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High-density Plasma Experiments in Heliotron J
ヘリオトロンJにおける高密度プラズマ実験

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This paper describes the high-density plasma operation in Heliotron J. A short-pulsed high-intensity gas fueling (HIGP) enables us to access the high density plasma around $1\text{x}10^{20}\text{m}^{-3}$ with the recovery of the stored energy. A transition phenomenon to an improved confinement mode was observed, which was characterized by (1) sudden drop of the H_α/D_α intensity, (2) reduction in the edge density fluctuation and (3) recovery of the ion/electron temperatures in the peripheral region. Before the transition, bursting mode was observed with the repetition period of 0.3-0.6 ms. A cross-correlation analysis for the low-frequency density fluctuation by BES shows a particle exhaust in the peripheral region before the transition.

1. Introduction

In magnetically confined plasmas, optimization of particle fuelling is an important subject to achieve high performance plasmas. In Heliotron J, several fuelling methods have been tried to control the plasma profile and to improve the performance: Supersonic molecular beam injection (SMBI) and shot-pulsed high-intense gas puffing (HIGP) [1]. These methods have been applied aiming at core fuelling and reducing edge recycling. Recently, we have obtained plasmas having the density more than $1\text{x}10^{19}\text{m}^{-3}$ by the HIGP method. The improvement in the energy confinement has been observed with the reduction in the edge density fluctuation and H_α/D_α intensity. In this paper, we present the experimental result of the high density plasma operation by HIGP [2]. The confinement characteristics and the behavior of the density fluctuation in the high density plasma experiments are described.

2. Experimental Results and Discussions

Heliotron J is a medium-sized (R/a = 1.2/0.17m) helical-axis heliotron device with an L/M = 1/4 helical winding coil, where L and M are the pole number of the helical coil and helical pitch, respectively. The working gas was deuterium in this study. Figure 1 shows the waveform of the high density plasma discharge using the HIGP method, which was obtained in the NBI heated plasmas in the configuration with lower toroidal magnetic component (low ε_t). The co and counter NBs were injected at the port through power of 0.4 and 0.7MW, respectively. An high-intensity gas fuelling, several times higher than that for the normal one with short period (10-20ms), was applied from t=210 ms. In this period, small degradation of the stored energy was observed. The response to the H_α/D_α intensity near GP almost corresponds to the quantity of fuelling by GP, while the strong reduction in the H_α/D_α intensity far from GP was observed at t=238ms in accordance with reduction in the edge density fluctuation by beam emission spectroscopy (BES). After that, the stored energy reached a maximum value, which corresponds to the diamagnetic beta of 0.8%.

The radial profiles of the electron temperature (T_e), the electron density (n_e), the ion temperature (T_i) and the H_α/D_α intensity ($I_{H\alpha/D\alpha}$) are plotted in Figs. 2(a)-(b) before (t=210ms), just after (232ms) and 20ms after (242ms) HIGP. The effect of the Shafranov shift due to the plasma beta is not considered yet. Due to HIGP, n_e at the core region increased twice from t=210ms to 232ms, while the change in T_e was small. At t=242ms, T_e and T_i in the peripheral region increased remarkable, then the increase in the stored energy was mainly due to the increase in the edge temperatures. At the timing of t=242ms, the maximum density around $1\text{x}10^{20}\text{m}^{-3}$ was observed at r/a=0.4. The decreased in $I_{H\alpha/D\alpha}$ was about 50% from t=232ms to 242ms. The neutral particle transport analysis shows that the neutral density reduces about 50% after HIGP.

As shown in Fig. 3, bursting fluctuations with the frequency chirping from 5 to 40kHz were observed before the drop of $I_{H\alpha/D\alpha}$. The bursting fluctuation has the toroidal mode number of n=2 (or 6, 10…) with the bursting interval of 0.3-0.6 ms, corresponding to the modulation frequency of 1.8-3.3kHz. The H_α/D_α intensity is synchronized with the bursting fluctuations. The timing of peak intensity is delayed about 0.05-0.1ms. Moreover, some delay can be seen in $I_{H\alpha/D\alpha}$ between inner and outer torus sides. To interpret this phenomena, particle transport at the peripheral region should be taken into account in conjunction with the SOL

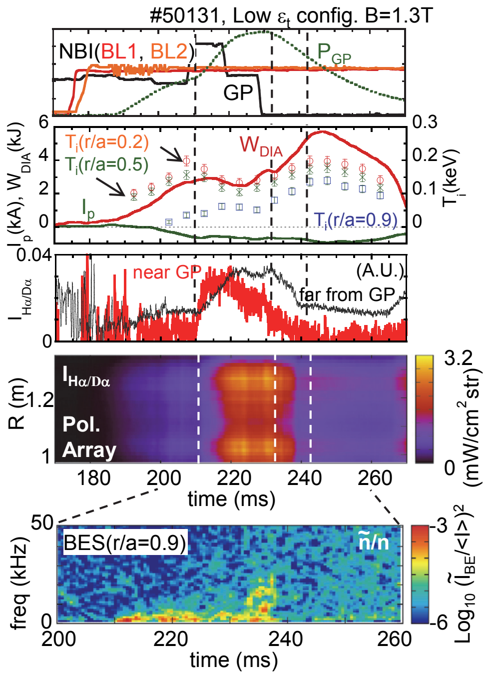

Fig. 1. Time evolution of heating/fueling, stored energy, toroidal current, ion temepreture, Hα/Dα emission intensity and power spectrum of density fluctuation by BES.

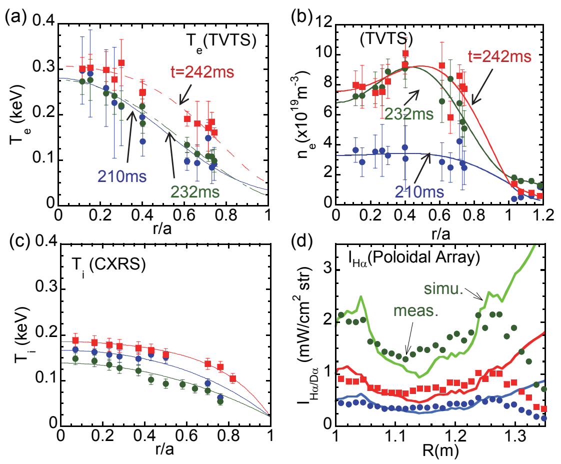

Fig. 2. Radial profile of (a) electron temperature, (b) electron density, (c) ion temperature and (d) Hα/Dα intensity before (t=210ms), during (232ms) and after (242ms) intense GP. The Hα emission intensity calculated by simulation is plotted by the solid lines.

plasma behavior.

The NB power absorption analysis shows the energy confinement time normalized to the international stellarator scaling law ISS95 improves after HIGP, which indicates the transition to an improved confinement mode after HIGP.

Figure 4 shows the cross-correlation function for the density fluctuation by BES during the bursting fluctuations (i.e. before the transition) in the frequency range of 1-3kHz. In the peripheral region, we observed that the low-frequency fluctuation propagates from core to edge region, suggesting a particle exhaust due to the fluctuations. Measurements of the propagation of the density fluctuation in the poloidal direction are required to reveal the relation between the fluctuation and the confinement improvement.

3. Summary

Using the HIGP method, the high density plasma around 1×10^{20}m^{-3} was achieved with the recovery of the stored energy. A transition phenomenon to an improved confinement mode was characterized by (1) the sudden drop of $I_{H\alpha/D\alpha}$, (2) the reduction in edge density fluctuation and (3) the recovery of T_e and T_i in the peripheral region. Before the transition, the particle exhaust in the peripheral region was suggested by the BES measurement.

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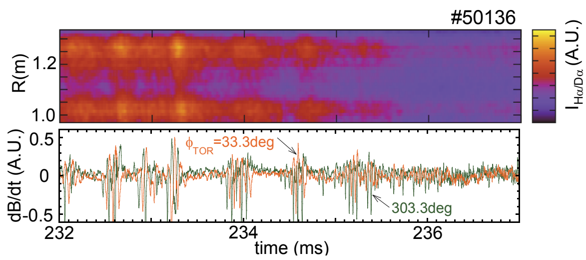

Fig. 3. Time evolution of $I_{H\alpha/D\alpha}$ and Mirnov signals.

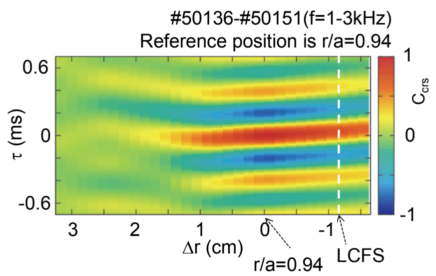

Fig. 4. Cross-correlation function for density fluctuation by BES.