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

Study of operation scenarios for high density plasma formation in Heliotron J

S. Kobayashi[1], G. Motojima[2], T. Mizuuchi[1], K. Nagasaki[1], H. Okada[1], T. Minami[1], S. Kado[1], S. Yamamoto[1], S. Ohshima[1], X.X. Lu[3], N. Kenmochi[4], Y. Otani[3], D.L. Yu[5], K. Ida[2], K. Watanabe[2], T. Kobayashi[2], A. Ishizawa[3], Y. Nakamura[3], Y. Nakashima[6], M. Yoshikawa[6], S. Konoshima[1]
[1]Institute of Advanced Energy, Kyoto University, [2] National Institute for Fusion Science,
[3]Graduate School of Energy Science, Kyoto University, [4]The University of Tokyo,
[5] Southwestern Institute of Physics, [6] Plasma Research Center, University of Tsukuba
e-mail: kobayashi@iae.kyoto-u.ac.jp

In order to obtain high performance plasmas, we have studied the optimization of fueling scheme using supersonic molecular beam injection (SMBI) and high-intensity gas puffing (HIGP) in Heliotron J [1,2]. Recently, a hydrogen ice pellet injection has been successfully demonstrated [3]. In these fueling schemes, control of the edge neutral hydrogen density simultaneous with effective core fueling is key subject since it affects not only the energy loss through charge-exchange reaction but also the momentum loss due to the neutral friction force, which has a contribution to the formation of the radial electric field (E_r) shear in the peripheral region. In this paper, we describe the operation scenarios for high density plasma formation in Heliotron J.

The Heliotron J is a medium sized (R/a=1.2/0.17m) magnetically confined fusion device whose configuration is designed based on the concept of the non-symmetric quasi-isodynamic optimization [4]. Since the Heliotron J has a four-field-period magnetic configuration, the HIGP fuelling is carried out with four Piezo-electric type valves located at each toroidal section to achieve uniformly distributed particle fuelling. The pellet injection system has been designed to so as to match the pellet size and its speed with the Heliotron J plasma conditions [3].

High density discharge experiments have been carried out in the NBI or NBI+ECH plasmas in Heliotron J. In the high density plasma operation using the HIGP fueling method, a short-pulsed (10-20ms) high intensity gas whose fueling rate is several times higher than that of the normal fueling is applied, after that, the gas fueling is stopped. In the typical HIGP-fuelled plasmas, the electron density starts to increase at the timing of HIGP turn-on, while it decreases just after the HIGP turned-off, at that time the decrease in the stored energy (W_{DIA}) is seen simultaneously. In the case that the amount of fueled gas by HIGP is optimized, the recovery of both the stored energy and the electron density is observed about 5-10ms after the turned-off of HIGP, even the external fueling is not applied. In some cases, an H-mode transition has been observed at the timing of the re-increase in the electron density simultaneous with the drop of the H_α-line emission intensity and the rapid decrease in the density fluctuation at the peripheral region. Finally, the line-averaged electron density more than 5×10^{19} m^{-3} is attained. The electron density profile measurement shows the flat or hollow density profile is formed by HIGP with a steep density gradient at the peripheral region. The energy confinement time normalized to the International Stellarator Scaling law (ISS04) indicates that the normalized energy confinement time improves more than unity after HIGP.

Recently, we have developed the poloidal charge exchange recombination spectroscopy to obtain the poloidal flow velocity and E_r profile [5]. In the high density plasmas produced by the HIGP method, the relatively high poloidal velocity shear was observed in the peripheral region, which suggests the $E_r\times$B flow shear had a contribution to improve the energy confinement. From the neutral particle transport analysis using a Monte-Carlo simulation, the neutral hydrogen density in the peripheral region decreases less than 1/3 after HIGP, which can reduce the energy loss through the charge-exchange or radiation processes and the momentum loss due to the neutral friction force. These results show that the HIGP fueling enables us to obtain the effective core fueling and control of edge neutral density at the same time.

The hydrogen ice pellet injection experiments have been carried out to optimize the pellet size and the injection speed. By considering the Heliotron J plasma condition, the injection barrel for smaller and slower pellets are required [3]. Three different sizes of the barrel (ϕ=0.6, 0.8 and 1.0 mm) with tapered structure at both the sides (upstream and downstream) are prepared. In the case of the barrel size of ϕ=0.8 mm, a preferable plasma performance (stored energy and electron density) was obtained as compared with the other two barrels. In this case, the pellet speed was measured to be about 300m/s. From the H_α-line emission measurement, the pellet penetrated near the magnetic axis. By adjusting the target plasma density before the pellet injection, the core density close to 1×10^{20} m^{-3} was observed with a peaked density profile.

References

[1] T. Mizuuchi, et al., IAEA-CN-221/EX/P4-29 (2014).
[2] S. Kobayashi, et al., 40th EPS conf. (2013) P1.148.
[3] G. Motojima, et al., Rev. Sci. Instrum. **87**, (2016) 103503.
[4] T. Obiki, et al., Plasma Phys. Control. Fusion, **42** (2000) 1151.
[5] X.X. Lu, et al., accepted to Plasma Fusion Res. (2018).