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ヘリオトロンJにおける2.45 GHzマイクロ波補助によるNBIプラズマ着火のモデル解析

Model Analysis of NBI Plasma Start-Up with assistance of 2.45 GHz Microwaves in Heliotron J

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In a number of stellarator/heliotron devices, plasmas are initiated by the electron cyclotron resonance heating. This method limits the operating magnetic field strength. Plasma start-up using only neutral beam injection (NBI) has been proposed to mitigate this limitation of the field strength. This is useful for beta scaling and high beta experiments. In Heliotron J, NBI plasma start-up has been done with the aid of the seed plasma generated by 2.45 GHz microwaves under the non-resonance condition before the NBI.

To clarify the physical processes in the density build-up phase, a zero-dimensional (0-D) model has been developed, which includes the time-dependent particle and energy balance equations for fast hydrogen ions from NBI, molecules (D_2 and H_2), molecular ions (D_2^+ and H_2^+), ions (D^+ and H^+), and electrons.

Figure 1 shows the dependence of the electron density after the main gas puff on the seed plasma density, where red open circles and blue crosses show the cases of with and without density build-up in the experiments, respectively [1]. The threshold in the seed plasma density for the density build-up is deem to be in the shaded area, which area was not measured in the last year experiments due to the difficulty in the control of the pre-filled gas pressure. The simulated dependences for the particle and energy confinement time of τ = 3, 5, and 10 ms are indicated as black closed squares, circles, and triangles, respectively. These reproduce the tendency of the experimental seed plasma density dependence. The shaded area is supposed to be measured in the 2015 experiments. Figure 2 shows the time evolutions of the main variables for the seed plasma density of 6.0×10^{17} m^{-3}. The simulated electron density and the stored energy agree with the experimental data within a factor of 2. Electrons are heated through the Coulomb collisions with fast hydrogen ions produced by mainly the charge exchange collisions of the neutral beams (NBs) with deuterium ions, and they ionize the main gas puff. The physical processes for the seed plasma density of 0.6×10^{17} m^{-3} are also discussed, in which case the electron temperature is around 10 eV because of the low fast hydrogen ion density of the order of 10^{14} m^{-3}. The fast hydrogen ion density has been found to be suppressed by the low NB ionizations and by the charge exchange collisions of fast hydrogen ions with deuterium and hydrogen molecules.

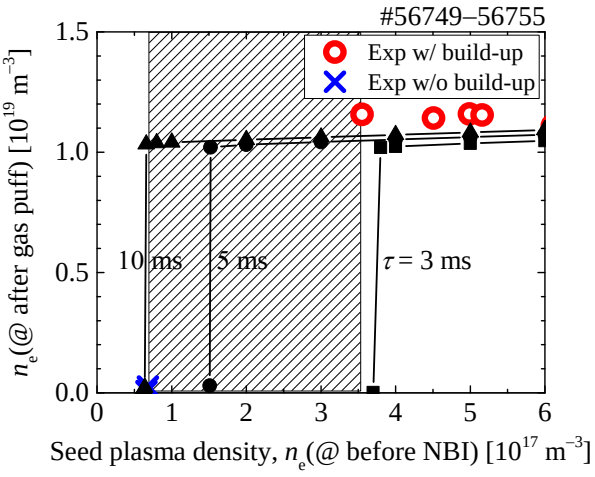

Figure 1 Dependence of the electron density after a main gas puff on the seed plasma density for the cases of with and without density build-up.

[1] K. Hada *et al.*, ISHW 2015, P2S3-38

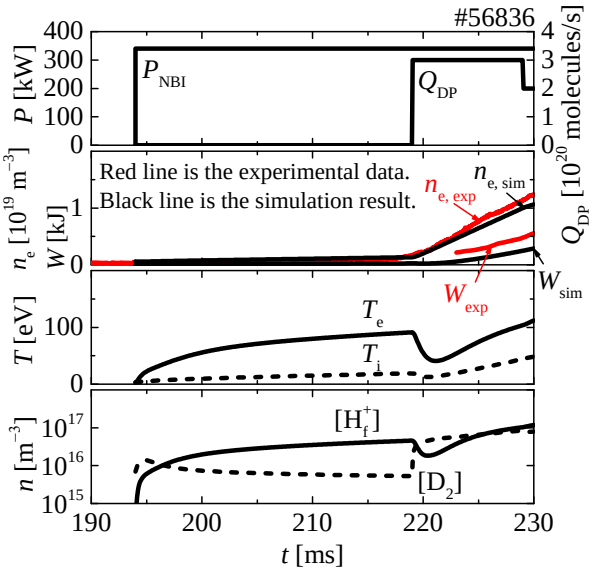

Figure 2 Time evolutions of the NBI power (P_{NBI}), the main gas puff (Q_{DP}), the electron density (n_e), the stored energy (W), the electron and ion temperature (T_e and T_i, respectively), the fast hydrogen ion density ([H_f^+]), and the deuterium molecule density ([D_2]).