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JT-60U トロイダル回転プラズマにおけるタングステン輸送の解析
Analysis of Tungsten Transport in JT-60U Toroidally Rotating Plasmas

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1. Introduction

In JT-60U, it was observed that tungsten accumulation is enhanced with increase in the toroidal rotation in the opposite direction (CTR-rotation) to the plasma current in H-mode plasmas [1]. From theoretical considerations, Hoshino et al. have proposed PHZ pinch and Er pinch model related to toroidal rotation and radial electric field [2]. We have introduced these models in TOTAL code and studied dependence of the tungsten accumulation on the toroidal rotation [3]. We investigated the effect of the PHZ pinch only because the Er pinch model equation was not valid in the experimental conditions. By introducing the PHZ pinch, the larger accumulation observed experimentally at higher toroidal rotation was reproduced in the simulation. However, the dependence on toroidal rotation was weaker in the simulations than in the experiments.

In the experiment, tungsten ions and bulk plasma seem to rotate with the similar speed. In the original PHZ pinch model, however, orbits of tungsten ions are analyzed neglecting the effect of bulk plasma rotation. The plasma rotation causes centrifugal force, which makes poloidal asymmetry in heavy impurity ion density. In fact, it was observed that tungsten ions were concentrated on low field side in JET [4]. In this study, we numerically analyze the PHZ pinch when the centrifugal force is taken into account.

2. PHZ Pinch for Rotating System

It is considered that bulk plasma and tungsten ions rotate at the similar velocity. Considering in a system rotating with bulk plasma (rotating system), tungsten ions are concentrated on low field side on magnetic surface due to the centrifugal force. Thereby the fraction of the trapped particle increases. In this study, radial electric field is not considered as a first step.

In rotating system, the sum of potential energy derived by centrifugal force and kinetic energy is conserved.

$$\mathcal{E} = \frac{1}{2} m_Z (v^2 - R^2 \Omega_*^2) \tag{1}$$

$$\Omega_* = \Omega \left[1 - \frac{Z m_i T_e}{m_Z (T_i + T_e)} \right]^{1/2} \tag{2}$$

Here, the velocity of tungsten ion is thermal speed ($v = v_{th,w}$).

The charge state Z, the position r and poloidal angle θ are given by

$$\frac{dZ}{dt} = \frac{\partial \nu}{\partial T} \frac{\partial T}{\partial r} (r - r_0) + \frac{\partial \nu}{\partial Z} (Z - Z_0) \tag{3}$$

$$\frac{dr}{dt} = v_r = -v_d \sin\theta \tag{4}$$

$$\frac{d\theta}{dt} = \frac{v_\parallel}{q R_0} \tag{5}$$

where ν is reaction frequency ($\nu = n_e (\langle \sigma v \rangle_i - \langle \sigma v \rangle_r)$) and $v_\parallel$ is the velocity parallel to the magnetic field. PHZ pinch velocity in pitch angle ξ ($\xi = v_{\parallel 0}/v$) is given by

$$V_{PHZ} = \langle v_r \rangle = \frac{\int v_r \, dt}{T} \tag{6}$$

3. Result

We numerically calculate the V_{PHZ} for all pitch angles. The plasma parameters were as follows: major radius = 3.35 m, magnetic field = 3.5 T, plasma current = 1.6 MA, neutral beam (NB) heating power = 15 MW. T_e, T_i, n_e and q are taken from experimental data. Figure 1 shows V_{PHZ} at r_0=0.8 m and the particle orbit ($\xi = 0.7$). V_{PHZ} becomes larger with increase in the rotating velocity until $V_t = 0.5 \times 10^4$ m/s. Passing particles have become trapped particles by the effect of centrifugal force. When the fraction of trapped particle is large enough for $V_t >$ 0.5×10^4 m/s, V_{PHZ} almost vanishes. However, the simple average PHZ velocity for all pitch angle $\langle V_{PHZ} \rangle$ does not change very much with increase in the rotating velocity until $V_t = 0.5 \times 10^4$ m/s.

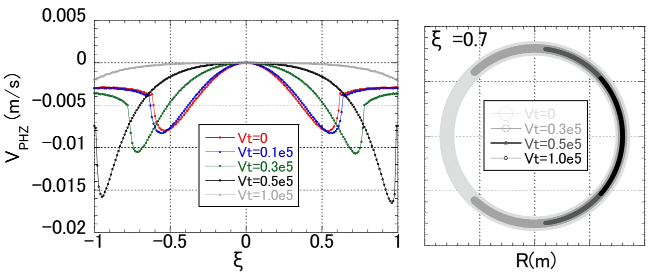

Fig.1 V_{PHZ} for all pitch angles at r_0=0.8 m when the V_t changes and the particle orbit at the each V_t ($\xi = 0.7$)

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