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Real-time feedback and plasma controls for steady-state plasma operation

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Demonstration of long-pulse plasma discharge is one of the critical issues in making fusion reactors true. In the Large Helical Device (LHD), we realized the duration time of 48 min with the electron density of 1.2e19 m-3, the plasma temperature of 2 keV, and the heating power of 1.2 MW using the ICRF and ECRF waves in hydrogen minority helium plasmas He(H). Several feedback systems kept the plasma parameters constant, and we could successfully control fueling without perturbation for electron density. For auxiliary heating, injection power was real-time controlled with an FPGA circuit, and boost injection for heating power could mitigate gradual density rising associated with outgassing and rapid density rising in unintended impurity contamination. The critical time for real-time feedback was approximately energy confinement time (< 100 ms). If there was no additional heating support during energy confinement time, plasmas were terminated just after events.

Controlling the concentration of hydrogen particles for ICRF heating during long-pulse plasma duration is one of the essential tasks for keeping heating efficiency because single-pass absorption for minority heating was strongly associated with minority concentration. The optimized single-pass absorption for minority heating was 3 ~ 5 % around ICRF resonances, and accurate minority concentration controls are required during long-pulse plasma duration. In hydrogen minority deuterium or helium plasmas, D(H) and He(H), we have studied particle confinement time with superimposed hydrogen gas puffing with the same frequency and injection during long-pulse plasma. The time evolution of particle confinement time (p) gradually increased in a few ten seconds, and then two kinds of p were observed. The initial expectation of the time evolution of p was gradually increased, and then finally, we could get the single-particle p for the primary gas fueling. However, this experiment phenomenon was different from the initial expectation, and it seemed to be one of the long-pulse phenomena caused by wall recycling and particle fueling.

In this paper, we show the heating control associated with the plasma parameters, the recovery operation from the unintended impurity contamination, and the time evolution of particle confinement time during long-pulse plasma duration in D(H) and He(H) plasmas. Finally, we suggest a minority concentration control scheme during ICRF heating in long-pulse plasma duration.

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