§47. Penetration Depth of Solid Hydrogen Pellets in LHD Plasmas

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In LHD, solid hydrogen pellet injection experiments have been performed to demonstrate high fuelling efficiency and capability to control electron density. It is necessary to clarify a physical mechanism in the ablation process of injected pellets to optimize the pellet injection scheme and develop the prospect of particle fuelling for a future reactor. An initial systematic study of the pellet penetration depth and its modeling is reported here.

Data of pellet penetration depth of hydrogen pellets injected into NBI heated plasmas in the standard magnetic configuration (R_{ax}=3.6m, $B_t \geq 2T$) are analyzed. The measured penetration depth is determined from the duration of H_α emission and the assumption of a constant pellet velocity which is measured by the time of flight prior to injection. The experimental results are compared with theoretical prediction of the neutral gas shielding (NGS) ablation model. This model is that the pellet is shielded from the incident electron heat flux by a surrounding neutral cloud ablated from the pellet surface. The recession speed of the pellet surface is given by

$$dr_p/dt \propto r_p^{-2/3} n_e^{1/3} T_e^{1.64}.$$

By assuming linear profiles for the electron temperature and density, the NGS scaling is given by the follow form,

$$\lambda/a = 0.079 T_e^{-5/9} n_e^{-1/9} m_p^{5/27} v_p^{1/3},$$

where λ/a, T_e, n_e, m_p and v_p are the penetration depth normalized by the plasma minor radius, the central electron temperature, the central electron density, the pellet mass and the pellet velocity, respectively. This scaling well agrees with experimental results in tokamaks.

Figure 1 shows a comparison of the measured penetration depth with the NGS scaling. The pellet velocity is scanned from 300 to 1000 m/s and the pellet mass is assumed to be constant (m_p=3x10^{20}atoms) from the shadowgraph measurement of the pellet. Pellets that penetrate beyond the magnetic axis are excluded. The experimental observation shows that the penetration depth is shallower than the NGS scaling and this trend looks larger for deeper fueling cases. One possible cause of this deviation is an effect of fast ions on ablation since the energy flux of the incident fast ions is significantly larger than the energy flux of the incident electron at ablation region in the present experimental condition (typically $q_{beam}/q_e > 20$).

The ablation rate of the pellet including contribution of fast ions to the ablation is calculated by means of the ABLATE code. Here the density profile of fast ions is calculated by the FIT code. A comparison of the measured penetration depth with that from ABLATE (with and without fast ions) is shown in Fig. 2. The penetration depth of the model including the effect of fast ions on ablation gives much better agreement with the measured one.

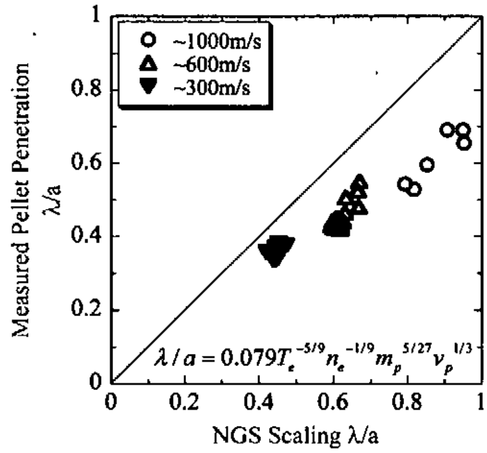

Fig. 1. Comparison of measured penetration depth with NGS scaling.

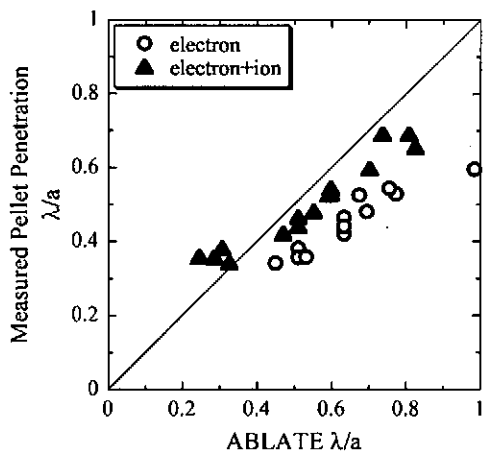

Fig. 2. Comparison of the measured penetration depth with the penetration depth using ABLATE (with and without the effect of fast ions on the ablation).

References

1) Nakamura, Y. et al. : Nucl. Fusion **26** (1986) 907.

2) Murakami, S. et al. : Fusion Eng. Design **26** (1995) 209.