

CHARACTERISTICS OF IMPROVED CONFINEMENT PLASMA IN HL-1M

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Abstract

Characteristics of improved confinement in IOC mode, sawtooth-free plasma in LH wave heating discharge and peaking current profile plasma in current ramp-down discharge on the HL-1M tokamak are reported in this paper.

I. INTRODUCTION

Improved confinement is one of the main topics in the tokamak experiment research. Several improved confinement regimes have been found in the plasma biasing, LHCD and pellet injection experiments on the HL-1M tokamak. Here we would explore the characteristics of another improved confinement regions: IOC mode, sawtooth-free plasma in LH wave injection discharge, and peaked current profile plasma in current ramp-down discharge, observed in HL-1M tokamak.

II. IOC MODE

During the current plateau phase, when the density $\bar{n}_e < 5 \times 10^{13}/\text{cm}^3$ and wall is siliconized (but not fresh), as the fuelling gas fuelled with gas puffing and super-sonic molecular beam is reduced the plasma density can be increased, indicating that the IOC mode is achieved. A typical of such discharge is shown in Fig. 1, from which it can be observed that as fuelling rate is reduced at 245, 290, and 550ms, the H_α intensity is dropped, indicating that plasma edge density is reduced, and the intensities of soft X-ray and plasma radiation are enhanced. In this case the central density is increased, as shown in Fig. 2. Considering the decrease in H_α intensity, it can believe that the density profile is peaking, indicating that the particle confinement is improved. The electron temperature and its profile, however, are not changed compared with that in the normal Ohmic plasma, similar to the observation on the ASDEX[1]. Fig.3 shows the profile of the plasma radiation $P_r(r)$. From the profiles in different phases in Fig. 3, it can be observed that the $P_r(r)$ is hollow in SOC phase, as the P_r profile at 300ms in Fig.3. The P_r is much higher in IOC phase than in SOC phase and the $P_r(r)$ is still hollow too in the density \bar{n}_e

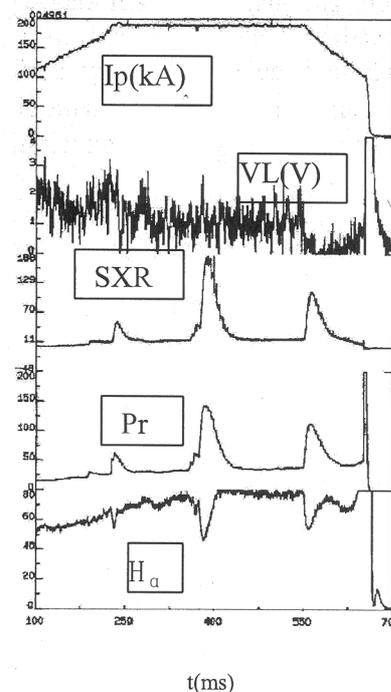


Fig.1 IOC mode is achieved as gas fuelling rate is reduced

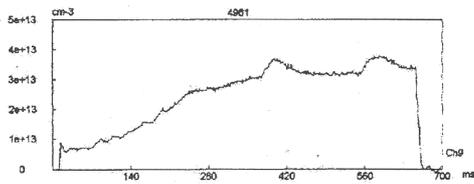


Fig. 2 Central line average plasma density is increased in IOC mode

increasing phase of IOC mode, as the P_r profile at 380ms in Fig. 3, but $P_r(r)$ is peaking in \bar{n}_e decreasing phase of IOC

mode, as the P_r profiles at 410ms in Fig. 3.

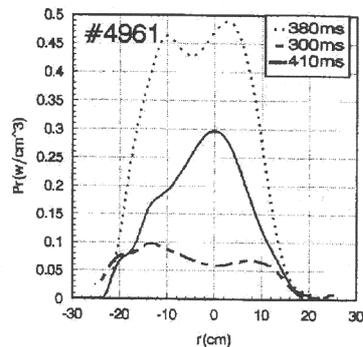


Fig. 3 P_r Profiles in OH and IOC mode phase

This means that the increases in the intensities of the plasma radiation and soft X-ray radiation is not only related to the increase in the central density and the peaked density profile, but also related to the impurity accumulation in the plasma center. Although the profile of the plasma radiation is peaking, the sawtooth oscillation still exists. This is difference from the sawtooth-free plasma in Ohmic discharge in which the profile of the plasma radiation $P_r(r)$ is peaking and the sawtooth disappear[2]. From the electron density and temperature it can be derived that the central electron pressure P_e is enhanced and its profile is peaked, indicating that the confinement is enhanced. When $\bar{n}_e > 5 \times 10^{13}/\text{cm}^3$ the density is not apparently increased and the profile is almost not changed as the fuelling gas is reduced, indicating that the IOC mode can not be achieved beyond $\bar{n}_e > 5 \times 10^{13}/\text{cm}^3$.

III. SAWTOOTH-FREE PLASMA IN LH WAVE HEATED DISCHARGE

Confinement improvement has been observed in Ohmic sawtooth-free discharge in HL-1M[2]. Similar sawtooth-free plasma can be obtained in high density LH wave heating discharge ($\bar{n}_e = 3-5 \times 10^{13}/\text{cm}^3$). In this density range of $\bar{n}_e = 3-5 \times 10^{13}/\text{cm}^3$, the role of LH wave is heating plasma ion, not driving current. As the LH wave is injected into such high-density plasma, normally it can be observed that increases in ion temperature and density, but no change in electron temperature. This means that the ion is heated by the LH wave. A typical LH wave heated discharge with sawtooth-free is shown in Fig. 4. In this discharge it can be observed that as the LH wave is injected at 390ms, the H_α intensity is decreased, indicating that the particle confinement is improved at the plasma edge, and the sawtooth period becomes longer and longer, the soft X-ray intensity becomes higher and higher, indicating that the density is

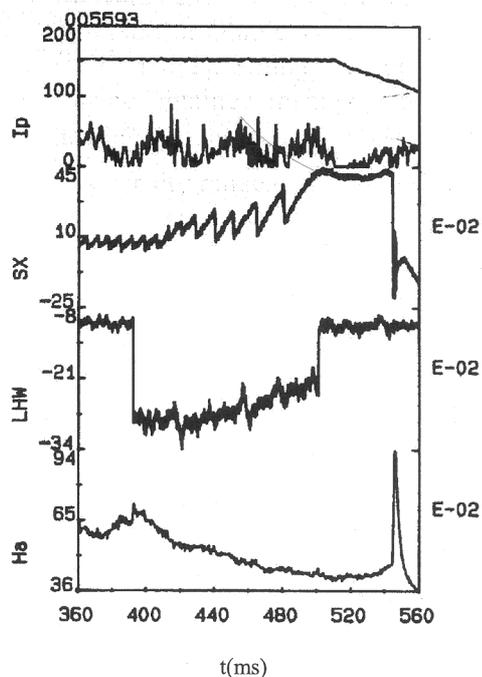


Fig. 4 Sawtooth-free in LH wave heated discharge

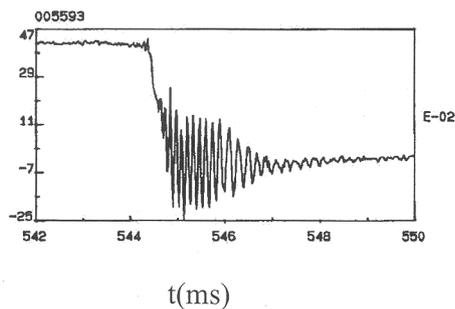


Fig.5 Sawtooth-free is ended by a big crash followed by post-cursor with large amplitude

increased and impurity is accumulated in the plasma center and implying that

confinement is improved in the plasma center.

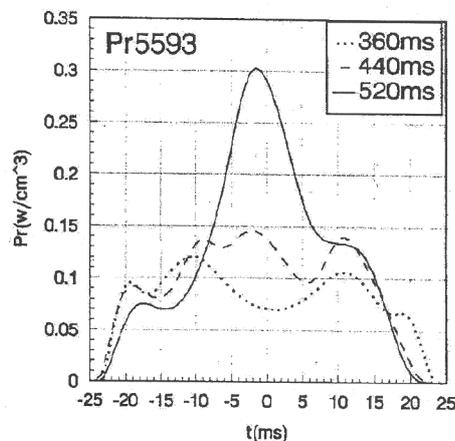


Fig. 6 Pr Profile is peaking in sawtooth-free plasma

The sawtooth-free is achieved at 490ms. When the LH wave is moved at 505ms, the sawtooth-free is still maintained and the H_{α} intensity is still decreased, indicating that the good confinement is still kept. The sawtooth-free is ended by a big crash, at which the soft X-ray intensity is dropped about 80%, but the H_{α} intensity jumps up 2-3 times, indicating the confinement is degraded. None of any MHD oscillations are observed in this sawtooth-free phase, may implying that $q(0) > 1$. The big crash is followed by the post-cursor oscillation with large amplitude and frequency $f \approx 7\text{kHz}$, as shown in Fig. 5. This post-cursor has 1ms saturation oscillation and then decays in 2ms. After the big crash the sawtooth is recovered. Fig. 6 shows the profiles of the plasma radiation $Pr(r)$, from which it can be observed that the Pr profile at 360ms is hollow which is in sawtooth phase, the central Pr is higher and its profile at 440ms is hollow too which is in the LH wave heating phase with sawtooth and longer sawtooth period,. But the Pr profile at 520ms is peaking, which is in sawtooth-free phase, and the central plasma radiation is increased about 2 times than in sawtooth phase, indicating that impurity is accumulated in the plasma center, similar to the behavior of the sawtooth-free plasma in HL-1M Ohmic discharge[2]. The increase in soft X-ray intensity, the decrease in H_{α} intensity and the peaked plasma radiation can indicate the plasma density or plasma temperature is peaking. The improved particle confinement and a peaked density profile also can lead to the impurity accumulation in the plasma center.

IV. PEAKED CURRENT PROFILE DISCHARGE

The current profile can be modified with fast current ramp up or ramp-down[3] and an improved confinement with increasing internal inductance l_i has been observed in current ramp-down discharge. The duration of the current ramp is several times the energy time. A peaked plasma current profile has been obtained with current ramp down ($dl_p/dt \approx -(1-2)\text{MA/s}$) in HL-1M, as shown in Fig. 7. The plasma current ramps down from 190kA to 90kA during the time from 650ms to 750ms. This leads to much increase in the global confinement time τ_E and the poloidal beta β_p , and the internal inductance l_i ($l_i = dVB_p / (\langle B_p \rangle_a^2 V)$) also increases. The increase in internal inductance l_i indicates the current

profile becomes peaking, which means that the improved confinement is correlated with peaked current profile.

V. CONCLUSION

Improved confinement is observed in IOC mode, which can be achieved as gas fuelling rate is reduced after the wall is siliconized, sawtooth-free plasma in LH wave heated discharge and current ramp-down discharge in HL-1M. The improved confinement is correlated to the peaked density profile in IOC mode, to the peaked density profile in sawtooth-free plasma in LH wave heated discharge, and to the peaked current profile in the current ramp-down discharge. The improved confinement in IOC mode and sawtooth-free plasma is also correlated to the accumulation of

impurity in the plasma center.

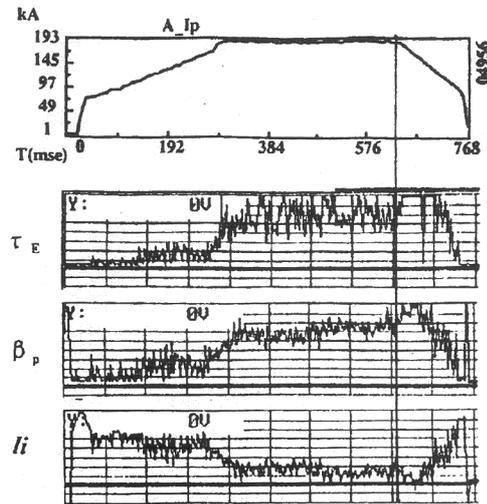


Fig. 7 Increases in τ_E , β_p and I_i in current ramp-down discharge

References

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