§10. Complete Detachment and the Impact of Power Modulation in ECH Plasmas

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Complete detachment of electron cyclotron heating (ECH) plasmas with the electron Internal Transport Barrier (e-ITB) has been achieved for the first time in the 17th campaign experiment [1]. In the 18th campaign, a systematic scan of the heating power and the density has been conducted at R_{ax} = 3.60 and 3.65 m, B_0 = 2.705 T, γ_c = 1.254, and B_Q = 100 % (#127541-#127599). Typical waveforms are shown in Fig. 1. It has been usually observed that the ion saturation current, I_{sat}, measured on the divertor plates and the divertor electron density, n_{e_div}, measured on the line of sight through the divertor leg increase with the main plasma density. Also in the case shown in Fig. 1, both n_{e_div} and I_{sat} increased with the density ramp up started from t ~ 5 s. However, although gas puffing was continued and the line-averaged electron density, n_{e_bar}, increased until t ~ 7 s, both n_{e_div} and I_{sat} begun to roll over at t ~ 6 s. This suggests the occurrence of detachment.

As a piggyback of the ECH complete detachment experiment, the ECH modulation experiment has been also performed. In a sub-ignition fusion reactor, modulation of auxiliary heating will be beneficial to mitigate the load of the heating device and to suppress excess generation of high-energy particles. In the experiment, the density, the base P_{ECH}, and the modulation frequency was scanned. Typical waveforms in ECH modulation discharges are shown in Fig. 2, where three discharges without ECH modulation (#127583), with 30 % modulation (#127586), and 60 % modulation (#127594) are compared at the similar density. In the case of the 30 % modulation, the amplitude variation of the beta squared, β^2, which is roughly proportional to the fusion output in the reactor, P_{fusion}, was ~10 % and similar to that in the case without modulation. In the case of 60 % modulation, on the other hand, the amplitude variation of β^2 was as large as ~50 %. This result suggest a heating power dependence of $\beta^2 \propto P_{ECH}^{0.6}$, *i.e.*, $\beta \propto P_{ECH}^{0.3}$. This is similar to, or slightly smaller than the gyro-Bohm type dependence of $\beta \propto P_{ECH}^{0.4}$, as recognized in the international stellarator scalings 1995 [2] and 2004 [3]. According to the results shown in Fig. 2, a moderate modulation of the auxiliary heating power will be acceptable in the fusion reactor, as long as a small fluctuation of P_{fusion} is acceptable.

1) J. Miyazawa, et al., Proc. 21st International Conference on Plasma Surface Interactions, Kanazawa, Ishikawa, Japan, 26-30 May, 2014, P1-083.
2) U. Stroth, et al., Nucl. Fusion **36** (1996) 1063.
3) H. Yamada, et al., Nucl. Fusion **45** (2005) 1684.

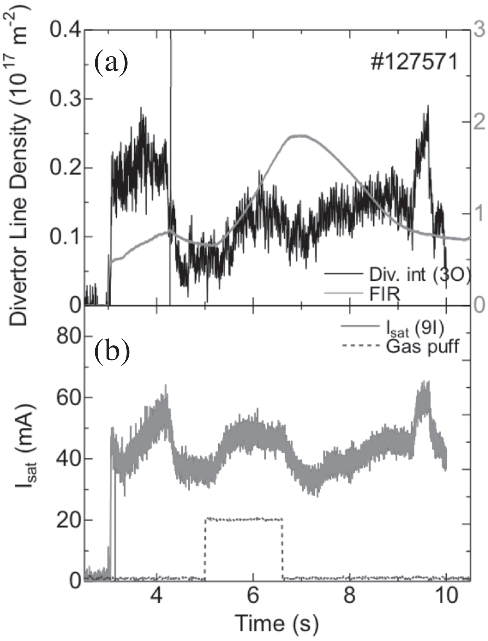

Fig. 1. Typical waveforms in an ECH complete detachment discharge, where (a) the divertor line electron density, n_{e_div}, and the line-averaged electron density, n_{e_bar}, (b) the ion saturation current measured on a divertor plate at the 9I port, I_{sat} (9I), and the gas flow pattern of the gas puffing are shown.

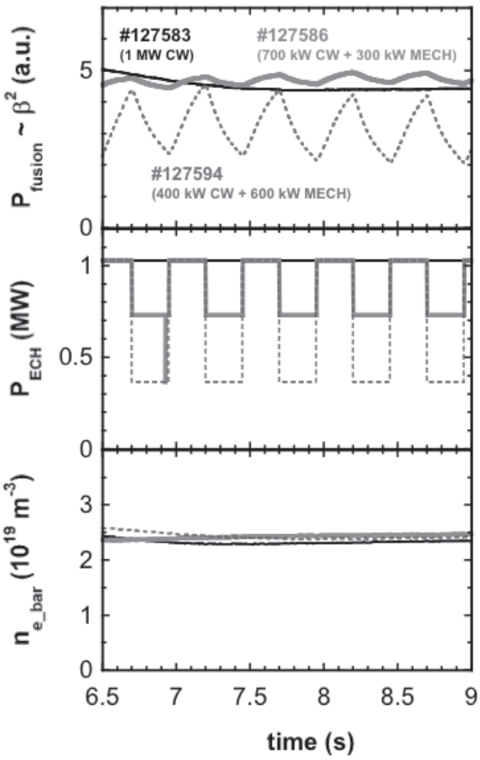

Fig. 2. Typical waveforms in discharges with, or without ECH modulation. From top to bottom, shown are the square of the plasma beta, β^2 ($\propto P_{fusion}$ in the fusion reactor), the ECH power, P_{ECH}, and the line-averaged electron density, n_{e_bar}.