Direct Observation of Inward Electron Flux being Blocked in the Large Helical Device

Kazumichi NARIHARA, Ryuichi SAKAMOTO, Ichihiro YAMADA, Hisamichi FUNABA, Mamoru SHOJI, Masayuki YOKOYAMA, Hiroshi HAYASHI and the LHD Experimental Group

National Institute for Fusion Science, Toki 509-5292, Japan

(Received 11 January 2006 / Accepted 23 March 2006)

We present a particle transport phenomenon caused by a hydrogen ice pellet injection (PI) into the Large Helical Device. The electron density (n_e) profile evolution after a PI was measured by using a 200-channel Thomson scattering diagnostic. The highly hollow n_e-profile caused by a PI faded out as time elapsed with a very slight increase in the n_e at the core region, giving a direct evidence for the inward electron flux being almost completely blocked in the core region.

Keywords: particle transport, anomalous convection, pellet injection, LHD, Thomson scattering

DOI: 10.1585/pfr.1.023

The nature of particle transport in magnetic confinement devices is still a riddle. In tokamaks, the shape of electron density profiles is peaked even when the neoclassical Ware pinch is absent [1], indicating anomalous convection. Likewise, particle transport in the Large Helical Device (LHD) is anomalous [2]. In this *Rapid Communication,* we present a relevant particle transport phenomenon caused by a pellet injection into the LHD.

The plasma (#56112) that we present here was created by ECH in a vacuum magnetic configuration with the magnetic axis at 3.6 m and field intensity 2.75 T, heated by 1.3 MW NBI, and fueled by repetitive solid hydrogen pellets. A multi-channel Thomson scattering system was used to measure the evolution of the electron temperature (T_e) and density (n_e) profiles in response to the NBI and pellet injection (PI). Figure 1 shows eight successive snapshots measured every 0.1 s. Before the PI, the T_e-profile shape was a triangle and the n_e-profile shape was slightly hollow. The pellet entered at approximately 2.45 s. Just after the PI, the n_e-profile evolved to a deep hollow in the shape of a cat's head. The difference in size between the right and left cat's ears is probably due to laser misalignment, which makes the n_e calibration somewhat incorrect and linearly deforms the n_e-profile, which, however, has only a small effect on the following results. The T_e-profile just after the PI shrunk slightly but soon regained its initial triangular shape. The n_e-perturbation caused by the PI apparently did not propagate into the core region. To see this more clearly, we over-plot the n_e-profiles between two PIs in Fig. 2. One can see that particles diffusing into the core region were almost blocked up to the surface intersecting at $R = 3.2$ m and 4.0 m. Only a small amount of particles (< 10%) entered the core region just after the PI and resided there for a longer time, thus boosting the background profile as a whole. Except this small increase, the n_e-profile regained almost the same shape as before the PI.

We examine the above blocking phenomenon somewhat quantitatively. Assuming the usual form of the particle flux $\Gamma = -D\nabla n_e + V n_e$ with assumed diffusion coefficient D and convection velocity V, we follow the left-side n_e-profile after 2.47 s (2nd frame) by solving $A\partial n_e/\partial t = \partial(A\Gamma)/\partial\rho$, where ρ is the minor radius and $A(\rho)$ is the area of the flux surface. Here we drop the source term, since at 2.47 s, 20 ms after PI, the injected hydrogen atoms were almost completely ionized and hence the particle source localized at the plasma edge had no influence on the evolution of the perturbed n_e-profile. The simplest model of $(D, V) = (\text{constant}, 0)$ hardly reproduces the observed n_e-profile evolution. As shown in Fig. 3 (A), the fit

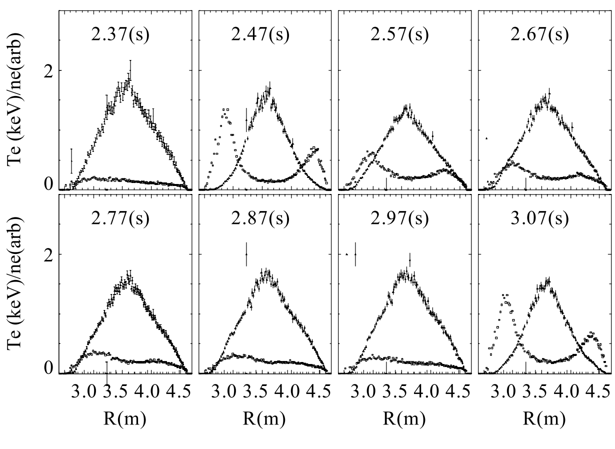

Fig. 1 T_e (triangle) and n_e (hollow) profiles every 0.1 s. Pellet entered at 2.45 s. The n_e lies in the 10^{19}m^3 range.

author's e-mail: narihara.kazumichi@LHD.nifs.ac.jp

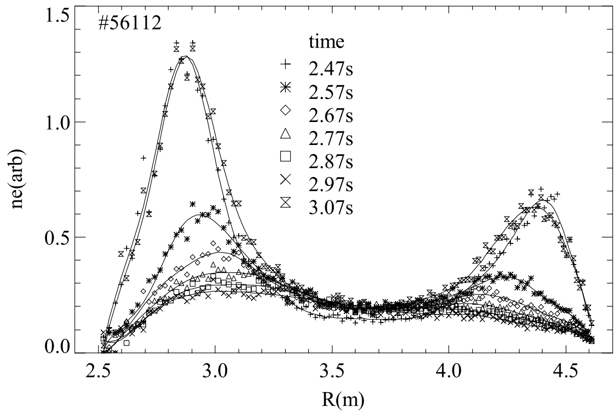

Fig. 2 Evolution of n_e-profile between two pellet-injections.

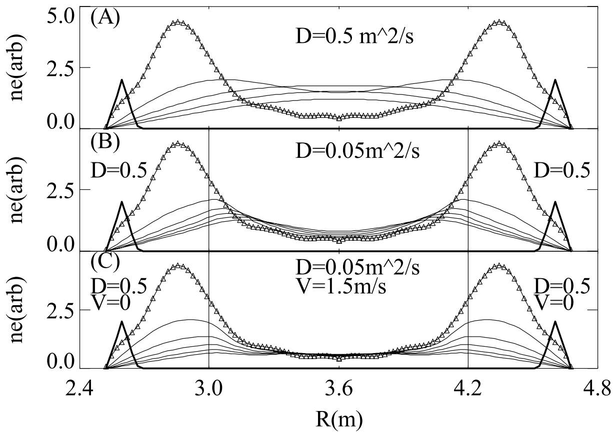

Fig. 3 Calculated n_e-profile evolutions every 0.1 s after a pellet injection: for (A) uniform $D = 0.5\,\mathrm{m}^2/\mathrm{s}$; (B) an 'ITB' with 10-times insulation; (C) the 'ITB' plus an outward convection. The right side of each figure is a reflection of the left with the plane of symmetry at $R = 3.6$ m. The triangles at the edges are the estimated source profile.

with $D = 0.5\,\mathrm{m}^2/\mathrm{s}$ inevitably accompanies an in-going n_e-perturbation. This inward propagation is hindered by deliberately lowering the D in the inner region, which mimics an internal transport barrier (ITB) as shown in Fig. 3 (B).

One can better reproduce the observation by choosing a two-valued (D, V) combination:

$D = 0.5\,\mathrm{m}^2/\mathrm{s}$, $V = 0$ m/s in the outer region,
$D = 0.05\,\mathrm{m}^2/\mathrm{s}$, $V = 1.5$ m/s in the inner region,

as shown in Fig. 3 (C). Here the boundary between the inner and outer regions is guessed to be at $R = 3.0$ m and 4.2 m, which are marked in the figure by vertical lines.

For the sake of discussion, we split Γ into two parts: one is the neoclassical flux, which is well formulated and expressed as [3]

$$\Gamma_{\mathrm{nc}} = -n_e D_{\mathrm{nc}}(\nabla n_e/n_e - eE_r/T_e + y\nabla T_e/T_e), \qquad (1)$$

where e is elementary charge, E_r is radial electric field, and y is a constant of $O(1)$; the other is the anomalous flux expressed as $\Gamma_a = -D_a\nabla n_e + V_a n_e$ with anomalous diffusion coefficient D_a and convection V_a. Defining $\xi = (D_a + D_{\mathrm{nc}})/D_{\mathrm{nc}}$ and neglecting E_r, which is slightly negative for the present case, we have the total flux

$$\Gamma = -n_e\xi D_{\mathrm{nc}}(\nabla n_e/n_e + y\nabla T_e/(T_e\xi)) + V_a n_e. \qquad (2)$$

The GSRAKE-transport-code [3] yields $D_{\mathrm{nc}} = (13.5, 8.1, 5.3, 4.3) \times 10^{-3}\,\mathrm{m}^2/\mathrm{s}$, $y = (3.1, 2.9, 2.5, 2.4)$, $\xi = (3.7, 6.2, 9.4, 11.6)$ for $n_e = (0.8, 1.7, 3.3, 5.0) \times 10^{19}\mathrm{m}^{-3}$, respectively, and $T_e = 500$ eV around $R = 3.0$ m. Using these numerical values, we estimate the first term in Eq. (2). During the evolution, $\nabla n_e/n_e$ at $R = 3.0$ m decreased from $3.75\,\mathrm{m}^{-1}$ to $1.0\,\mathrm{m}^{-1}$, while $\nabla T_e/T_e$ was held constant at $\sim -3\,\mathrm{m}^{-1}$. For example, at $t = 2.57$ s and $R = 3.0$ m, $n_e \sim 3.3 \times 10^{19}\mathrm{m}^{-3}$, $\nabla n_e/n_e = 1.9\,\mathrm{m}^{-1}$, and $y\nabla T_e/(T_e\xi) = -0.75$. Thus the neoclassical outward flux $-n_e D_{\mathrm{nc}} y\nabla T_e/T_e$ is not sufficient to block the inward diffusion flux $-D\nabla n_e$. This imbalance, though decreasing, continued during the evolution.

This work is supported by NIFS under Contract NIFS05ULHH502, and by JSPS under Contract 14380221.

[1] G.T. Hoang, Phys. Rev. Lett. **90**, 155002 (2003).
[2] K. Tanaka *et al.*, Nucl. Fusion **46**, 110 (2006).
[3] C.D. Beilder and W.D. D'haeseleer, Plasma Phys. Control. Fusion **37**, 463 (1995).