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Toroidal plasma flow and radial electric field structures at the separatrix in JT-60U ELMy H-mode plasmas

JT-60UのELMy Hモード境界層におけるトロイダルプラズマ流と径電場構造

Kensaku Kamiya, Mitsuru Honda, Hajime Urano, Maiko Yoshida and Yutaka Kamada

神谷健作, 本多充, 浦野創, 吉田麻衣子, 鎌田裕

Japan Atomic Energy Agency (JAEA), Naka, Ibaraki-ken 311-0193, Japan

日本原子力研究開発機構 那珂核融合研究所 〒311-0193 茨城県那珂市向山801-1

Boundary condition of the toroidal plasma flow of fully stripped carbon impurity ions (V_ϕ^{C6+}) and radial electric field (E_r) in the JT-60U tokamak peripheral region imposed at the separatrix in ELMy H-mode plasmas has been identified, comparing between co- and counter-NBI discharges. We found that the V_ϕ^{C6+} value at the separatrix is not held fixed at the zero, varying with momentum input direction, but being not strongly affected by the ELM event. Improved understanding of physics process in pedestal structure formation for the V_ϕ^{C6+} and E_r is also discussed.

1. Introduction

The plasma toroidal and/or poloidal flows play a key role for plasma stability and enhanced plasma confinement [1]. The phenomenon of spontaneous flow is observed in nearly all tokamaks, in which there is a strong (and/or complex) relationship between the core and edge regions.

Intrinsic plasma flows will dominate in future burning plasma experiments, such as ITER or DEMO, since the external momentum input by neutral beam injection (NBI) will be less effective. Therefore, understanding the origin of spontaneously generated plasma flows is a key finding for controlling future reactors.

With regard to determining the E_r structure at the pedestal region, we utilized the fitting curve for identifying the plasma flow structure to evaluate the E_r component of the toroidal velocity term in previous study on JT-60U for the FY2007-2008 experimental campaign, since the toroidal viewing array was discretely arranged rather than that of poloidal one [2]. We apply a novel diagnostic for the toroidal plasma flow measurements system with high spatial resolution (termed as Modulation Charge eXchange Recombination Spectroscopy, MCXRS), in which the object lens in front of the optical fiber bundles could be shifted by 0.5 mm with a Piezo-element using a cosine wave modulation frequency up to 30 Hz, and hence we could obtain the spatial information instead of plasma position sweep with respect to the diagnostic points [3].

2. Experimental setup

We performed the following NBI heating experiments, comparing the external momentum input directions between co- (discharge E049228) and counter- (discharge E049229) cases under a matched plasma shape condition; The plasma current, I_P, was 1.6 MA, and the toroidal magnetic field, B_T, was 3.9 T. The corresponding safety factor at the 95% flux surfaces, q_{95}, was thus 4.2.

One of the main targets in this study is established Type-I ELMy H-mode plasmas with ELM frequency of f_{ELM} ~ 30 to 50 Hz. Comparing between co- and counter-NBI discharges, we found that somewhat smaller and frequent ELMs in counter-NBI discharge than that of co-NBI discharge during high power (11-12 MW) H-mode phases at t = 6.0 ~ 7.3 s.

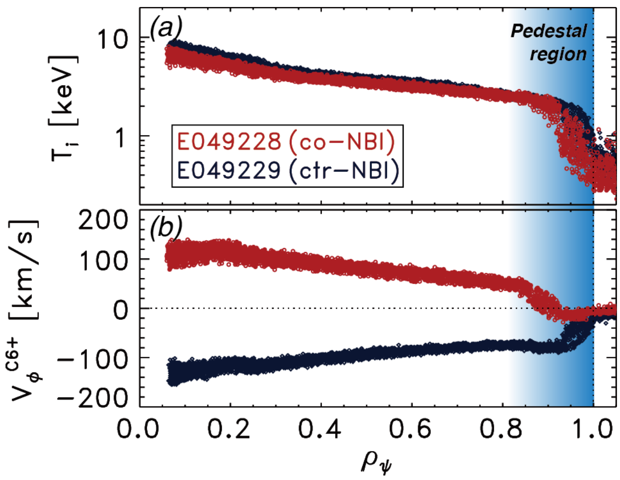

Fig.1. Radial profiles of (a) ion temperature and (b) toroidal plasma rotation velocity for carbon impurity ions measured by the Modulation CXRS system during an inter ELM phases from t = 6.0 ~ 7.3 sec (All sampling data are overlaid) as function of the poloidal flux normalized to one at the separatrix, comparing between

two discharges (co-NBI in red and counter-NBI in blue).

3. Results

Figure 1 shows the radial profile of T_i and V_{ϕ}^{C6+} measured by MCXRS, demonstrating that the V_{ϕ}^{C6+}-well structures are clearly seen in both co- and counter-NBI discharges, starting to fall from the plasma boundary, at which the -∇T_i has nearly zero value. We found that the boundary condition of the V_{ϕ}^{C6+} seems not to be held fixed at zero value, varying at separatrix depending on the parallel momentum input directions, systematically. The systematic uncertainty in the V_{ϕ}^{C6+} measurements with MCXRS is estimated to be a few km/s (due to an absolute calibration error by using the samarium hollow cathode discharge lamp), but difference in the V_{ϕ}^{C6+} value around the separatrix between co- and counter-NBI discharges, $\delta V_{\phi}^{C6+}(\rho\sim 1)$, is about 10 km/s. It should be noted that the $\delta V_{\phi}^{C6+}(\rho\sim 1)$ value was evaluated by means of statistical analysis with the Gaussian like fitting function, which is larger than that of the systematic uncertainty.

Figure 2 shows the ELM effect on the impurity ion density, n_i, temperature, T_i, toroidal plasma flow, V_{ϕ}^{C6+}, for carbon impurity ions, and radial electric field, E_r. For improved statistics to assess the temporal behavior (in particular pre- and post-ELM phases) of the measurements, we used the data determined from multiple and reproducible ELM cycles, mapping them onto a single-time basis, as defined by the time of the measurement relative to the ELM. We found that the V_{ϕ}^{C6+} value at the separatrix seems not to affect strongly by ELM event for both co- and counter-NBI discharges. Indeed, the gradients of T_i and n_i (and hence pressure gradient, ∇p_i) at the bottom of pedestal (near separatrix) as one of the driving forces in the parallel momentum transfer seem to be small enough, except for their pedestal gradient. Momentum transport and the origins of intrinsic rotation, including the correlation of E_r-shear and/or its curvature with the pedestal structure, are discussed in this talk.

4. Summary

With regard to determining the edge toroidal plasma flow in JT-60U, by means of MCXRS diagnostic, an improved spatial resolution with high signal-to-noise ratio (S/N) was achieved. Boundary condition of toroidal plasma flow for the carbon impurity ions imposed at the separatrix in JT-60U ELMy H-mode plasmas has been identified, comparing between co- and counter-NBI discharges. We found that the toroidal plasma flow at the separatrix was not held fixed to be zero, but vary with momentum input direction, being unaffected by the ELM event. These results will be available as a constraint for the neoclassical prediction [4].

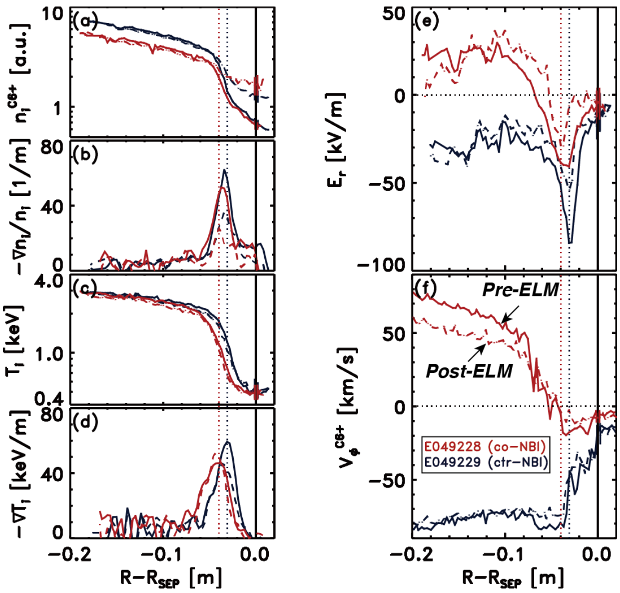

Fig. 2. Radial profiles of (a) n_i^{C6+}, (b) $-\nabla n_i^{C6+}/n_i^{C6+}$, (c) T_i, (d) $-\nabla T_i$, (e) E_r, (e) V_{ϕ}^{C6+}, comparing between co-NBI (red line) and counter-NBI discharges (blue line) just before (solid lines) and after (doted lines) an ELM as function of the distance from separatrix $R-R_{SEP}$. The data are measured just before and after a set of reproducible ELMs. Vertical dotted lines correspond to the locations at which -∇T_i has a local maximum value.

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References

[1] P. H. Diamond, S. -I. Itoh, K. Itoh, and T. S. Hahm, Plasma Phys. Control. Fusion **47** (2005) R35–R161.

[2] K. Kamiya, M. Honda, N. Miyato, H. Urano, M. Yoshida, Y. Sakamoto, G. Matsunaga, N. Oyama, Y. Koide, Y. Kamada, K. Ida and I. Murakami, Nucl. Fusion **52** (2012) 114010.

[3] K. Ida, Y. Sakamoto, M. Yoshinuma, S. Inagaki, T. Kobuchi, G. Matsunaga, and Y. Koide, Rev. Sci. Instrum. **79** (2008) 053506.

[4] M. Honda, S. Satake, Y. Suzuki, M. Yoshida, N. Hayashi, K. Kamiya, A. Matsuyama, K. Shinohara, G. Matsunaga, M. Nakata, S. Ide and H. Urano, "Integrated Modeling of Toroidal Rotation with the 3D Non-local Drift-kinetic Code and Boundary Models for JT-60U Analyses and Predictive Simulations" in proceeding of the 25th IAEA Fusion Energy Conference, St. Petersburg, Russia (2014).