§24. High Performance Steady-state Plasma Duration Associated with PWI Study in LHD

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A long-pulse plasma duration is one of critical issues to design a fusion reactor, and there are many challenges to demonstrate long-pulse plasma duration with plasma density over 10^{19} m^{-3}. Large Helical Device (LHD) has great advantage for magnetic configuration which there is no need plasma current to make, and plasma duration time of one hour with heating power of 3MW is one of missions for LHD. In recent steady-state operations, long-pulse plasma discharges with duration time over 40 min were repeatedly demonstrated with electron density of 10^{19} m^{-3}, ion and electron temperatures over 2keV and total heating power of 1.2 MW. In order to achieve repeated long-pulse plasma durations, developments of heating systems and gas-fueling systems worked effectively, and then they mitigated perturbations associated with long-time scale plasma-wall interactions. Certainly, there are same perturbations which occur in short-pulse discharges, but some particular behaviors in short-pulse discharges are frequently occurred in repeated long-pulse discharges. In LHD, these behaviors strongly depended on mixed-material layers which were grown up as plasma duration time increased, and the source of mixed-material layer come from divertor plates with large heat flux and high temperature, relatively[1].

By developments of gas-fueling systems, adequate evaluations of gas fueling to keep target density with time evolution for PWI were carried out, and particle retention study in hydrogen minority regime (~ 10%) for helium plasma has been investigated on graphite divertor plate and stainless steel first wall in LHD. Three phases of gas-fueling rates were observed as one of particular behaviors in long-pulse plasma discharges, and particle fueling rates were re-increased just after particle fueling rate went to particle exhausting rate for turbo pump with keeping neutral pressure constant inside of vacuum vessel. After repeated long-pulse plasma discharges with duration time of 10 min, two gas-fueling phases, large particle retention and particle retention was gradually decreased, were observed, but third phase did not occur in these discharges[2]. If the third phase for gas-fueling rate was caused by a simple saturation for particle retention of plasma facing components (PFC), re-increasing gas-fueling rates could not be explained. From laboratory experiments, it is reported that graphite material, for example divetor plates and mixed material layers, can retain large amounts of helium particle, and particle retention of mixed-material layer seems to be one of reasons for re-increasing gas-fueling rate. This is very important behavior to understand the particle retention and control in future long-pulse plasma devices with high heat flux and large particle fluence, and long time-scale plasma physics has been clearly observed in helium long-pulse operation with duration time ~ 40 min in LHD.

Sudden plasma terminations were one of critical issues for realizing steady-state plasma duration with keeping plasma parameters constant in a fusion reactor, and unidentified flying objects (UFOs) has been investigated in long-pulse plasma devices with duration time over a few hundred seconds in torus plasmas. Just after sparks inside vacuum vessel happed, and then plasma durations usually were terminated with decreasing electron temperature at plasma edge. To mitigate temperature perturbations just after UFOs going into plasma, short-pulse heating power boosts of ECH were carried out with very fast response ($t < 10$ μs) from confirming edge electron temperature drops measured from electron cyclotron emission (ECE) around $\rho \sim 0.8$. Power boosts help plasma duration with many UFOs events, and plasma duration times with higher density (>10^{19} m^{-3}) and heating power (> 1 MW) were easily extended (Fig. 1). In repeated long-pulse plasma durations, UFOs usually come from specific divertor plates with high heat flux (~ 5 MW/m^2 in plasma heating power of 1.2 MW) and geometrically dense region, and thick mixed-material layers and exfoliations were confirmed after experiment campaign. Observation frequency of UFOs going to plasma was increased after a few long-pulse plasma discharges which were only sustained by using radio frequency with heating power of ~ 1MW, and the observed frequency was very small or negligible after repeated short-pulse plasma duration (< 5 s) with high power heating (~ 24 MW) using NBI and total duration time was over a few hours. It suggests that continuous long-pulse plasma duration enhanced thickness of mixed-material layers and exfoliation of these layers rather than repeated short-pulse plasma durations, and long-pulse plasma duration will be useful to perform the study of UFOs and growth rate of mixed-material layers.

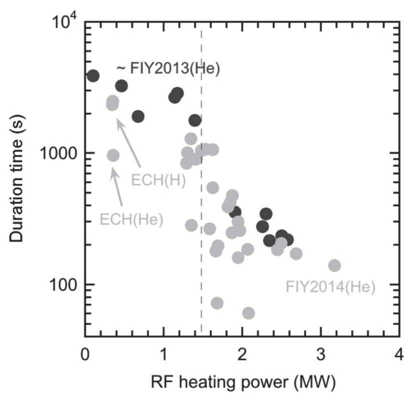

Fig.1. Operation region for steady-state operation in various heating powers, and major heating power derived from ICH.

1) Tokitani, M., et al., J. Nucl. Mater. **463** (2015) 91-98.
2) Motojima, G., et al., J. Nucl. Mater. **463** (2015) 1080-1083.