§8. Feedback Control of Plasma Density and Heating Power for Steady State Operation in the LHD

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In the long pulse plasma discharge experiments in the Large Helical Device (LHD), ion cyclotron range of frequency (ICRF) minority heating and electron cyclotron resonance heating (ECRH) are used for sustaining the plasma. To achieve the suitable long pulse discharge, two important tasks are required for the heating device power control and gas puffing control system for the steady state operation. We upgraded the RF heating power control and gas puffing control system.

The first task is to sustain the plasma density and temperature by controlling the ICRF and ECRH injection power and the gas supply. The gas supply is controlled based on the Propotional Integral Derivative (PID) of the electron density measured by the FIR interferometer. When a density increase event occurs due to the ionization of impurities or additional gas from the wall, we sustain the target density by decreasing the puffing gas and increasing the ICRF and ECRH injection power automatically by the system. Figure 1 shows the time evolution of the ICRF and ECRH power and electron density in the steady state operation. A density increasing event occurred at 521.5 s and then RF power was immediately increased for sustaining the plasma and for decreasing the plasma density by the system. An ECRH antenna for short pulse operation was used to sustain the plasma at the moment of the event, and then for increasing the ICRF power in order to decrease the plasma density.

The second task is the restraint the ICRF system for stable and safety operation. Stabilization of the ICRF injection power is important in sustaining the stable density of the plasma, as described above. In order to stabilize, when some unwilling event such as increasing the ICRF power reflection occurred to the heating devices, immediate shutdown and restart are important for the fast interlock system. In the developed system, many kinds of fast interlock systems are prepared for the safe operation and their response time is set based on the oscillation of the plasma or the measurement noise. In the example case in Fig. 2, reflection ratio interlock was triggered at 7 s because the reflection power was more than 20% of the forward power. The system intended to restart at 9 s and 12 s, then the injection power restart at 13 s in this case. The interlock system worked fine in the 17th cycle of the LHD experiment and there were no problems with the ICRF hardware.

Using this system, we achieved the stable operation up to 47 minutes with electron density of more than $1x10^{19}/m^3$.

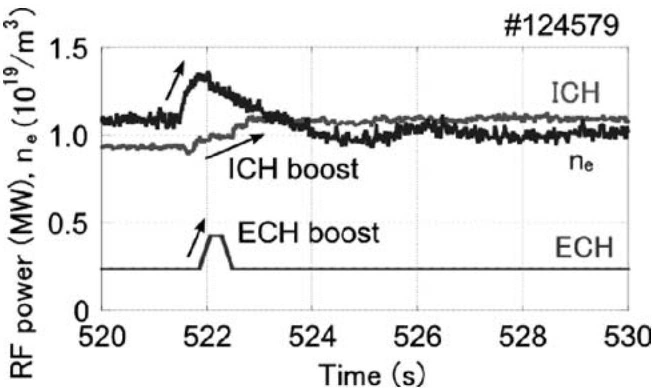

Fig. 1. Time evolution of the ICRF and ECRH power and electron density in the steady state operation. After the density increasing event at 521.5 s, the boost system was worked for sustain the plasma and decrease the plasma density.

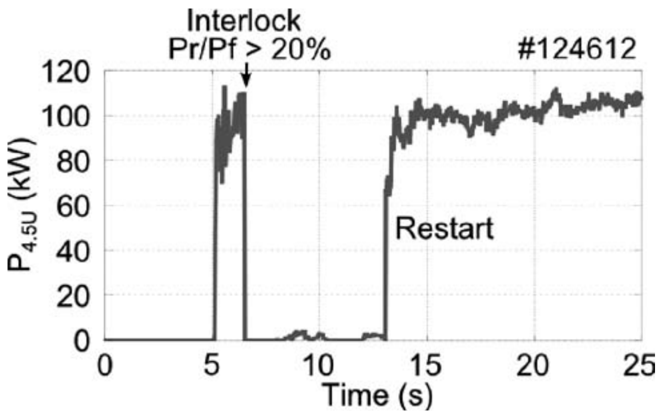

Fig. 2. Time evolution of the 4.5U FAIT antenna injection power. Power reflection ratio interlock was triggered at 7 s, and restarted at 13 s.