and provide guidelines for designing future neutral beam injection system on HL-2M Tokomak. © 2012 American Institute of Physics. [http://dx.doi.org/10.1063/1.4737184]

I. INTRODUCTION

Neutral beam injection systems for heating and sustaining plasma on HL-2A Tokomak require the production of hydrogen and deuterium ion beams of high current density and minimum beam divergence. These neutral beams are formed from four magnetic multi-poles line-cusp ion source in one beam line on HL-2A Tokomak. Recent experimental evidence indicates the hydrogen ion beam power of one ion source is about 40 kV × 20 A. Some ion beam characteristics are researched by experimental method. In order to improve the beam optics, the computation of ion beam optics is studied by numerical simulation.

Machine computations are available using algorithms that iterate between a solution of Poisson’s equation and a calculation of ion trajectories with deposition of space charge. The earlier efforts started the ions on an equipotential surface in the sheath region of the source plasma, which typically are approximately 10 to 15 Debye lengths from the plasma electrode. The approximate position, potential, and field of this surface, as well as the initial directed ion speed, are given by a solution to the collisionless one-dimensional Poisson-Vlasov equation in the sheath region. A procedure has been worked out that, given the emitting surface potential, adjusts the emitter position automatically so that the electric field is consistent with one-dimensional solution. However, this presumes that the electric field is the same and is constant along such a potential surface in the actual two-dimensional problem. Another problem is that the ion direction at the sheath must be specified even though it is unknown for the two-dimensional case. In order to avoid these problems, the emitting surface in this paper is taken far back into the plasma, which is 100 Debye lengths from the plasma electrode, and the iteration schemes converge is improved after utilizing an advanced schemes. The computer program applied to study ion beam optics is developed independently by Southwestern Institute of Physics in China recently. It is revision of program where emitting surface is taken at classical sheath position.

In Sec. II, the computation techniques and mathematical formulation are described. In Sec. III, the typical simulation results are shown and the effect of plasma properties upon ion beam optics is examined by comparing with experimental results. In Sec. IV, conclusions are presented.

II. MATHEMATICAL FORMULATION AND COMPUTATION TECHNIQUES

Poisson equation, ion movement equation, and ion current continuity equation are solved simultaneously

$$\nabla^2 \phi = -\frac{1}{\varepsilon}(n_i + n_e),$$

$$\frac{d(M_i V_i)}{dt} = q_i(V_i \times B - \nabla \phi),$$

$$\nabla \cdot (n_i V_i) = 0,$$

where $\phi, n_i, n_e, q, M, V, B$ are electric potential, ion and electron charge density, ion electric charge, ion mass, ion velocity, and magnetic field, respectively. In this system magnetic field is absent, so B is zero. The electron density is assumed to be in Boltzmann distribution. These equations have been solved previously. In recent attempts, the ions emitting surface is taken into the plasma where 100 Debye lengths far away from plasma electrode. Therefore, ion initial nonregular thermal velocity distribution is taken into account. We assume that ions velocities distribution obeys the Maxwell distribution. And these initial average velocities in two dimension plane could be referred to analytical solution.

Poisson’s Equation (1) with Dirichlet and Neumann boundary conditions is solved by finite element methods, using the method of successive over-relaxation. Assuming the potential is in linear distribution in each triangular mesh element, the movement equation is solved by direct

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