9th Asia-Pacific Conference on Plasma Physics, 21-26 Sep, 2025 at Fukuoka

Dynamic Behavior of Pellet Fueling in Heliotron J from Ablation Cloud to Reheat Phenomena

S. Kado[1], G. Motojima[2,3], S. Inagaki[1], R. Matsutani[4], C. Feng[4], K. Ogihara[4], A. Iwata[5], T. Kawamukai[4], T. Shikama[6], F. Cai[4], F. Kin[1], S. Kobayashi[1], S. Inagaki[1], A. Matsuyama[4], Y. Nakamura[4], A. Ishizawa[4], T. Mizuuchi[1], S. Konoshima[1], S. Ohshima[7], H. Okada[1], T. Minami[1], K. Nagasaki[1]

[1]Institute of Advanced Energy, Kyoto University, [2]National Institute for Fusion Science, [3]SOKENDAI (The Graduate University for Advanced Studies), [4]Graduate School of Energy Science, Kyoto University, [5]Faculty of Engineering, Fukuoka University, [6]Graduate School of Engineering, Kyoto University, [7]University of California, Irvine.

e-mail (speaker): kado@iae.kyoto-u.ac.jp

Hydrogen pellet injection is considered as an effective fueling method for fusion-relevant magnetic confinement devices. The fueling process typically progresses in three phases[1]:

1) **Ablation and Plasmoid Formation**: The solid hydrogen pellet undergoes ablation, forming a neutral cloud that subsequently ionizes into a high-density, low-temperature plasma known as the plasmoid.
2) **Plasmoid Expansion and Homogenization**: The plasmoid evolves and expands along the magnetic flux surfaces, distributing the fuel.
3) **Fuel Deposition and Plasma Profile Reconstruction**: The injected fuel integrates with the bulk plasma, modifying the density profile and completing the fueling process.

Optimizing pellet fueling scenario requires then a detailed understanding of both microscopic atomic processes and macroscopic transport phenomena throughout the dynamic ablation process.

We have investigated the effect of the injection of small pellet, having a barrel diameter of 0.6 – 1.2 mm[2], on the plasma particle fueling and subsequent confinement in Heliotron J, a medium-sized helical device with a major radius (R) of 1.2 m, and a minor radius (a) of ~ 0.2 m, and a typical magnetic field strength (B) of 1.25 T.

For the phase 1) we developed a 2D fast visible spectrometer. The emission collected from the pellet trajectory is imaged onto a fiber optic bundle arranged in a 12 x 12 channels 2D imaging array, which is then rearranged into a 1D array along the entrance slit of the spectrometer. Non-unity magnification (300/180 focal ratio of the photographic lenses) allows the large acceptance (35 mm) of the slit height with good imaging quality. The reciprocal linear dispersion (RLD) is 3.50 nm/mm for the H_β line at 486.13 nm for 1200 grooves/mm grating.

Employment of a high-speed camera (Photron FASTCAM APX-RS) enables the recording of the Stark broadening of H_β line at the frame rate of 10k fps. The intensity and density profiles as well as the trajectory of the ablation cloud were successfully captured, providing a view of the entire ablation process of approximately 0.4 ms per pellet fraction[3].

For the phase 2) we have developed the event-triggered Thomson scattering system which enables the tracking of bulk plasma profile with an arbitral interval (≥ 0.32 ms) from the ablation event using the Hα emission signal as the trigger[4]. Subsequently, a high-speed camera (Photron FASTCAM SA5) operating at 100k fps captured the perturbation of emission intensity from the ablation cloud[5]. This can also be regarded as the initial stage of the homogenization process.

The response of bulk plasma parameters, the phase 3), to the pellet ablation is characterized by a cold pulse during which highly charged impurity spectra suddenly disappear while those from lower charged ions increase. After several milliseconds, the spectra from the highly charged ions reappear, reaching levels higher than before ablation, correlating with an increase in stored energy signal(Wp). This behavior resembles the phenomenon known as "reheat" mode[6]. Understanding the mechanisms behind reheat mode and the impurity behavior will provide significant insight into high-performance plasma achievement[7].

References

[1] A. Matsuyama, *et al.*, *Plasma Phys. Control. Fusion* **54 (**2012**)** 035007.
[2] G. Motojima, *et al.*, 2019, *Plasma. Phys. Control. Fusion.*, **61**, (2019) 075014.
[3] S. Kado, *et al.*, 2023, *Proc. 49th EPS conference, Bordeaux,* P4.040.
[4] R. Matsutani, *et al.*, 2023, *Proc. 49th EPS conference, Bordeaux,* P4.043.
[5] S. Ohshima, *et al.,* Scientific Reports, **12**, 14204(2022).
[6] S. Morita *et al.*, Proc. 14th Int. Conf. Plasma Physics and Controlled Nuclear Fusion Research 1992, Würzburg, Vol.2, p.515 (1992).
[7] K. Ogihara *et al.*, Scientific Reports, **15**, 16503 (2025).