§19. Modeling of Pellet Ablation and Deflection for the Pellet Injection Experiments in LHD

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Pellet injection is a promising fueling scheme for achieving high-density operation relevant to fusion reactors. In the LHD experiment, the sustainment of a high-density core plasma is successful with direct fueling inside the last closed flux surface by the pellet injection [1]. Although detailed mechanism of material deposition has not been elucidated in the LHD, the experimental scaling of pellet penetration has suggested that fast ions produced by NBI heating whose beam energy is of 150-180 keV play a key role in determining the initial deposition of pellet material [2]. In earlier work, the experimental penetration and ablation profiles have been compared with the numerical code, ABLATE [3], which is based on the conventional neutral gas shielding (NGS) model. However, the recent study [4] has clarified that the NGS model provides a limited physics picture of ablation of pellets injected to magnetically confined plasmas. In the present work, we introduced the HPI2 code [5] to analyze the particle deposition process in the LHD experiment, which has been developed for the modeling of pellet fueling in axisymmetric tokamaks on the basis of well-established ablation and four fluids Lagrangian drift theories.

We have investigated the ablation process including interaction between the pellet and fast ions produced by high-energy NBI heating. The numerical code was extended to take into account realistic 3-D geometry of LHD plasmas, which enables us to properly interpret the experimental penetration and ablation profile evaluated from duration of the H_α line emission. Additionaly, the pellet motion inside the last close flux surfaces is solved numerically with toroidal deflection due to rocket effects during unbalanced NBI heating. [6]

The code prediction was compared with ablation behavior of a number of well-documented pellets in the LHD database. Figure 1 shows the comparison of ablation profiles for discharges with high ($W_{fast}/W_{dia} > 5\%$) and low ($W_{fast}/W_{dia} < 5\%$) beam stored energy as functions of the distance from the last closed flux surface, where W_{fast} is the stored energy of beam component and W_{dia} is the plasma stored energy. For both cases, the good agreement has been obtained between the prediction and the H_α emission. For these shots, penetration depth of the pellets is 50-70% of estimate by the model neglecting fast-ion ablation. The analysis of the shielding effect of ablation cloud and of electrostatic sheath clarifies that fast ions penetrate deeply into the ablation cloud and reach the pellet surface, which yield the significant enhancement of the ablation rate.

The simulation of pellet motion during one-sided NBI heating is compared with the pellet location diagnostics using the fast-imaging cameras with the stereo method in Figure 2. Our simulation is based on the unbalance ablation equation that was proposed to interpret the toroidal deflection due to plasma current in ohmic tokamaks. The simulation resonably reproduces the pellet trajectories that are curved in direction of the neutral beam injection. The calculated pellet acceleration is of the order of 10^6 m/s^2, which is consistent with the observation. Our results support that the enhancement of ablation rates on the pellet surface exposed to fast-ion fluxes and the associated unbalance of the ablatant flows near the pellet are the cause of the deflection phenomena.

In summary, the modeling of pellet fueling in the LHD has been improved by appliying the state-of-the-art ablation code developed for axisymmetric tokamaks. The realistic 3-D geometry was taken into account and the comparison with experiments was successfull for the pellet penetration and ablation profile for typical pellet and plasma parameters.

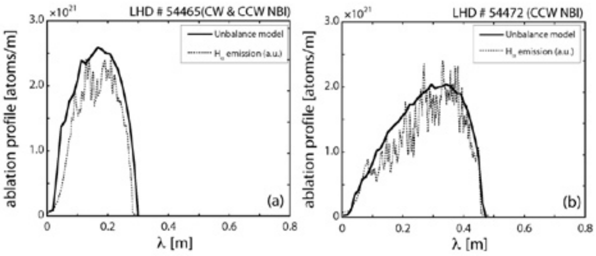

Fig. 1. Ablation profiles of the pellets injected into discharges with high and low beam stored energy.

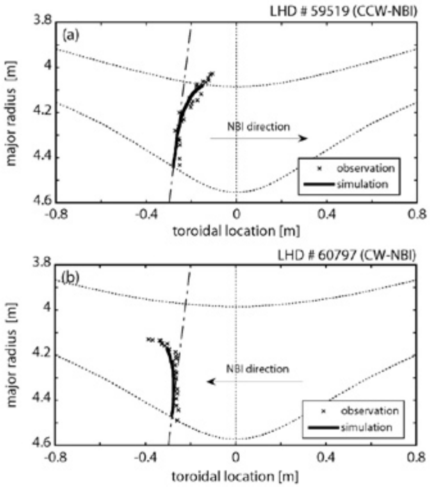

Fig. 2. Comparison between the simulated pellet trajectories and the observation.

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