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Analysis of Tungsten Transport in JT-60U Plasmas
JT60 プラズマにおけるタングステン輸送の解析

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In JT-60U, it has been observed that accumulation of tungsten is enhanced with increasing the toroidal rotation in the opposite direction (CTR-rotation) to the plasma current in H-mode plasmas. Two pinch models (PHZ pinch and Er pinch) due to the toroidal rotation and the radial electric field are proposed. We introduce these two pinch models into TOTAL, and study dependence of the tungsten accumulation on the toroidal rotation. In the high toroidal rotation velocity, we obtained the tungsten accumulation four times as large as in the low one. The model reproduces the trend observed in the experiment.

1. Introduction
In tokamak devices, accumulation of impurities from plasma facing materials results in increase in the radiation loss, and dilution of the fuel. Accumulation of tungsten (W) is concerned in particular because of its large radiation loss due to its high atomic number (high Z). In JT-60U, it was observed that accumulation of tungsten is enhanced with increase in the toroidal rotation in the opposite direction (CTR-rotation) to the plasma current in H-mode plasmas [1]. This phenomenon cannot be explained by the conventional neoclassical transport. From theoretical considerations, two pinch models (PHZ pinch and Er pinch) due to the toroidal rotation and the radial electric field were proposed [2]. PHZ pinch is caused by changes in the ion charge state along its drift orbit. Er pinch is caused by the effect of the radial electric field through Coulomb collisions. We have introduced these two pinch models into transport code TOTAL [3] and studied dependence of the tungsten accumulation on the toroidal rotation. We used the experimental data of the 5 cases; shot E049530 t = 7.5 s and t = 9.0 s, E049537 t = 7.5 s, E049538 t = 9.0 s and E049540 t = 9.0 s. The radial profile of plasma toroidal rotation are shown in Fig. 1 for these 5 cases.

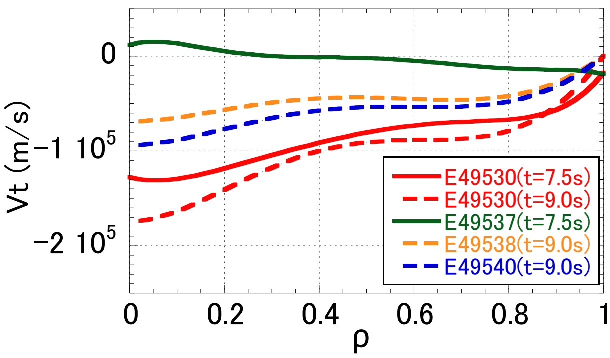

Fig.1. Toroidal rotation profiles

2. Model
The tungsten transport is solved by using the 1.5-dimentinal (1.5-D) transport code 'TOTAL'. Temperature and density profiles are fixed to the experimental values. The tungsten accumulation is evaluated when it reaches steady state. The radial electric field Er is calculated with TOPICS [4].

2.1 Transport Model
The tungsten ion flux on the normalized minor radius ρ is given by

$$\Gamma_k = \Gamma_k{}^{NC} - D_k{}^{AN}\frac{\partial n_k}{\partial \rho} + V_k{}^{\mathrm{pinch}} n_k,$$

$$\Gamma_k{}^{NC} = -D_k{}^{NC}\frac{\partial n_k}{\partial \rho} + V_k{}^{NC} n_k \qquad (1)$$

where Γ_k is particle flux of impurities in the charge state k, n_k is density of impurities in the charge state k. Pinch models with the toroidal rotation is introduced in the V_k^{pinch} term. The neoclassical radial velocity V_k^{NC} and the neoclassical diffusion coefficient D_k^{NC} are calculated by NCLASS module [5] implemented in TOTAL. The anomalous diffusion coefficient D_k^{AN} is assumed to be uniform; the value is 0.01m^2/s.

2.2 Pinch Model

The PHZ pinch velocity is given by the following equation;

$$V_{PHZ} = \frac{{v_{d0}}^2}{2Z_0}\frac{C_T C_{\nabla T}}{{C_Z}^2+\omega^2} \quad (2)$$

where v_{d0} is the magnetic drift velocity, ω is the angular frequency of the poloidal motion of tungsten ions ; $\omega = (V_t - E_r/B_\theta)qR_0$, $C_T = \partial n_e(\langle\sigma v\rangle_i - \langle\sigma v\rangle_r)/\partial T$, $C_Z = \partial n_e(\langle\sigma v\rangle_i - \langle\sigma v\rangle_r)/\partial Z$, $C_{\nabla T} = dT/d\rho$. The ionization rate $\langle\sigma v\rangle_i$ and the recombination rate $\langle\sigma v\rangle_r$ are taken from [6].

The Er pinch velocity is given by following equation;

$$V_{Er} = \frac{(1-2\alpha)k{\Delta_0}^2}{2(1-\alpha)^3}\frac{\nu_c}{1+(\nu_c/\omega)^2} \quad (3)$$

where $\alpha = E_r/B_\theta V_t$, $k = ZeE_r/(m{V_t}^2)$, $\Delta_0 = v_{d0}/\omega_0$, ν_c is the collision frequency of the impurity with the background plasma. The above formula is valid when $\alpha < 1$, and $2k\Delta r < 1$.

3. Results

3.1 Pinch Velocity

Figure 2 shows the radial velocity of PHZ pinch estimated for the 3 cases (t=9.0s). For these three cases and also the other two cases, $\alpha > 1$ over the entire range and Er pinch model is not applicable. Thus, we calculate the tungsten accumulation setting $V_{Er} = 0$ in this study.

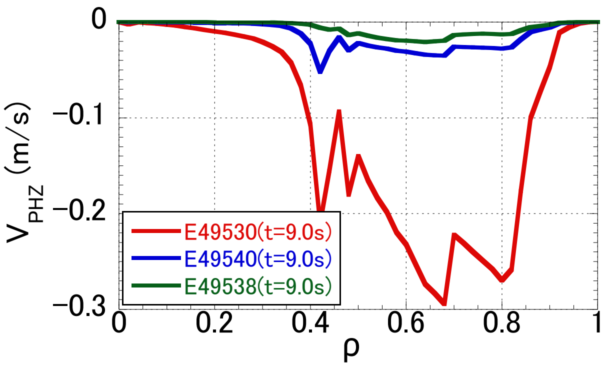

Fig.2. radial velocity of PHZ pinch (9.0s)

PHZ pinch has a peak value at ρ=0.4-0.8, where ω is nealy zero due to the Er.

3.2 Tungsten Accumulation

Figure 3 shows the dependence of the tungsten accumulation on the plasma toroidal rotation. The influx of tungsten is assumed to be constant

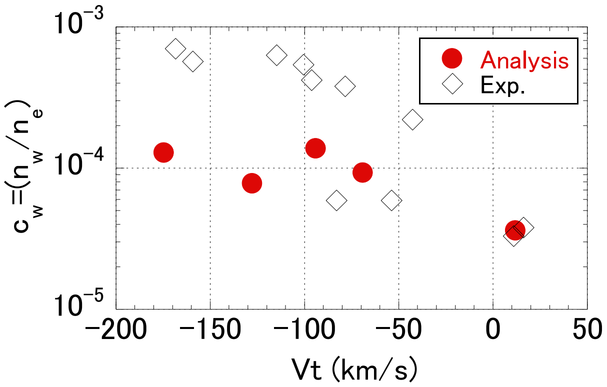

Fig.3. the dependence of the tungsten accumulation on the toroidal rotation

In the high rotation case, the tungsten accumulation is about four times as large as in the low rotation case. Compared with the experimental value shown by open diamonds, dependence of tungsten accumulation on the plasma rotation speed is small. However, the model reproduces the trend observed in the experiment.

4. Future Plan

In the CO-rotation, it has been observed that tungsten is not accumulated very much. The reason is that PHZ pinch and Er pinch cancel each other. Thus, further validation in such as the CO-rotation case are required.

Acknowledgments

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Reference

[1] T.Nakano, J. Nucl. Mater. 415, S327-S333 (2011)

[2] K.Hoshino, et al., Nucl. Fusion **51**, 083027 (2011)

[3] K.Yamazaki and T.Amano, Nucl. Fusion **32**, 633 (1992)

[4] H.SHIRAI, et al., Nucl. Fusion **39** 1713 (1999)

[5] W.A.Houlberg, et al., Phys. Plasma **4**, 3230 (1997)

[6] OPEN-ADAS, http://open.adas.ac.uk/