MFP-29 AAPPS-DPP2018

2nd Asia-Pacific Conference on Plasma Physics, 12-17,11.2018, Kanazawa, Japan

Statistical Analysis of Hydrogen Recycling in the Peripheral Region of LHD

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1. Introduction

In magnetic confined fusion plasmas, it is one of important studies to control particle recycling at the plasma facing components such as first wall and divertor for the improvement of core plasma properties. For this purpose, it is necessary to understand the behavior of the peripheral plasma located between the core plasma and the wall. Although simulation technique by EMC3-EIRENE code [1] has been developed, it is still difficult to quantify relationship between measured data because of high computational cost and many inaccessible plasma parameters in real experiments.

In this study, we fit a statistical model to experimental data of Large Helical Device (LHD), and quantified the relationship among multiple measurement data. We discussed hydrogen recycling near the divertor plate based on the result.

2. Statistical modeling

Let $\varGamma_\mathrm{i}$ be the ion particle outflux from plasma to the divertor plate and $\varGamma_\mathrm{H}$ be the neutral atom influx to the plasma. If most of neutral atoms are generated by the recombination on the divertor plate, $\varGamma_\mathrm{H}$ is expected to be proportional to $\varGamma_\mathrm{i}$. We approximate this relation by the following form,

$$\delta\varGamma_\mathrm{H} = \delta\varGamma_\mathrm{i} + \varepsilon \qquad (1)$$

where $\delta\varGamma_\mathrm{H}$ and $\delta\varGamma_\mathrm{i}$ are temporal changes in $\varGamma_\mathrm{H}$ and $\varGamma_\mathrm{i}$ during small time interval δt, respectively, while ε approximates the remaining cause of the atom generation, e.g. thermal desorption of atoms from the plate. We further approximate $\delta\varGamma_\mathrm{i}$ and ε follow independent Gaussian distribution,

$$\delta\varGamma_\mathrm{i} \sim \mathcal{N}(0, \sigma_\mathrm{i}^2) \qquad (2)$$

$$\varepsilon \sim \mathcal{N}(0, \sigma_\varepsilon^2) \qquad (3)$$

where σ_i^2 and σ_ε^2 are variance of $\delta\varGamma_\mathrm{i}$ and ε, respectively. With this assumption, $\delta\varGamma_\mathrm{H}$ and $\delta\varGamma_\mathrm{i}$ jointly follow a multivariate Gaussian distribution,

$$p\left(\begin{bmatrix}\delta\varGamma_\mathrm{i}\\ \delta\varGamma_\mathrm{H}\end{bmatrix}\right) = \mathcal{N}\left(\begin{bmatrix}0\\0\end{bmatrix}, \begin{bmatrix}\sigma_\mathrm{i}^2 & \sigma_\mathrm{i}^2\\ \sigma_\mathrm{i}^2 & \sigma_\mathrm{i}^2+\sigma_\varepsilon^2\end{bmatrix}\right) \qquad (4)$$

The correlation coefficient r between $\delta\varGamma_\mathrm{H}$ and $\delta\varGamma_\mathrm{i}$ is

$$r = \sqrt{\frac{\sigma_i^2}{\sigma_i^2 + \sigma_\varepsilon^2}} \qquad (5)$$

In this work, we measured the ion saturation current i_is on the divertor plate and the Balmer-α emission intensity I_H for LHD plasmas. The sampling frequency for both measurements is 100 Hz. We assume i_is and I_H are proportional to $\varGamma_\mathrm{i}$ and $\varGamma_\mathrm{H}$, respectively, and estimated $\delta\varGamma_\mathrm{i}$ and $\delta\varGamma_\mathrm{H}$ from the AC components (with the frequency larger than 15 Hz) of measured signals.

3. Discussion

Figure 1 shows temporal evolution of i_is and I_H measured for the plasma (shot number 137141). Figure 2 (a) and (b) show relations between the AC components of i_is and I_H measured at $t = 3.85 \sim 4.15$s and $t = 4.75 \sim 5.05$s, respectively. The value of the correlation coefficient r in $t = 3.85 \sim 4.15$s is larger than that in $t = 4.75 \sim 5.05$s.

This difference suggests the different generation paths of the neutral hydrogen between these two timings. At the former timing, since σ_ε^2 in equation (5) is smaller than σ_i^2, $\delta\varGamma_\mathrm{i}$ in equation (1) becomes dominant compared with ε. It indicates that neutral atoms are mainly generated from the direct recombination of ions on the divertor plate. On the other hand, σ_ε^2 is larger than σ_i^2 in the latter case, suggesting neutral atoms are dominantly generated by another effect which has little correlation with $\varGamma_\mathrm{i}$.

References
[1] Y. Feng et al., *Contrib. Plasma Phys*. **44**, 57 (2004)

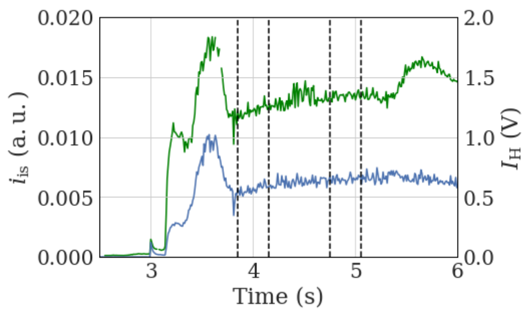

Fig. 1 Measurement data of ion saturation current i_is (green line) and balmer alpha emission intensity I_H (blue line) in shot number 137141.

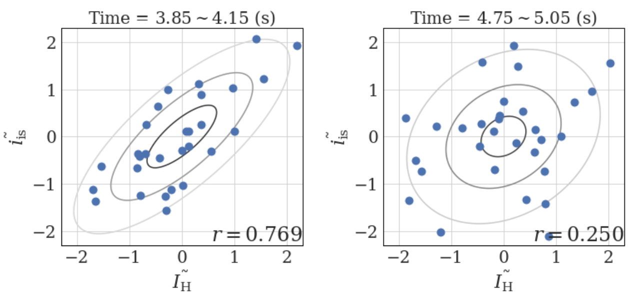

Fig. 2 Scatter diagrams of the AC component of i_is and I_H (a) at $t = 3.85 \sim 4.15$s, and (b) at $t = 4.75 \sim 5.05$s (corresponding to the time intervals enclosed by the dotted lines in Fig. 1). Each variable is normalized to mean 0 and standard deviation 1. Correlation coefficients are shown at the lower right of these figures.