§46. Instantaneous ECH Injection for ICRF Heated Long Pulse Plasma Discharge

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During the long pulse plasma discharge sparking was frequently observed especially just before the plasma collapse. It seemed that a heavy impurity such as Fe penetrate the plasma, which was often detected using VUV spectrum [1]. The sparking was found between the divertor tiles, whose position was sometimes different in different plasma discharges. A subsequent penetration of heavy impurities, eg., Fe resulted in the reduction of the electron temperature, the increase in the electron density and the collapse of the plasma.

A trial of the instantaneous ECH power injection (which we call ECH camphor injection) was carried out to restore the electron temperature using the sudden increase in the density as a trigger, as shown in Fig.1. A small amount of heavy metal penetrated at 178.2 sec, but the subsequent density increase was less than 25% (the level set to launch ECH power injection as the trigger threshold in this plasma discharge) and was not enough to trigger such ECH power injection. Heavier metal penetrated at 178.4 s. accompanied by a sudden increase in the electron density and a reduction of the electron temperature. Then the ECH power was simultaneously injected as shown in Fig.1; the electron temperature was increased to 2.1keV and the electron density was decreased by $0.2\times10^{19}m^{-3}$, as often observed in the high electron temperature plasma discharge [2, 3].

The effect of the ECH injection was confirmed in a series of 12 plasma discharges ($n_e\sim1\times10^{19}m^{-3}$ with $P_{ICH}+P_{ECH}$=1.4~1.6MW). Plasma duration times of five plasma discharges without ECH camphor injection and seven ones with it are described in Table. The average duration time of the plasma discharge was 136.6s (T_{avwo}) without the ECH power injection and 235.6s (T_{avw}) with it as seen in Table. The standard deviations from these samples are 26.1s (σ_{wo}) and 32.6s (σ_w), respectively. In accordance with t-test of statistics,

$$U^2 = \frac{N_{wo}\sigma_{wo}^2 + N_w\sigma_w^2}{N_{wo} + N_w - 2}$$

$$T = \frac{T_{avw} - T_{avwo}}{\{(\frac{1}{N_{wo}} + \frac{1}{N_w})U^2\}^{1/2}}$$

$|T| = 5.128$ is calculated as shown above. Here N_{wo} and N_w are the number of plasma discharges without and with ECH camphor injection, respectively. The critical value a is deduced to be $\alpha<0.001$ from $t_{10}(\alpha)=5.128$. The possibility that ECH injection was effective was deduced to be more than 99%. However, when the second impurity penetration occurred, further elongation has not been achieved so far even though more ECH power has been injected. It is thought that at the second penetration a larger heavy impurity might be penetrating, and the ECH power of 300kW for 0.6 s. is not enough to restore the plasma. An injection of ICRF heating power up to 1MW for 1~2 sec using one antenna among 4 antennas is planned as a camphol injection in the next (10th) experimental campaign.

It is now an open question why sparking occurs between the divertor tiles, but there seems to be an intimate relation between frequent sparking and an excitation of RF electric field in the toroidal direction. A transverse electromagnetic wave (TEM) can travel in the presence of the plasma in the LHD vacuum. A phase control and employing a slightly different frequency between antenna sets will be tried in to reduce the the standing wave the next experimental campaign.

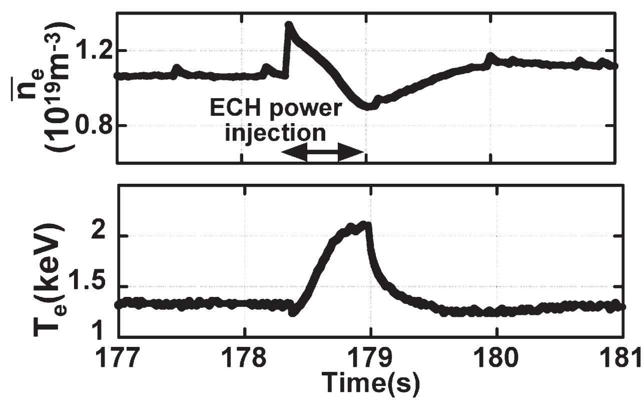

Fig.1 Time evolutions of n_e and T_e before and after ECH power injection at 178.4sec.

	without ECH (s)	with ECH (s)
1	103	190
2	175	185
3	135	230
4	155	270
5	115	263
6		261
7		250
average(s)	136.6	235.6
standard deviation from samples(s)	26.1	32.6

Table Experimental data from 12 discharges

References
[1] R.Kumazawa et al., Nucl. Fusion **46**(2006) S13
[2] H.Idei et al., Fusion Engineering and Design **26**(1995) 167
[3] K.Tanaka et al., Nucl. Fusion **46**(2006) 110