Detachment control with feedback impurity seeding and ECRH injection in LHD

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Divertor detachment operation is foreseen as a scheme to mitigate divertor heat load in future reactors. During the detachment phase, the impurity radiation layer is usually unstable and is needed to be stabilized to ensure safe divertor operation. In LHD, a detachment control system has been developed by using impurity gas puff and ECRH injection. The bolometer raw signal is sampled with 50kHz by cRIO-9035 (National Instruments), and the raw signal is processed by NI Linux Real-Time LabView 2019 and FPGA (Xilinx Kintex7) to be converted to radiated power. Two thresholds are defined for the impurity puff and the ECH injection, respectively. The impurity is seeded with several millisecond pulses with 5 to 10 Hz until the radiated power reaches the first threshold. The 154GHz gyrotrons are operated in a boost injection mode and injected when the radiated power exceeds second threshold to supress the radiation power and thus to avoid radiation collapse.

In NBI heated plasmas, stable divertor detachment was sustained with Ne seeding and ECH injection in the feedback-controlled mode until the end of the NBI. The achieved steady sate radiated power was 36%, while the radiation collapse occurs around 40% without the ECH feedback injection. The detachment feedback control was attempted also with Ar seeding, where the steady state radiation was 42%, which is slightly higher than the Ne seeding case. The divertor heat flux decreased at all toroidal sections. It is found that the ECH deposition at the peripheral region ($\rho = r_{eff}/a_{99} \sim 0.9$) is more effective to recover the edge temperature, and thus to avoid radiation collapse.

When we tried higher radiation fraction beyond 40%, divertor re-attachment occurred during the ECH injection phase, and the re-attachment lasted about one second until the detachment is recovered. This is considered caused by a feedback loop between the ECH injection and turn-off of impurity seeding because of the elevated radiation power due to the increased input power by addition of ECH. At the conference, dynamics of impurity radiation obtained by spectroscopy and plasma response, and a future plan of the system upgrade are presented.

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