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Characterization of solid hydrogen-pellet penetration in fusion plasmas of the large helical device

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Characteristics of penetration depth and velocity of solid hydrogen-pellet are discussed with the results from the large helical device (LHD) experiment.

The solid hydrogen pellet injection is a promising method for fueling to maintain the fusion plasmas confined by the magnetic field. This method is expected to be highly efficient direct fueling for future large-scale fusion reactors since pellets penetrate into a core region beyond a hot scrape-off layer. Fuel particles are deposited in the core region through the ablation of pellets and the following drift motion of high-density plasmoid. Therefore, the integrated understanding of physical properties such as pellet velocity and mass, target plasma parameters, and the operational magnetic field is a prerequisite for establishing control of the fueling position. The aim of this study is the comprehensive characterization of the penetration of the pellet and resultant fuel deposition.

The experiment with pellet injection was conducted by varying the target plasma conditions in the LHD. Through these, a data set consisting of parameter regions and pellet velocities over a wide range of plasma temperature and density, magnetic field strength, and ECH/NBI heating power was created. The neutral gas shielding (NGS) model [1] has been used as a basic theoretical prediction model for pellet ablation. According to this theory, a representative NGS model scaling law for LHD was derived based on the NGS model using the modeled electron temperature and density profiles as shown in Eq. (1).

$$\lambda /a = 0.027 T_{e0}^{-0.62}\ n_{e0}^{-0.13}\ V_p^{0.34} \quad (1)$$

where λ /a, T_{e0}, n_{e0}, and V_p are the penetration length normalized by plasma minor radius, electron temperature, electron density, and pellet velocity. The negative dependence of this scaling law on electron temperature and density and the positive dependence on pellet velocity agree with the expression obtained by Baylor et al. [1]. Figure1 demonstrates a comparison between the experimental data and the predictions of the scaling law for the LHD plasmas. A systematic difference between the NBI-heated plasmas and the ECH-heated plasmas is observed, which is potentially attributed to the presence of fast ions from the NBI.

Furthermore, a regression analysis was performed on the dependence of the pellet penetration length including the magnetic field strength B and the fast ion density $\boldsymbol{n_{f.ion}}$, which have not been treated in the NGS model, for the NBI-heated plasma, resulting in Eq. (2) (see Fig.2).

$$\lambda /a \propto T_{e0}^{-0.30}\ \bar{n}_{e0}^{-0.19}\ V_p^{0.24} B^{0.38}\ n_{f.ion}^{-0.25} \quad (2)$$

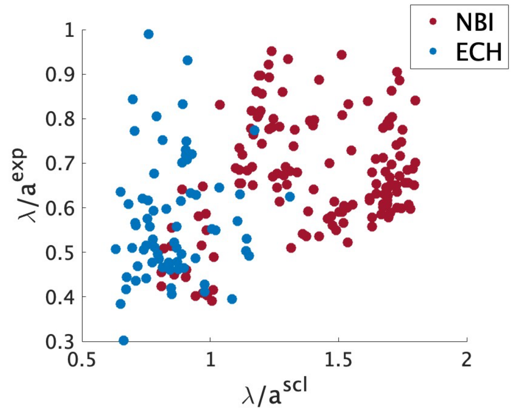

Fig. 1 Comparison of pellet penetration length between the experiment and prediction from the scaling of LHD (Eq.(1)).

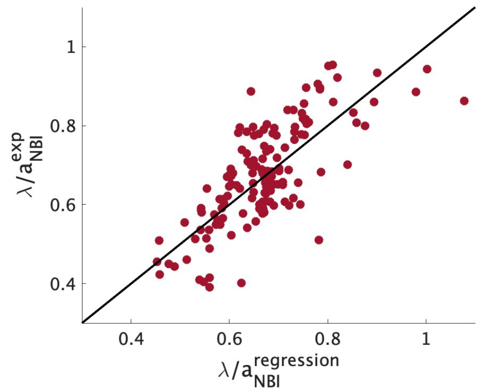

Fig. 2 Comparison of pellet penetration length between experimental and scaling law values in NBI-heated plasmas(Eq.(2)).

The dependence on temperature, density, and velocity is in qualitative agreement with the results of Baylor et al. In addition, significantly, positive magnetic field dependence and negative fast ion density dependence were also obtained. This suggests that the fast-ion elution by NBI is related to the shielding properties of the plasmoids, which are constrained by the magnetic field. The scaling is further discussed with the results from the numerical computation with HPI2 code [2].

References

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