Analysis of Ion Temperature in High Intense Gas Puffing Experiment on Heliotron J

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Abstract

We report on the heat transport in NBI plasmas of Heliotron J based on the ion temperature profile measurement and the heat transport analysis. The heat diffusivity analyzed in the plasma fueled by a novel gas puffing method, high-intensity gas puffing (HIGP), is compared to that observed in a conventional gas puffing (GP) A dramatical reduction in heat transport coefficient at the core region is achieved with a peaked density profile at the HIGP fueling compared with GP fueling. The phenomenon refers to the relationship between a peaked density profile and a low heat transport coefficient.

Introduction

Fueling control is a key issue to improve the confinement in high-density plasmas. High-intensity Gas puffing is a novel fueling technique developed on the Heliotron J device [1,2]. In recent experiments, a peaked electron density profile was achieved by controlling the pulse width and quantity of HIGP. The ion temperature profile is measured with a Charge eXchange Recombination Spectroscopy (CXRS) in this study to fully understand how the confinement was changed. The heat transport analysis based on the NBI power deposition will show the characteristics of the HIGP plasma and its difference from that observed in normal gas puffing cases. In the experiment setup, we will briefly explain the HIGP fueling, and then give some basic information about the two cases we will use for comparison in this study. In the experiment results, the ion temperature measured with the CXRS system, and the electron temperature and density profiles measured with a YAG-TS system are exhibited. the NBI deposition and the heat transport coefficient calculated by the FIT3D code and TR-SNAP code will be shown.

Experiment Setup

Heliotron J is a medium-sized stellarator/heliotron device with an L/M=1/4 helical coil where L and M are the pole number of the helical coil and its helical pitch. The plasma can be initiated and heated by electron cyclotron heating (ECH) and neutral beam injection (NBI).

To control the density, four piezoelectric valves are mounted on the inboard side for gas puffing. The main idea of HIGP is to puff enough fuel to satisfy the high-n_e requirement while lowering the neutral density simultaneously. Compared with conventional GP, a short pulse with a much higher flow rate fueling is applied from the valves along with the tours.

Two types of discharges are compared in this study; HIGP fueling and conventional GP fueling. The discharging conditions such as the magnetic configuration and the heating power are the same except for the fueling method. As shown in figure 1, the plasma is initiated by a 200kW 70GHz ECH pulse from 170ms to 200ms, and then heated by a 220kW co-NBI pulse from 200ms to 260ms. For the gas puffing, the gas puffing is intensified from 220ms to 230ms and then turned off in the HIGP case, while the gas is puffed continuously until 260ms in the conventional GP case.

We have observed that the time evolution of stored energy and line averaged density is different between the two cases although the maximum value is very similar. For the HIGP case, the maximum stored energy is about 1.5kJ, and the line-averaged density is about $1.1\times10\mathrm{m}^{-3}$. For the conventional GP case, the maximum stored energy is also about 1.5kJ, and the line-averaged density is about $1.3\times10\mathrm{m}^{-3}$. The H_α signal was measured at port#7.5, far from the gas puffing valves. The H_α is a little higher from 220ms to 230ms, in the HIGP discharging.

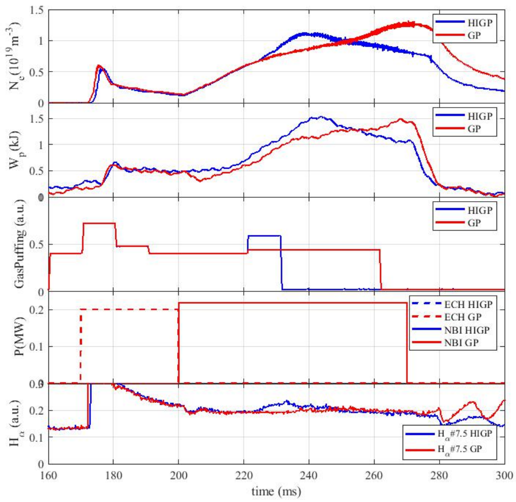


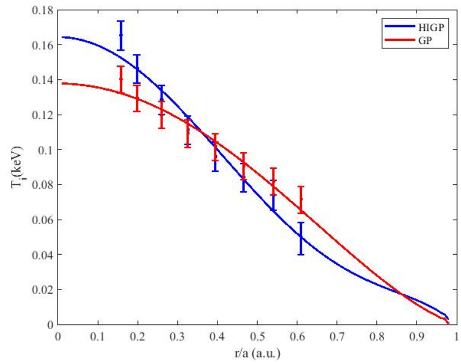
Figure 1. Discharging parameter of HIGP case (blue line) and the conventional GP case (red line).

We have measured the ion temperature profile with the parallel/toroidal CXRS diagnostic system equipped with the Heliotron J device [3,4]. The system includes 16 sightlines on both the NBI injection region and the background region with a frequency of 200 Hz. The electron density and temperature profiles are obtained from the Nd: YAG Thomson Scattering diagnostic system.

Experiment Results

We chose one specific moment from both cases for the comparison. Normally， the effect of HIGP will be shown in 20~30ms after HIGP is stopped. We noticed that at t=260ms, $dWp/dt \approx 0$, which means, we can consider the state as a quasi-steady state, and also at this moment, the conventional gas puffing still exists. Thus, we chose t=260ms for both cases for comparison.

The ion temperature profile is shown in figure 2. The ion temperature T_i at r/a=0 is higher by 20eV in the HIGP case. Also, the T_i profile of HIGP is more peaked at the region r/a<0.6



The profiles of electron temperature T_e and the electron density n_e are shown in figure 3. A more peaked n_e profile with a higher core n_e is achieved in HIGP discharging. Also, a more peaked T_e profile with higher core T_e is observed. That means when the n_e profile becomes higher and more peaked, the T_e profile will be higher and more peaked simultaneously.

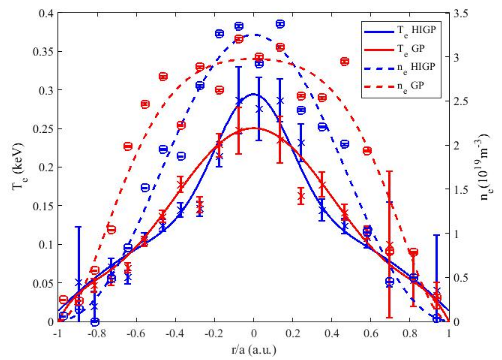


Figure 3. T_e (solid line) and n_e (dash line) profile of HIGP (blue) and conventional GP case(red)

Data Analysis

The NBI deposition and the heat transport coefficient χ are calculated by the FIT3D [5] code and the TR-SNAP [6] code. The TR-SNAP code is based on the following transport equation:

$$\chi_j = \frac{\int P_j V' dr - \langle|\nabla r^2|\rangle u_j n_j T_j - \frac{3}{2} V'\Gamma_j T_j}{\langle|\nabla r^2|\rangle V' n_j \frac{\partial T_j}{\partial r}}$$

Parameters, *j, r, V',* Γ_j and u_j represent the particle species, the minor radius, $\partial V/\partial r$, the particle flux, and the particle pinch, respectively.

As shown in figure 4, the NBI deposition profile is not so different from each other. The maximum difference is no more than 20kW/m^3. However, there is some difference between the two NBI deposition profiles. This difference might be caused by the different shapes of the n_e profile.

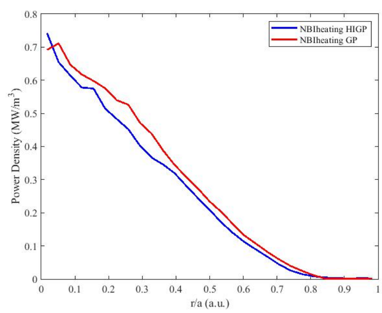


Figure 4. NBI deposition of HIGP case (blue) and conventional GP case (red).

The heat transport coefficient χ and n_e profile are plotted in figure 5. At the core region, a dramatic reduction of χ is observed. The electron heat transport coefficient χ_e is reduced by up to 60% while the ion coefficient χ_i is reduced by up to 50% at the core region. We noticed that the peaked density region is similar to the low χ region. That may refer to the relationship between the peaked density and the low heat transport. However, in this analysis, we are based on the assumption that plasma is in a quasi-steady state. And we neglected the convective term and the charge exchange loss term. Thus the heat transport coefficient in this study is the 'effective' heat transport coefficient. To study the real heat coefficient, more terms will be concerned in future studies.

Conclusion

By adjusting the quantity and timing of the HIGP pules, we have observed more peaked $T_{i/e}$ and n_e profiles compared with conventional GP fueling. With HIGP fueling, dramatically reduction of heat transport coefficient is observed at the core region, χ_e and χ_i are reduced by up to 60% and 50% respectively. Also, higher core ion/electron temperature is observed in the HIGP fueling case. The phenomenon refers that while the particle transport is deducted at the core region, the heat transport will be deducted as well. This means HIGP might be a method to improve the confinement of helical plasmas.

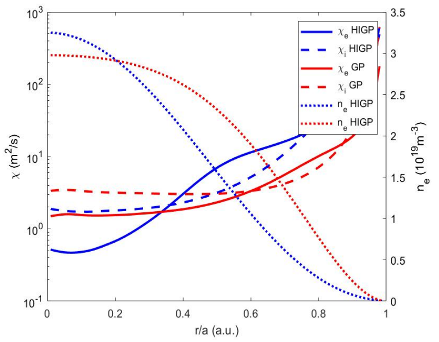


Figure 5. χ_e(solid), χ_i(dash) and n_e (dot)profile of HIGP(blue) case and conventional GP (red) case.

Acknowledgment

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