Confinement Studies during LHCD and LHW Ion Heating on HL-1M

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ABSTRACT:

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LHCD experiments were conducted on HL-1M in the past years. The LHW system is composed of a 2×12 multijunction launcher and two klystrons of 500kW. The confinement improvement by LHCD was confirmed on HL-1M. The investigations on the relationship between the confinement and the edge plasma phenomena were carried out. The confinement improvement seems to be related with the production of radial electron field during LHCD. Recently several distinctive phenomena related with plasma confinement were observed during LHCD. These phenomena include an ELM-like perturbation in boundary plasma and a sudden collapse of soft-X ray radiation from central plasma. Usually ELM mode was obtained in divertor configuratin, while on HL-1M the ELM mode was trigged by LHCD in limiter configuration. Moreover, at high density, distinct ion heating by LHW was observed. Analyses shows that the parameter decay instability seems to play a role in the mechanism of the ion heating.

1. Introduction

HL-1M is a circular cross-section tokamak with R=102cm, a=26cm. Up to now, ECRH, LHCD, NBI, ICRH and pellet injection experiments have been conducted on HL-1M. Advanced wall condition techniques such as boronization, siliconization and lithium coating have been used. Among them the siliconization is the most successful and most frequent-used wall condition technique on HL-1M. The wall conditioning enhanced plasma merits greatly. In this paper we only concentrate on the confinement improvement by LHCD and ion heating by LHW.

LHCD was investigated extensively in many fusion devices not only as a promising method of non-inductive current drive but also as a effective way to control plasma profile and to improve the confinement of plasma. LHCD experiments were conducted on HL-1M in past a few years with a LHW system, composed of a 2×12 multijunction launcher and two klystrons of 500kW. Recently for LHCD experiments on HL-1M, more attentions were paid to the confinement improvements by LHCD and the its mechanism. We carried out investigation on the relationship between the confinement and the edge plasma phenomena. Several distinctive phenomena related with plasma confinement were observed during LHCD. These phenomena include an ELM-like perturbation in boundary plasma and a sudden collapse of soft-X ray radiation from the central plasma. Moreover, at high density, distinct ion heating by LHW was observed.

2. Confinement Improvement by LHCD and the mechanism analysis

The confinement improvement during LHCD was observed in the modest density range ($n_e \leq 1.5\times10^{13}cm^{-3}$) on HL-1M[1]. It was confirmed by the following phenomena. When LHW is launched into the plasma, the density increases and the H_α from edge plasma decreases as shown in figure 1. In the more direct way, the confinement improvement was studied by injecting a small amount of impurity such as Al with laser blow-off. The impurity particle confinement could be estimated with the decay time of the brightness of the Al spectrum. It was found that the particle confinement time during LHCD is τ_P=33mS, while τ_P=15mS for similar shots of ohmic heating alone.

The improvement of confinement during LHCD was found to be always accompanied with the increase of poloidal flow velocity V_{pol} at the boundary plasma. Furthermore, it was found that the direction of the poloidal flow reverses as the toroidal magnetic field B_T reverses, while the plasma current keeps unchanged direction[2]. It seems that the increase of the poloidal flow velocity is related with the B_T. This suggests that the increase of the poloidal flow velocity can be clarified as the effect of $E_{\perp}\times B$. It is thought that the increase of the poloidal rotation and its shear will lead the formation of the barrier of transport, which results in the improvement of confinement. The results support the model for explaining the improved particle confinement during LHCD proposed by Voitskhovich[3]. In the model the production of radial electric field due to the energetic electrons loss is considered to play a dominant role in the improvement of confinements. Meanwhile, the density and temperature profile in the boundary region, which were measured with a set of Langmuir probes, get steeper during LHCD than ohmic discharge, as is shown in Fig.2.

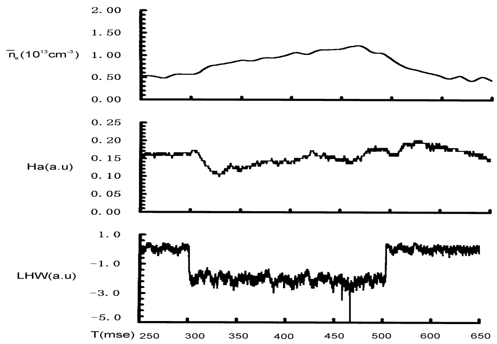

Figure 1. Evolution of line-average density and H from edge plasma during LHCD

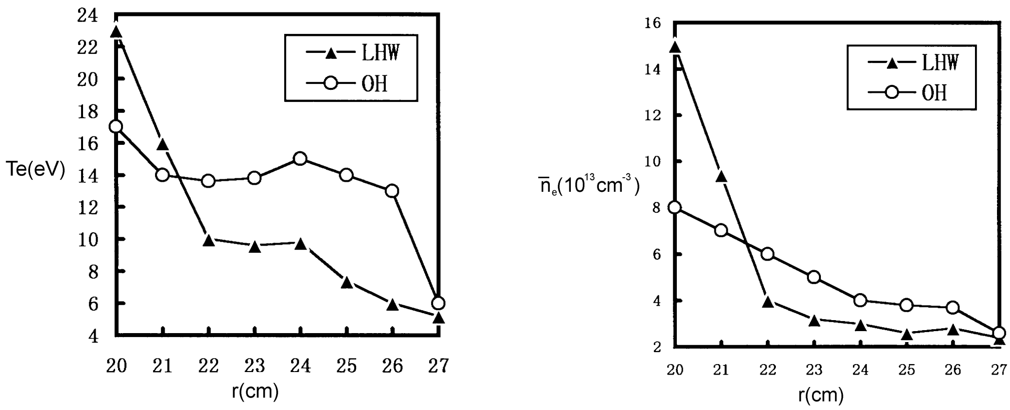

Fig. 2 The comparison of the parameters profile at plasma boundury for Ohmic and LHCD discharge (a) Temperature, (b) Density.

The improvement of confinement was found to be always accompanied with the suppression of the fluctuation of the boundary plasma. The behaviors of the ion saturation current of the boundary plasma were measured with four probes located at inboard and outboard midplane, top and bottom of the plasma, sequentially. The decrease of the ion saturation current means a decrease of the outward particle flux from the core plasma to the scrape-off layer plasma. In general, the decrease of the ion saturation current and the suppression of the fluctuation seem to be related to the enhanced poloidal rotation and its shear of the edge plasma, as mentioned above.

Furthermore, it was found that the behaviors of the suppression of the fluctuations for the siliconized wall are different from those for the boronized wall. The suppression of the fluctuation is symmetry for the siliconized wall, while it is asymmetry for boronized wall with mainly the fluctuations at the outboard side and at the bottom side were suppressed. Therefore it is concluded that the suppression of the fluctuation is even related to the wall condition which dominates the recycle of edge plasma.

3. ELM-like behavior and low frequency perturbation mode during LHCD

On HL-1M, two types of perturbations have been observed for different density during LHCD. One is ELM-like mode, under the condition of the density of less than $1\times10^{13}cm^{-3}$, which features a

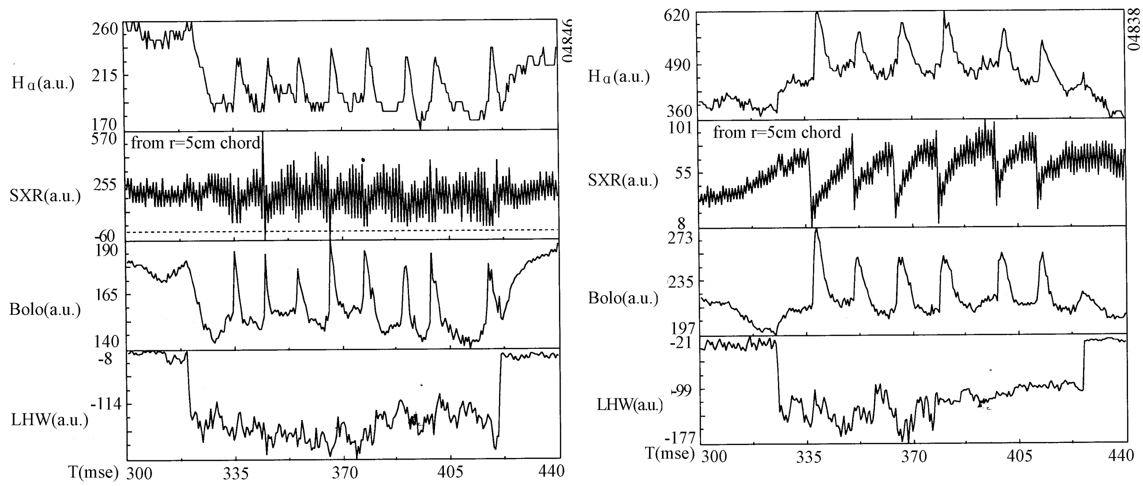

Fig.3 (a) ELM-like perturbation at low density (b) Low-frequency perturbation at high density

decrease of H radiation from edge plasma and spikes on the H_α radiation, as shown in Fig.3(a). It should be noted that total radiation from the bolometer measurement behaviors almost same with Hα, while the soft-X ray from the central plasma almost keep constant. This shows that the perturbation is limited in non-central region of the plasma. So this seems to be a typical ELM mode. In this case, the particle confinement was always improved. Usually ELM mode was obtained in divertor configuratin, here the ELM mode was trigged by LHCD in limiter configuration.

The other type of perturbation emerges at the high density of about $2\times10^{13}cm^{-3}$, which features an increase of H_α from edge plasma and bolometer signal, as shown in Fig.3(b). As opposed to ELM-like mode metioned-above, there is sawtooth-like oscillation on the soft-X ray from the central part of the plasma. This shows that the perturbation is involved in total plasma region. Through further analyses, the oscillation on the soft-X ray was identified not to be a normal MHD behavior. Usually, the perturbation occurred during LHCD just after impurity injection by the laser blow-off. So it may be related to the concentration of impurity in the plasma. In such case, the confinement of plasma is no longer improved.

4. Collapse phenomena during LHCD

As we know that the collapse events in plasma are important in determining the achievable plasma parameters for a fusion device and the understanding of the collapse phenomena is one of the essential problems in fusion plasmas.

During LHCD at the density of about $1.8\times10^{13}cm^{-3}$ on HL-1M, a sudden collapse of the all signals of soft-ray radiation from different chords was observed with no significant change on plasma density, measured by HCN interferometer, as is shown in figure 4. The plasma temperature, monitored by

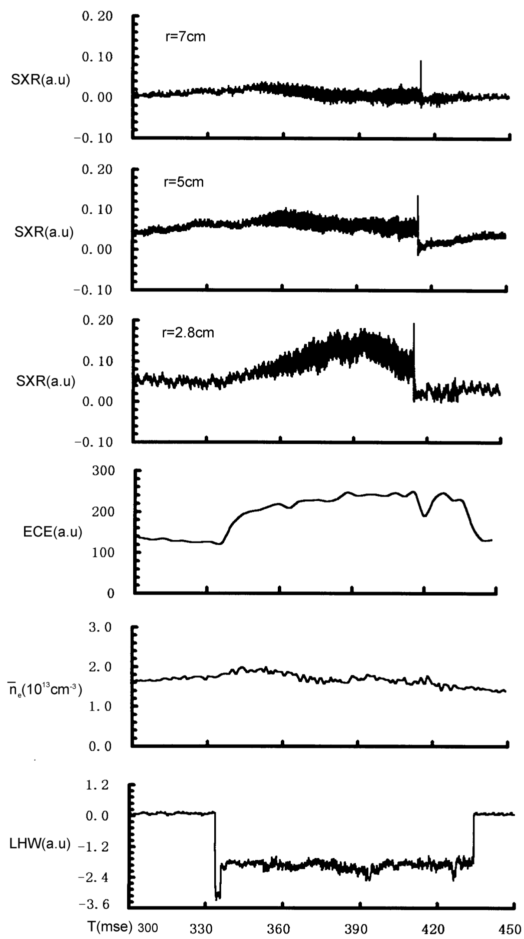

Fig.4 Plasma behaviors before and after the collapse of the soft-X ray radiation

ECE, after LHCD did not varied in comparison with that before LHCD. It should be noticed that in figure 4 the signal of the ECE was masked during LHCD by the radiation from the non-thermal electrons. Furthermore, there was even no remarkable change on thermal radiation measured by bolometer for the collapse of soft-X signal. All signal of soft-X ray from different chord collapsed simultaneously, i.e. no propagation of the crash in the plasma was observed. The time scale for the Collapse is estimated to be less than 0.2 ms from the data acquisition rate.

It is believed that the collapse like this occurred as a consequence of the steep plasma gradients due to the improved confinement by LHCD. This idea was supported by two facts as follow: first, the profile of the soft-X ray peaked before the collapse during LHCD; second, the plasma profile at boundary plasma generally get more steep during LHCD, as is shown in figure 2. But in our case, no detail of core plasma gradient profile was obtained. Further investigation is required for the mechanism of the collapse.

Based on the magnetic braiding and turbulence-terbulence transition, a so-called M-mode transition model was proposed by S-I.Itoh[4]. The phenomenon of the collapse on HL-1M is roughly agreeable with the theory model of Itohs.

Meanwhile, the effects of LHCD on MHD activities were studied with the soft X-ray detector array on HL-1M. A complete suppression of sawtooth and a complete suppression of the Mirrnov fluctuation were observed during LHCD in separated shot. Here the Mirrnov fluctuations before and after LHCD was verified as m=1 mode. These results were reported in [5]. In both of the cases it is suggests that the current profile was modified by LHCD.

5. Ion heating with LHW

Although the 90 phased antenna on HL-1M launches a almost unidrectional wave spectrum, which is suitable for efficient current drive, remarkable ion heating by LHW was observed when the plasma density was over 3.5 $10^{13}cm^{-3}$[6] The ion energy spectrum was measured with a charge exchange analyzer[7]. It was observed that beside the increase of the temperature of bulk ion, a large amount of ion tail was formed in the ion spectrum in this case. It was found that the increase of T_i is in direct proportion to plasma density and in inverse proportion to electron temperature (namely Ip). The condition for ion heating is similar to these of parameters decay instability[8]. So it is believed that the parameter decay instability is the most possible mechanism.

Acknowledgments

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