Spatio-temporal structure of pellet-plasmoid in high-temperature plasmas

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Solid hydrogen (pellet) injection is used as a highly efficient fueling method and as a control tool for plasma instability for fusion plasmas. The pellet is ablated by the heat flux of high-temperature plasma and high-energy particles, then absorbed into the plasma. Understanding the ablation mechanism of pellets is an important issue because it leads to understanding of the property of high-density plasmas and reduction of plasma instabilities such as edge localized mode (ELM) in magnetic confined fusion devices. In addition, pellet ablation physics is relevant to high energy density science in space and laser plasmas. It undoubtedly contributes to understanding the physics of warm dense matter.

Recently, we have established a new platform to observe the pellet ablation process at the Heliotron J device at Kyoto University. Heliotron J is a medium-sized magnetic fusion device with a quasi-omnigenous structure of the magnetic field. It is capable of low-speed (260 ± 30 m s^{-1}) and small-sized (1.1 – 1.2 mm) pellet injection [2], which enables high-density plasmas in relatively small devices [3]. Various spectroscopic techniques have been introduced to allow for two-dimensional spatial measurements of the electron density of the plasmoid formed around the pellet.

The electron density of the plasmoid can be measured by the Stark broadening of Balmer-lines of hydrogen attributed to the emission from the plasmoid. So far, imaging techniques were utilized for the internal distribution of the plasmoid [4]. However, spatio-temporal measurements have been challenging due to smaller scaling (several mm) and faster time scale (microseconds) physics. To tackle the issue, we have developed a new spectroscopic system using a fiber bundle and a high-speed camera. This spectroscopy enables the measurement with spatial resolution, and it is possible to measure the internal distribution of the electron density of the plasmoid. We successfully measured the intensity distribution of the hydrogen Balmer β line and we evaluated the electron density distribution from the Stark broadening of the hydrogen Balmer β line in the plasmoid. The electron density range is found to be 2.5×10^{19}–1.1×10^{21} m^{-3}. The electron density of the plasmoid is a fundamental value for ablation. Therefore, this measurement is useful for comparing the pellet ablation between experiments and theoretical calculations.

High-speed camera measurements also show a fluctuating component in a filamentary structure of the plasmoid for the first time [5]. This fluctuation was found to propagate around the pellet across the magnetic field with a normalized fluctuation level of 15 %. The structure of this fluctuation was calculated with a magnetic field tracing code, and the spatio-temporal structure of the fluctuation during the ablation process of the pellet was successfully reconstructed. The fluctuations were found to be toroidally displaced from the pellet and propagated in the cross-field direction (ion diamagnetic direction) around the pellet injection axis along the magnetic field lines. The fluctuations are considered to be driven by the strong inhomogeneity formed around the pellet and can cause gradient relaxation through cross-field transport induced by the fluctuations. The behavior could affect pellet ablation and pellet fueling processes. Such fluctuations may be ubiquitously present in the pellet ablation process of fusion devices due to the inhomogeneity formed around the pellet.

These experimental results are also compared with numerical simulations of pellet ablation. We are currently proceeding the comparative analysis between Heliotron J with other magnetic fusion devices such as Large Helical Device (LHD) in NIFS, Japan and TJ-II stellarator in CIEMAT, Spain.

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