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Impurity Migration Pattern Simulated by Test Particle Module Under BOUT++ Framework

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Abstract. A test particle module is developed under BOUT++ framework. The guiding-center orbits in real divertor geometry can be calculated. The turbulence transport is implemented by random walk model. Impurity migration patterns under different turbulence transport levels are simulated by this module. As transport increase, migration pattern is modified significantly. More particles are lost and the lost at low field side boundary increase significantly.

AMS subject classifications: 65Z05, 68U20, 82D10
Key words: Impurity migration, test particle, BOUT++.

1 Introduction

Impurity control is important for tokamaks [1]. The impurity can enhance the power exhaust by radiation in front of the divertor plates, and reduce the heat load to divertor. On the other hand, the impurities in the core region could reduce the fusion power due to fuel dilution and the energy confinement degradation by radiation loss. The physical mechanism of impurity production and transport is usually studied by experimental diagnostics and code simulations. The impurity transport and SOL(Scrape-Off Layer) plasma transport are strongly coupled with each other through the force acting on impurity ions and radiation. The impurity density profile is highly asymmetric in the poloidal plane due to this interaction. Flow velocity and detailed 2D profile of the background plasma parameters in the SOL strongly influences impurity transport, so it is important to diagnostic these data experimentally. The edge flow can be measured by Charge Exchange Recombination (CER) spectroscopy [2] and probes [3,4]. Recently, 2D measurements of flow profile is done by coherence imaging in MAST [5], ASDEX upgrade and

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Wendelstein 7-X [6] and DIII-D [7]. At the same time, comparison of experimental results and simulation results helps to understand the physics better.

These codes are classified into fluid codes and kinetic (often Monte Carlo) codes. Although Monte Carlo codes demand more computational resource, they can carry out the simulations in realistic tokamak geometry and various collisional effects, such as ionization, recombination and Coulomb scattering with the background particles, correctly and simultaneously. After the background plasma is calculated by fluid code, the impurity transport properties can be simulated in real divertor geometry by Monte Carlo codes and compared with experiment results. For example, B2.5/Eirene and two-dimensional Monte Carlo impurity transport code DIVIMP are combined to simulate the carbon impurity transport in SOL/divertor plasma with Ohmic heating on EAST tokamak [8].

The kinetic effect is one of key issues for improving the modeling. This is because of the steep radial gradients in the edge, with scale lengths comparable to drift orbit widths, and because of the significant equilibrium temperature, density and potential variations along magnetic field lines on length scales comparable to collisional mean free paths. And assumption of strong collisionality is required if fluid modelling of the impurities is used. However, this is usually not fulfilled for lower charge states impurities which lives shortly and is ionized further. For example, the thermal force was found to have the opposite direction for impurity ions with high speeds by using a drift kinetic model [9,10], compared to the thermal force in fluid model which is averaged over a Maxwellian velocity distribution of impurity ions. The complete kinetic behaviors can be simulated only by the kinetic modeling [11]. The PARASOL code [12] is the closest to first principles, full-ion dynamics and drift-kinetic electrons are utilized.

In this paper, a test particle module is developed under BOUT++ framework. The guiding-center orbits of impurity in real divertor geometry is traced. For low-Z impurity species, such as C, Ar, Ne, guiding-center approximation is usually satisfactory, which assumes the Larmor radius to be small compared with local gradients. For high-Z impurity species, they have larger Larmor radius and the full orbit should be calculated, such as IMPGYRO [13] code.

BOUT++ [14] is developed from the original BOUndary Turbulence 3D 2-fluid tokamak edge simulation code BOUT [15]. It has a modular, object-oriented structure by using C++. An arbitrary number of equations in 3D curvilinear coordinates can be solved using finite-difference methods. The complicated details such as differential geometry, parallel communication, and file input/output are separated from user-specified physics equations to be solved. The physics equations can be easily changed with only minimal knowledge of the inner workings of the code. The user can concentrate on the physic, rather than worry about the detailed numerics.

The paper is organized as follows. In Section 2, the model used in the test particle's module is introduced, including the particle's guiding-center equations, mapping method between two different meshes and random walk model for turbulence transport. The migration patterns of impurity with and without turbulence transport are compared in Section 3, and summary is given in Section 4.