§3. Termination of Steady State Plasmas Caused by Penetration of Impurity Metal Flakes

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Staedy state divertor operation with high performance plasmas ($n_e \sim 0.7 \times 10^{19} cm^{-3}$, $T_i \sim 2$ keV) was demonstrated for half an hour in the superconducting helical device LHD. The high performance plasmas have been sustained with an averaged heating power of 680 kW and achieved an injected energy exceeding 1.3 GJ. Long pulse experiments so far have been performed in the magnetic configuration with R = 3.6 m for NBI and ICH discharges. In the last experimental campaign, the optimum operational regime for long pulse ICH discharges was investigated by changing the magnetic axis during the discharge. As a result, we found the best operational regime in a magnetic configuration with R = 3.67 ~ 3.7 m as shown in Fig. 1. In the inward shifted magnetic configuration (R = 3.55 ~ 3.6 m), the discharge duration was limited to 160 s without any gradual density increase, which was observed in the previous experiments. As the magnetic axis moves outward, the discharge duration was extended, and then thirty minutes discharges were achieved by using a real-time magnetic axis swing with R = 3.67 ~ 3.7 m. In course of this experiment, we observed an abrupt termination of steady state plasmas without any trouble in the heating system. Therefore, we investigate the reason why the plasma is terminated unexpectedly.

Figure 2 shows a time history of steady state plasma just before the unexpected discharge termination. Unlike a normal discharge, the abrupt increase of density and radiation was observed in spite of constant heating power input. At this timing, there is no such a large increase of helium and hydrogen particle influx. The plasma temperature extremely decreases with increasing the radiation and it leads to a radiation collapse. After that, an extremely low temperature plasma was sustained for about 1 s. On the other hand, we observe the plasma with TV cameras at various positions and more frequently we can see something like a flake heated in the plasma just before the termination of the discharge. Therefore, in order to investigate which material comes into the plasma, spectroscopic measurements are carried out by observing visible lines and vacuum ultra violet (VUV) lines. As indicated in the last column in Fig. 2, it is found that the metallic impurity (mainly iron) line intensities not but light impurity ones increase suddenly at the same time as the increase of density and radiation. The spectral analysis indicates that highly ionized iron lines (FeXXIII etc.) are prominent in the steady state phase and low ionized lines (FeX etc.) explosively appear in the plasma termination phase. The penetration of metallic flakes makes a dramatic change in the profiles of electron temperature and density as shown in Fig. 3. The steady state plasma has a relatively smooth profile for temperature and density, respectively. However, a step-wise sharp density profile and a fast shrinking of temperature profile appear by penetrating the metal flake into the plasma. These events can be seen in most of long pulse discharges terminated unexpectedly. Most probably, steady state discharges are limited by the penetration of metal flakes into the plasma.

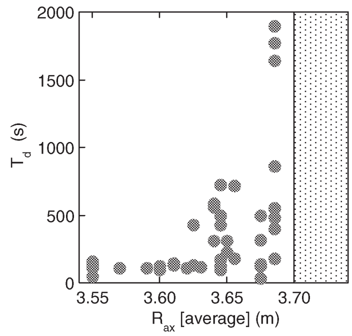

Fig. 1. Dependence of discharge duration on operational regime (magnetic axis)

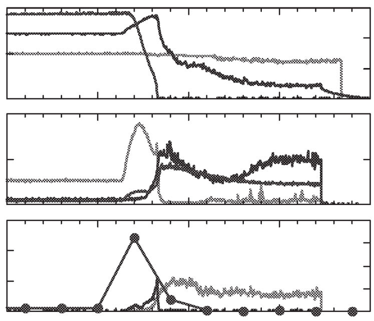

Fig. 2. Time history of long pulse discharge just before unexpected plasma termination

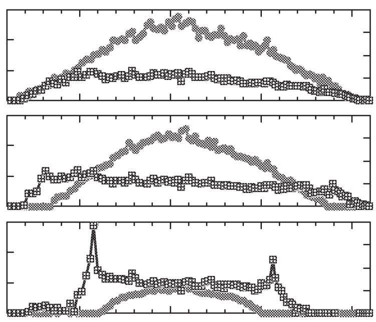

Fig. 3. Radial profiles of temperature and density before and after the abrupt increase of radiation