ENERGY AND PARTICLE FLUXES IN PRESENCE OF RMP IN AXISSYMETRIC 2D TOKAMAK PLASMAS

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The magnetic field model of the original IFOSIT code was improved by the analytical model of the magnetic field, which takes into account Shafranov shift, elongation, triangularity and up-down asymmetry. The spatial and velocity dependence of the CFP source can be taken into account in the renewed code. New options are employed in renewed IFOSIT: calculation of energy and particle fluxes, calculation of the spatial and velocity distributions of lost and confined particles and time evolution of these distributions.

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INTRODUCTION AND MOTIVATION

The particle transport and the confinement of fusion produced α-particles are important issues for a fusion reactor [1-2]. Resonant magnetic perturbations (RMPs) have become a powerful tool for modifying the edge transport properties and for plasma stability control in present day tokamaks. The application of non-axisymmetric RMP fields in the plasma edge region is a promising technique to suppress and mitigate ELMs for H-mode tokamak plasmas. It is confirmed by experiments on the DIII-D tokamak [3], and later on JET [4] and TEXTOR [5]. The alteration of transport properties of charged fusion products (CFP) induced by these perturbations can be regarded as the crucial point for approving the application of RMPs in future tokamak reactors [6]. Note that strong effect of RMPs on the confinement of NBI ions in ITER have been predicted recently in [7]. Because, a deeper understanding of how RMP fields modify charged particle dynamics; edge transport and stability are needed.

In order to understand the CFP losses driven by RMPs, a specific numerical code IFOSIT (Ion Full Orbit Simulation in Torus) has been developed [8]. The simulation is based on the test-particle approach. To calculate each particle trajectory the numerical solution of the full orbit equation is performed by the Runge-Kutta method. Coulomb collisions in the code are taken into account by a 3D Monte-Carlo operator employing a continuous spectrum of random velocity changes [9].

1. MAGNETIC FIELD MODEL

In current study, magnetic configuration of tokamak is assumed to be axisymmetric with non-circular flux surfaces. The analytical model for such configurations is described in details in [10]. It is supposed that flux surfaces are determined by the parametric dependence of the cylindrical coordinates

$$R(\rho,\chi)=R_0+\Delta(\rho)+\rho\cos(\chi), \qquad (1)$$

$$Z(\rho,\chi)=Z_{ax}-k(\rho)\rho\sin(\chi)\left[1-\Lambda(\rho)\cos(\chi)\right]^{\alpha}, \qquad (2)$$

where R and Z represent the spatial variables of the cylindrical coordinates $\{R,\varphi,Z\}$, ρ and χ represent variables of the new flux-like coordinates $\{\rho,\chi,\varphi\}$ $\Delta(\rho)$, $k(\rho)$ and $\Lambda(\rho)$ are flux surface parameters: the Shafranov's shift, the elongation parameter and the triangularity parameter respectively, and α is a flux surface model parameter, R_0 is vacuum vessel major radius, Z_{ax} is a Z coordinate of the magnetic axis. The coordinate ρ is a flux surface label and its value is equal to distance between the magnetic axis and the flux surface in the equatorial midplane, and χ is the analog of poloidal angle. The angle φ is the toroidal angle, and its value and direction coincide in both coordinate systems $\{R,\varphi,Z\}$ and $\{\rho,\chi,\varphi\}$.

Parameters of the magnetic field model

Parameter name, unit	Parameter value
Vacuum vessel major radius, *m*	$R_0=2.89$
Magnetic axis Z coordinate, *m*	$Z_{ax}=0.323$
Flux surface model parameter	$\alpha=-0.5$
Maximum minor plasma radius in equatorial plane, *m*	$a_{pl}=0.961$
Magnetic axis Shafranov shift, *m*	$\Delta_0=0.11$
Elongation profile parameters	$k_{e0}=1.36$, $k_{e1}=0.315$
Triangularity profile parameter	$\Lambda_{e0}=0.174$
Total poloidal current parameter, *T·m*	$J=-7.58$

Magnetic configuration calculated using parameters given in Table is in good agreement with typical axisymmetric equilibrium magnetic configuration in JET. This model was used in for calculation first orbit loss fluxes in tokamaks with non-circular cross-section, and examples of the flux surfaces, calculated on the basis of this model, can be found in [11].

2. FIRST ORBIT LOSSES OF α-PARTICLES

During the test runs, the dynamics of $D-T$ first orbit losses of $\alpha-$particles was simulated for the cases without RMPs. We assumed that the background plasma consists of the 50 % mixture of D- and T-ions. The number of electrons satisfies the charge neutrality condition $n_e = n_D + n_T$. Also, we assumed that the temperature of ion and electron specie are the same. The radial profiles of density (n_e) and temperature (T_e) of plasma components were chosen in the form $n_e(r) = n_{e0}\left(1-\rho_N^5\right)$ and $T(r) = T_0\left(1-\rho_N^2\right)$, where the subscript "0" denotes on-axis values. Using these radial profiles of the densities and temperatures, the CFP source (reaction rate) profile was calculated (Fig. 1). In order to simplify calculation of the weights, the parabolic fit $S_{fit}(\rho) \propto \left(1-\rho_N^2\right)^5$ was used.

The start positions of the test particles are uniformly distributed in the volume of the plasma trap with the help of the random numbers generator. To each particle the weight was attributed. This weight is proportional to the reaction rate in the region, where test particle starts it motion.

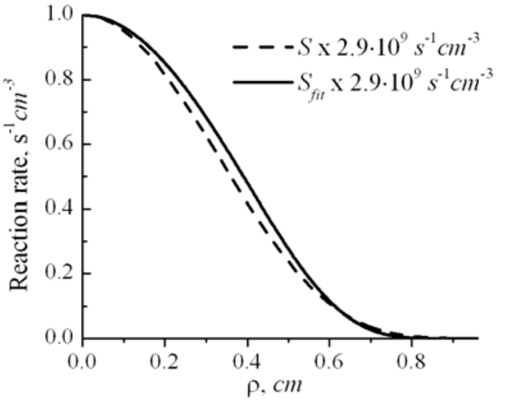

Fig. 1. The reaction rate profiles: calculated and fitted

In velocity space the test-particles were uniformly distributed on the sphere with radius equal to the birth velocity of particles.

We calculated the trajectories of 100'000 particles with next initial parameters: Initial energy (3.5 *MeV)*, velocity distribution (isotropic), simulated time (20x10^{-6} *s*), Runge-Kutta step (1/200 Tc_0) and Monte-Carlo Collisional step (100 Tc_0).

To evaluate the net flux of the lost CFP, we assumed that source is constant in time and used $\Gamma(t) = \frac{1}{t}\int_0^t \left|\frac{dn}{d\tau}\right| d\tau$, which sums the lost rates of fractions of CFP born at different time. The same procedure can be done for density evolution. As far as source is stationary, the net flux reaches the stationary value too. In contrast to density, which is obviously increasing, because only certain part of CFP is lost, and others continue to be confined in trap. The ratio of the lost particles can be easily estimated as 15 % (Fig. 2).

In conclusion, we would like to present the poloidal (Fig. 3) and pitch (Fig. 4) distributions of the lost CFP fluxes. These distributions are in good agreement with simulation results [11, 12], theoretical predictions for the first orbit loss mechanism [11, 13, 14] and results of the experimental study of these losses [15, 16].

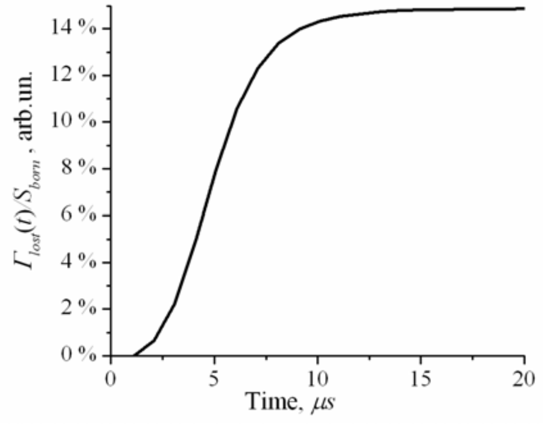

Fig. 2. Flux of lost particles

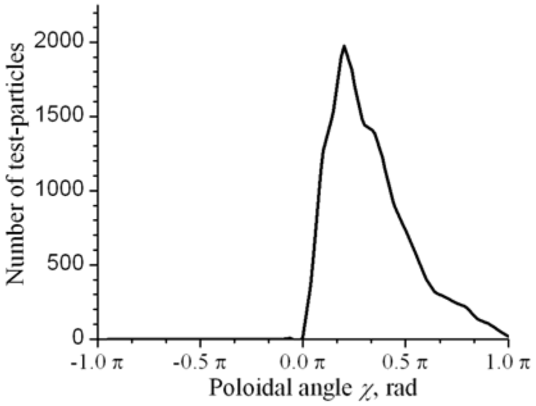

Fig. 3. Poloidal distribution of the flux

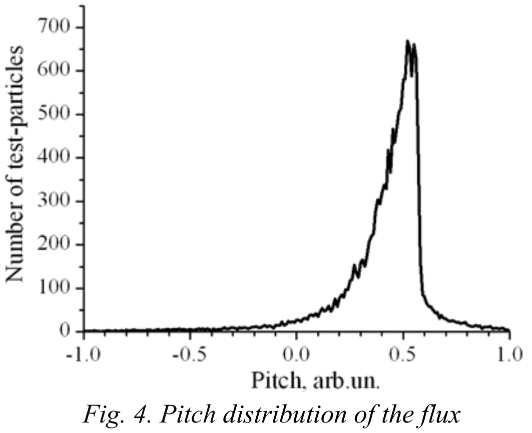

Fig. 4. Pitch distribution of the flux

CONCLUSIONS

The magnetic field model of the original IFOSIT code was improved by the analytical model of the magnetic field, which takes into account Shafranov shift, elongation, triangularity and up-down asymmetry.

The spatial and velocity dependence of the particle source can be taken into account in the renewed code now.

Smooth axially symmetric 2D wall is assumed here.

Optimized calculation procedures gives an opportunity to increase number of particles in simulated ensemble and to estimate statistic uncertainties.

New options are employed in the renewed IFOSIT:

- calculation of the energy and particle fluxes;
- calculation of the spatial and velocity distributions of lost and confined particles;
- the time evolution of the spatial and velocity distributions.

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ПОТОКИ ЭНЕРГИИ И ЧАСТИЦ ПРИ НАЛИЧИИ РМВ В ПЛАЗМЕ ОСЕСИММЕТРИЧНОГО 2D-ТОКАМАКА

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Модель магнитного поля в коде IFOSIT была расширена при помощи аналитической модели магнитного поля, которая учитывает шафрановский сдвиг, эллиптичность, треугольность и асимметрию «верх-низ». В обновленном коде теперь учитывается форма профиля источника заряженных продуктов синтеза как в реальном пространстве, так и в пространстве скоростей. В новой версии кода IFOSIT реализованы новые возможности: вычисление потоков энергии и частиц, расчет распределений теряемых и удерживаемых частиц в реальном и скоростном пространствах и эволюция этих распределений.

ПОТОКИ ЕНЕРГІЇ ТА ЧАСТИНОК ПРИ НАЯВНОСТІ РМЗ У ПЛАЗМІ ВІСЕСИМЕТРИЧНОГО 2D-ТОКАМАКА

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Модель магнітного поля в коді IFOSIT була розширена за допомогою аналітичної моделі магнітного поля, яка враховує шафранівський зсув, еліптичність, трикутність та асиметрію «верх-низ». У оновленому коді тепер враховується форма профілю джерела заряджених продуктів синтезу як в реальному просторі, так і в просторі швидкостей. У новій версії коду IFOSIT реалізовані нові можливості: розрахунок потоків енергії та частинок; розрахунок розподілів у реальному та швидкісному просторах для частинок, які втрачаються, та тих, які утримуються, та еволюція цих розподілів.