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Ablation and Subsequent Density Redistribution of Fueling Pellets Injected into LHD Plasmas

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1. Introduction

Pellet fueling has extended the operational region of the Large Helical Device (LHD) plasmas to higher densities, which cannot be attained by gas puffing while maintaining favorable dependence of the energy confinement on the density. However, deterioration of the effective fueling efficiency was observed with increasing heating power and/or plasma temperature. Our previous study has made it clear that the deterioration is due to fast time scale (within several 100 μs) outward density redistribution just after pellet ablation[1]. Similar deterioration is observed in tokamaks with the magnetic low-field-side (LFS) pellet injection, but significant improvement in fueling efficiency has been demonstrated with the magnetic high-field-side (HFS) pellet injection[2][3] in recent tokamak study. The mechanism for the improvement is not yet elucidated but could be caused by an E×B drift that arises from a vertical polarization of ablation cloud due to a ∇B and curvature drift[4]. This tokamak's success motivated studies to optimize injection location on LHD. Noticing the difference between tokamak and LHD on the magnetic structure, pellet injection experiments from the different locations have been carried out on LHD for the purpose of investigating effect of the magnetic structure on the density redistribution.

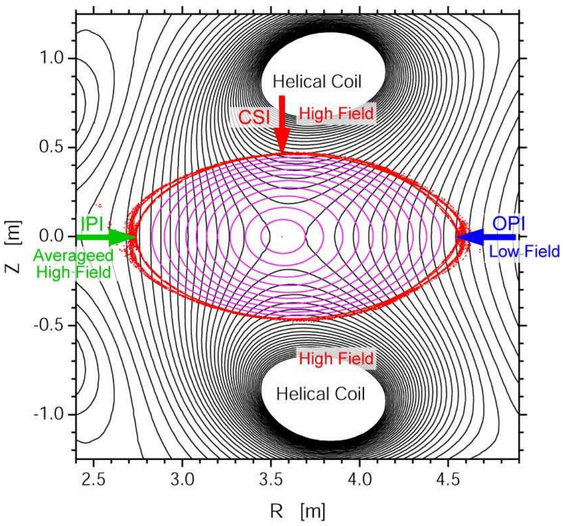

Fig. 1 *Magnetic field structure and schematic view of pellet injection location in LHD.*

2. Magnetic Field Structure and Pellet Injection Locations

Experiments were carried out on LHD, a heliotron type magnetic confinement device with continuous winding super-conducting coils. The major radius, averaged minor radius, magnetic field and plasma volume are 3.9 m, 0.6 m, 2.9 T and 30 m^3, respectively. Because the external coils, namely, a pair of helical coils establish magnetic confinement field, there are the following remarkable magnetic structures on LHD, (1)Fully negative shear and large rotational transform (q<1) at the plasma boundary, (2)saddle point of the magnetic field exist in the plasma center, (3)two kind of the HFS can be defined, i.e. the toroidal averaged-HFS and the local-HFS.

The injection locations are shown in fig. 1. The OPI (outer port injection) is injection from the torus outside and equal to the LFS on tokamak. The IPI (inner port injection) is injection from the averaged-HFS. CSI (coil side injection) is injection from the local-HFS. Typical pellet speed is 1200 m/s at conventional OPI, but because the pellet speed is limited in the curved guide tubes, only slow (up to 300 m/s)[5] pellet injection is available at alternative injection. Specially modified injector with mechanical punch was employed for slow pellets acceleration.

3. Experimental Results and Discussion

Typical temporal changes of electron density and ablation light (H_α intensity) for the high speed OPI case are shown in fig. 2. Line averaged electron density is divided into two part, core density $\bar{n}_e^{core}$ (ρ<0.7) and boundary density $\bar{n}_e^{boundary}$ (ρ>0.7), using multi-chord interferometer. The densities increase during ablation, and then core density begins to decrease just after pellet ablation, whereas boundary density increases continuously. This behavior suggests density redistribution of the core into boundary. The time scale of such density redistribution is several 100 μs.

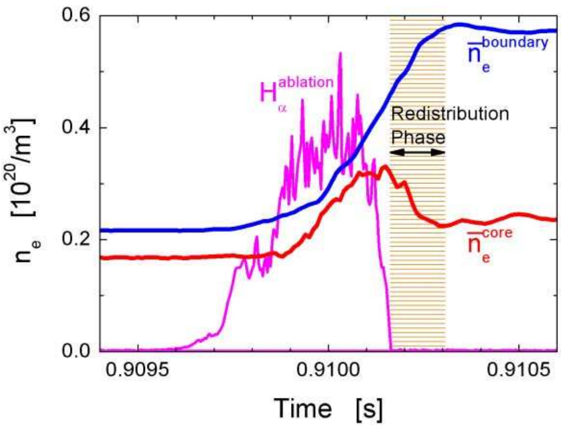

Fig. 2 *Temporal changes of electron density and H_α intensity at the high speed OPI case.*

Predictive pellet deposition profile, which is calculated from the NGS model using ABLATE code[6], is shown in fig. 3. As for alternative injection with slow pellets, a penetration depth of the pellet is shallower than high speed OPI. A temporal changes of electron density and

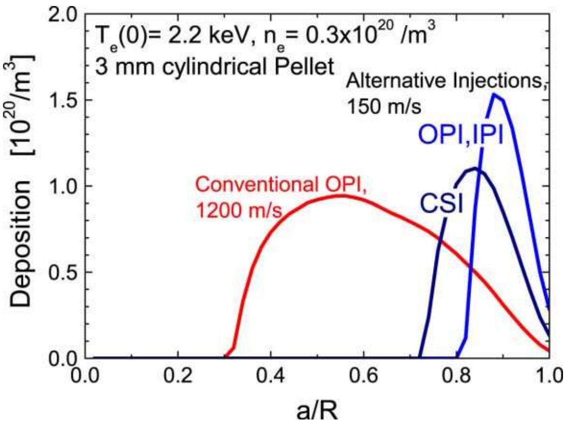

Fig. 3 *Predictive penetration depth from the NGS model.*

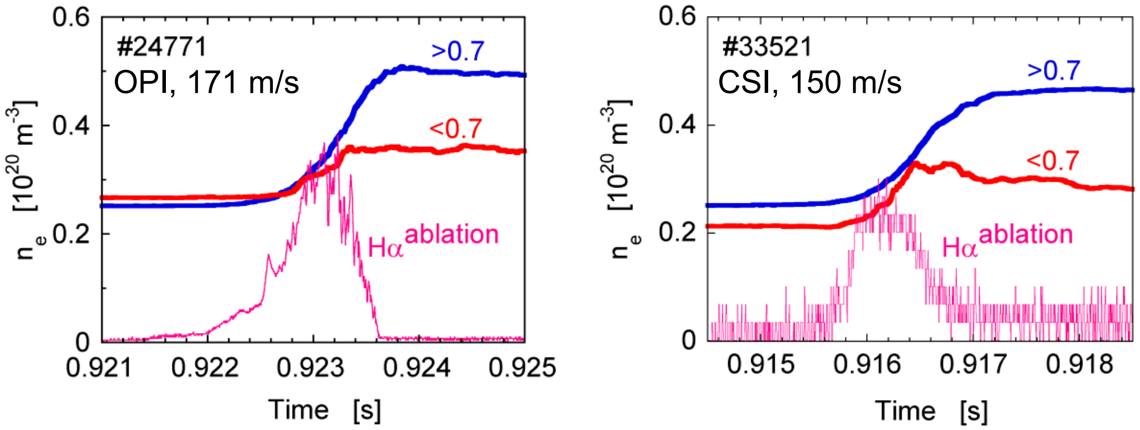

Fig. 4 *Temporal changes of the electron density and H_α intensity at the low speed OPI and CSI.*

ablation light (H_α intensity) for the CSI and OPI are shown in fig. 4. The penetration depths, which are estimated by duration of H_α emission from the ablating pellet, are 0.28 m (OPI) and 0.18 m (CSI). Considering the ablation in an elgodic layer, this penetration depth is consistent with the predicted value from the NGS models. Looking at the contour plot of the magnetic field intensity on poloidal section (fig. 1), OPI and CSI are obviously different from each other in the gradient of the magnetic field. From the direction of ∇B, we have expected preferable density redistribution on CSI case. However the evident density redistribution is not observed on CSI. Though this result is quite different from the behavior in tokamaks, we tried to understand this result from the viewpoint of the E×B drift model.

In consideration of the axis asymmetric field structure on LHD, E×B drift direction on the field line was calculated. For the qualitative discussion, only direction of vector was calculated,

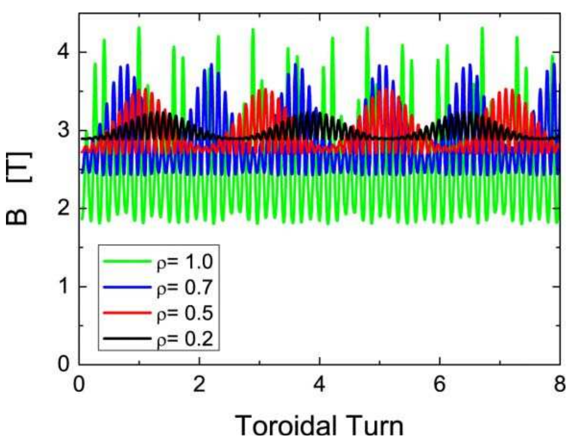

Fig. 5 *Plot of the magnetic field strength versus toroidal turn on the flux surface of ρ=1.0, 0.7, 0.5, 0.2.*

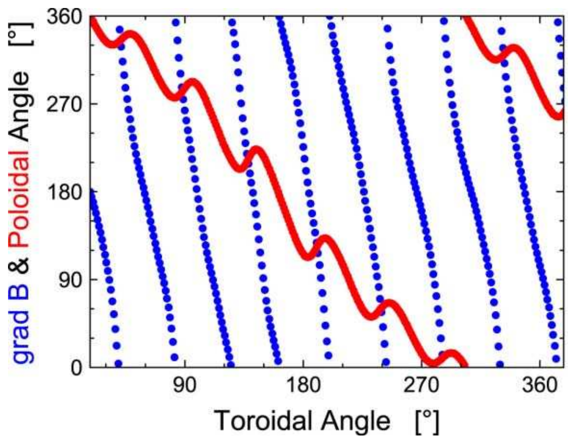

Fig. 6 *Plot of the ∇B direction (same definition as poloidal angle) and poloidal angle versus toroidal angle on the flux surface of ρ=0.9.*

i.e. $\mathbf{E}\times\mathbf{B} \approx -c(\mathbf{B}\times\nabla B)\times\mathbf{B} = -\nabla B$. Fig. 5 shows a plot of the magnetic field strength versus the toroidal turn on the flux surface of ρ=1.0, 0.7, 0.5, 0.2. Due to helical coils, there are helical ripples and large rotational transform at the plasma boundary region where the slow pellet ablates. Therefore the magnetic field strength alternate drastically with short period, while these effect become moderate in the core region of the plasma. The ∇B direction and poloidal angle at the point along the field line that begins at the ablation region of the slow pellet (ρ=0.9), is shown in fig. 6. ∇B makes 9 revolutions during one toroidal turn, i.e. direction of the ∇B polarization alternates with each 1 m moving of the pellet cloud along the field line. Therefore electric field, which drives the density redistribution, cannot be formed sufficiently in the pellet cloud. In addition, large rotational transform rapidly even out the influence of injection location on the density redistribution. Thus the density redistribution behavior on LHD can be understood qualitatively from the E×B drift model.

As for high speed OPI case, helical ripples and rotational transform at the ablation region are relatively small since the pellet ablates in the core region. Thus similar density redistribution to tokamaks could be observed.

4. Summary

Pellet injection experiments from the different locations have been carried out on LHD. Obviously density redistribution that observed in the high speed pellet case did not appear in any alternative pellet injection case. The result looks different from tokamaks, however the behavior could be understood qualitatively from the same E×B drift model.

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