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Density modulation experiment in Heliotron-J ECH plasma
ヘリオトロンJにおけるECHプラズマでの密度変調実験

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Density modulation experiments by using gas puff fuelling have been carried out in Heliotron-J ECH plasmas to evaluate the diffusion coefficient D_{core} and convection velocity V_{core} in the core region. Background line averaged density $\bar{n}_e$ was fixed around 0.6 or 0.9 × 10^{19} m^{-3}. $\bar{n}_e$ were modulated with the amplitude of 0.1 × 10^{19} m^{-3} in 50 Hz. According to the transport analysis, V_{core} are positive under both the conditions, and larger in low-density region. These imply that an outward convective term plays an important role to determine the particle transport in ECH plasmas, especially in the low-density region.

1. Introduction

Particle transport analysis is one of the important issues in the magnetically confined plasma research. The goal of this study is to reveal the feature of particle transport in Heliotron-J ECH plasma. Here, density modulation experiments by using gas puff fuelling have been carried out to evaluate the diffusion coefficient D_{core} and the convection velocity V_{core} in the plasma core region. Electron density profile measurement is required to analyze particle transport. In this study, n_e profile was measured with an amplitude modulation (AM) reflectometer [1, 2]. AM reflectometer is a useful diagnostic to measure n_e profile and to study particle transport [3, 4].

2. AM Reflectometer in Heliotron J

The schematic of the reflectometer is as follows: an AM type system is adopted to mitigate density fluctuation effects during profile measurement. The X-mode is selected as the propagation mode in order to measure even a flat or hollow n_e profile which is typically observed in ECH plasmas of helical devices. Such flat and hollow profiles have been measured in Heliotron-J ECH plasmas [2]. The carrier frequency of the reflectometer ranges from 33 GHz to 56 GHz, and can be swept as triangular wave with the sweeping frequency of 1 kHz for electron density profile measurement. Time resolution is 1 ms due to data averaging over 2 sweeps. The modulation frequency is 200 MHz.

3. Transport Analysis Method

The particle transport equations can be expressed as follows:

$$\begin{cases} \partial n_e / \partial t = -\nabla \cdot \mathbf{\Gamma} + S \\ \mathbf{\Gamma} = -D \nabla n_e + n_e \mathbf{V} \end{cases} \quad (1)$$

Here, $\mathbf{\Gamma}$ is the particle flux. S is the particle source and negligible in the region of $\rho \le 0.6$ since it is fuelled by gas puffing. It is assumed that the modulated component is described as

$$\tilde{n}_e = A(r)\sin\{\omega t - \phi(r)\} \qquad (2)$$

where A and ϕ are the amplitude and phase of the modulated component, ω is the modulated frequency. Then, D and V can be expressed as follows [5]:

$$\begin{cases} D = -\omega(Y\sin\phi + X\cos\phi)\{r(\partial\phi/\partial r)A\}^{-1} \\ V = -\omega[\{(\partial A/\partial r)Y - (\partial\phi/\partial r)AX\}\sin\phi \\ \quad + \{(\partial\phi/\partial r)AY + (\partial A/\partial r)X\}\cos\phi]\{r(\partial\phi/\partial r)A^2\}^{-1} \end{cases} \qquad (3)$$

Here,

$$X = \int_0^r rA\cos\phi dr\,,\quad Y = \int_0^r rA\sin\phi dr \qquad (4)$$

In this study, χ^2 is determined to estimate the coefficients in the core region, D_{core} and V_{core}, as [6]

$$\chi^2 = \sum_r \left[\{A_{\mathrm{exp}}\cos\phi_{\mathrm{exp}} - A_{\mathrm{calc}}\cos\phi_{\mathrm{calc}}\}^2 + \{A_{\mathrm{exp}}\sin\phi_{\mathrm{exp}} - A_{\mathrm{calc}}\sin\phi_{\mathrm{calc}}\}^2\right] \qquad (5)$$

where the suffixes of exp and calc indicate the experimental and calculated values. The experimental value is measured with the AM reflectometer measurement. The calculated value is estimated by using the following model and Eq. (3).

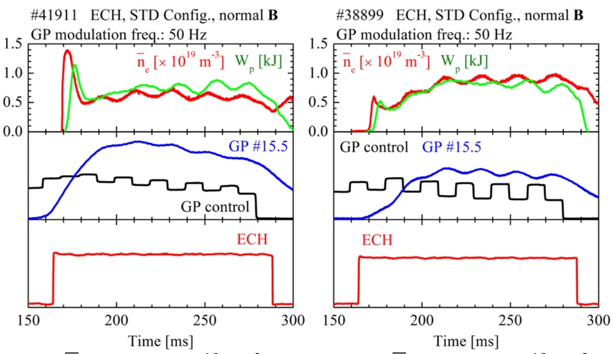
$$D = D_{\mathrm{core}}\,,\quad V = \rho V_{\mathrm{core}} \qquad (6)$$

Consequently, the minimum of χ^2 gives D_{core} and V_{core}.

4. Experimental Results and Discussion

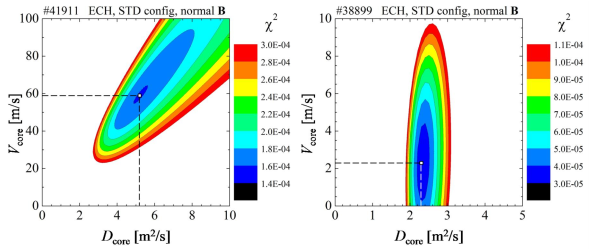
Density modulation experiments by using gas puff fuelling have been carried out in Heliotron-J ECH plasmas. Figure 1 shows the time evolutions of $\bar{n}_e$, W_p and gas puff (GP) control signal. The plasmas are produced and heated by using an ECH (70 GHz, 0.25 MW). The amount of injection gas puff fuelling can be controlled by applying voltage to piezoelectric valves. Considering recycling effect, the gas puff fuelling was gradually decreased to keep background $\bar{n}_e$ constant. Two cases of the background $\bar{n}_e$ were examined around 0.6 or 0.9 × 10^{19} m^{-3}. Under both conditions, $\bar{n}_e$ were modulated with the amplitude of 0.1 × 10^{19} m^{-3} in 50 Hz.

Figure 2 shows the χ^2 profiles calculated from the analysis as described in Sec. 3. The analysis results in D_{core} = 5.2 m^2/s and V_{core} = 59 m/s in the case of $\bar{n}_e$ = 0.6 × 10^{19} m^{-3}. Under the condition of $\bar{n}_e$= 0.9 × 10^{19} m^{-3}, D_{core} = 2.3 m^2/s, V_{core} = 2.3 m/s are obtained. V_{core} are positive in both conditions, and V_{core} in the low density case is larger than that in the high density case. These imply that an outward convective term plays an important role to determine the particle transport in ECH plasmas, especially in the low density region.



(a) $\bar{n}_e$ = 0.6 × 10^{19} m^{-3} (b) $\bar{n}_e$ = 0.9 × 10^{19} m^{-3}

Fig.1. Time evolutions of $\bar{n}_e$, W_p and GP control signal



(a) $\bar{n}_e$ = 0.6 × 10^{19} m^{-3} (b) $\bar{n}_e$ = 0.9 × 10^{19} m^{-3}

Fig.2. χ^2 profiles

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