19PA-023

1-D Analysis of Plasma Start-Up by Neutral Beam Injection using 2.45 GHz Microwaves in Heliotron J

ヘリオトロンJにおける2.45 GHzマイクロ波を用いたNBI加熱による プラズマ着火実験に関する1次元解析

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In Heliotron J, the conditions of seed plasma produced by 2.45 GHz microwaves are important for the subsequent NBI plasma start-up. The threshold of the seed electron for high-density plasma build-up was observed around 1 to 4×10^{17} m^{-3}. We have developed the 0-D model to investigate the threshold density and the physical processes. The simulation results using the 0-D model agree well with this threshold density within an error by a factor of 2. However, this model does not reproduce the time-evolution of electron density before the gas puff. Because the effect of radial profile is considered to be large, we are developing a 1-D model.

1. Introduction

Traditionally in stellarator/heliotron device, plasma is produced by the electron cyclotron resonance heating, which limits the operating magnetic field in the confinement region. Plasma start-up using neutral beam injection (NBI) has been proposed to extend the operational range of magnetic field, for example, which is useful for beta scaling experiments. In LHD, plasma start-up by NBI alone was successfully demonstrated for the first time in 1999[1].

In Heliotron J, this scheme has been applied with the assistance of 5 kW, 2.45 GHz microwaves [2]. Seed plasma is produced by 2.45 GHz microwaves and neutral beams (27 kV, 1 MW) are ionized by this seed plasma. The upper threshold of line density of the seed electron for high-density plasma build-up was observed around 1 to 4×10^{17} m^{-3}. After switching on NBI, the additional gas is puffed, and the main plasma is built up.

A zero-dimensional (0-D) model was developed to analyze the NBI plasma start-up for LHD [3]. In this paper, first, we investigate the threshold of the initial electron density using the 0-D model, and compare with the experimental results and next, we develop a one-dimensional (1-D) model.

2. Zero-Dimensional (0-D) Model

The 0-D model for NBI start-up consists of six particle and energy density equations: fast ion density, hydrogen ion density, electron and ion temperature, and hydrogen atom density inside and outside the last closed flux surface (LCFS). These are solved for spatially uniform plasma. The equation is presented in [3].

We have simulated the NBI plasma start-up by using the 0-D model. Figure 1 shows the dependence of the electron density at t = 270 ms on the initial electron density at t = 190 ms for different plasma volumes. We observe a threshold initial electron density which increases with increasing the plasma volume. This is because the fast ions generated by NBI are strongly dependent on the plasma volume. Although in Heliotron J the plasma volume is evaluated to be approximately 0.7 m^3, we could not reproduce the time behavior of plasma start-up if $V_p > 0.4$ m^3. Assuming V_p = 0.3 and 0.4 m^3, the simulation results using 0-D model agree well with the experimental results within an error by a factor of 2.

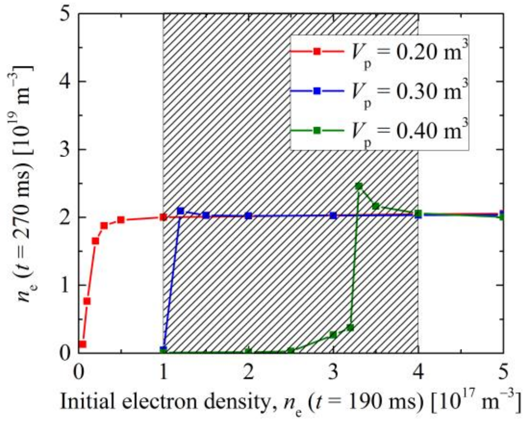

Fig. 1. Dependence of electron density at t = 270 ms on initial electron density at t = 190 ms.

Figure 2 shows the time behavior of NBI, gas puff, 2.45 GHz 5 kW magnetron, the simulation results of electron density, stored energy, fast ion density, electron and ion temperature, and the hydrogen atom density inside and outside LCFS for a successful plasma start-up, and the experimental results of line averaged density and stored energy (SHOT #41069). Here, the initial electron density is assumed to be 4.0×10^{17} m^{-3}, which is produced by 2.45 GHz microwaves. Neutral beam is applied starting at t = 190 ms, where the neutral beams collides with background neutral atoms, hydrogen ions, and electrons, and consequently the fast hydrogen ions are created. They contribute to the generation and heating of electrons. Gas is puffed at t = 230 ms, electron density drastically increases by the ionization of puffed gas while the fast hydrogen ions decreases because of the charge exchange process. Under these conditions, electron heating by neutral beam is high enough to ionize the puffed gas. The 0-D model reproduces the time evolution of electron density and stored energy between t = 240 and 270 ms. However, this model does not reproduces the slight increase of electron density from t = 210 ms. This is thought to be due to the fact that slender seed plasma is produced by 2.45 GHz microwaves in the initial start-up phase. The radial profile is considered to be important in this phase. The neutral beam energy components of 13.5 keV (E/2) and 9 keV (E/3) should also be included as well as 27 keV (FULL) in the model since they contribute to the creation of fast ions according to the ionization cross section data.

3. One-Dimensional (1-D) Model

We are developing a 1-D model including a radial structure in order to simulate the experimental results more quantitatively. The 1-D model comprises of the particle transport equations for fast ions, hydrogen ions, electrons and hydrogen

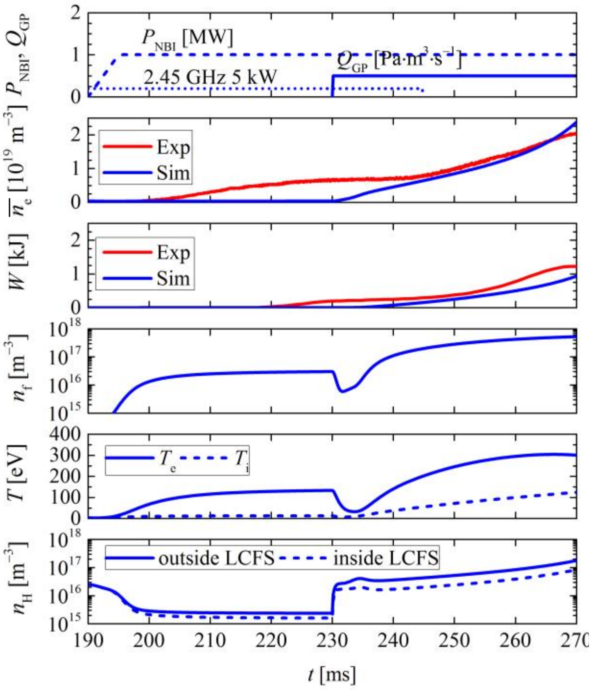

Fig. 2. Time evolution of NBI, gas puff, 2.45 GHz microwave, the simulation results of electron density, stored energy, fast ion density, electron and ion temperature, and hydrogen atom density. Experimental results of line averaged density and stored energy (SHOT #41069) for successful NBI start-up. P_{NBI} = 1.0 MW. Initial electron density is 4.0×10^{17} m^{-3}. Plasma volume is assumed to be 0.4 m^3.

atoms, and the energy transport equations for electrons and ions. These are solved for cylindrically symmetrical plasma. The detail will be shown in the presentation.

4. Summary

We have developed the 0-D model for NBI plasma start-up. The simulation results using 0-D model agree well with the threshold electron density within by a factor of 2. In order to explain the slight increase from t = 210 ms and discrepancy in plasma volume, we are developing the 1-D model. We plan to include the effects of E/2 and E/3 of NBI on the creation of fast ions into the model.

Acknowledgments

The authors are grateful to Heliotron J staff for conducting the experiments. This research was supported by JSPS KAKENHI, Grant-in-Aid for JSPS fellows (Grant Number 263037).

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