

CONTROL OF MAGNETOHYDRODYNAMIC ACTIVITIES BY LOWER HYBRID CURRENT DRIVE AND ELECTRON CYCLOTRON HEATING IN WT-3

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Abstract

Both $m=1, n=1$ and $m=2, n=1$ modes are suppressed by lower hybrid current drive due to the flattening of the current profile near the plasma center. On the contrary, the soft X-ray profile becomes fairly peaked and then new $m=1$ mode, which is quite different from that in the ohmic heating plasma, appears suddenly. By applying electron cyclotron heating near the $q=1$ surface, local flattening of the soft X-ray profile at the electron cyclotron resonance surface is observed and the $m=1$ mode is suppressed quickly. Furthermore, the central soft X-ray intensity also increases.

1. Introduction

Suppression of low mode number magnetohydrodynamic (MHD) activity is an important subject, related to the suppression of the major disruption and the improvement of the confinement. Recently, the classical $m=2, n=1$ tearing mode in ohmic heating (OH) plasmas was found to be suppressed by applying electron cyclotron heating (ECH) onto a narrow layer near the $q=2$ surface [1-4] as well as the $q=1$ surface [1,2]. On the other hand, by lower hybrid current drive (LHCD), sawtooth oscillations could be suppressed due to a flattening of the current profile [5-7], although an $m=1, n=1$ oscillation persisted even after the stabilization of the sawtooth. Further increase of LHCD power led to the suppression of the $m=1$ oscillation and resulted in a strong increase of central electron temperature, suggesting that removal of the $m=1$ mode led to the improvement of the thermal diffusivity. In WT-3, a similar $m=1$ mode is excited during LHCD on an OH plasma and applying ECH near the $q=1$ surface is found to be quite effective for the suppression of the mode. Namely, the time scale of the suppression is fast and the width of electron cyclotron resonance (ECR) layer effective for the suppression is wide compared to the case of ECH on the $m=1$ and $m=2$ tearing modes in the OH plasma, suggesting that the suppression mechanism is different.

2. Experimental Apparatus

The experiment is carried out in the WT-3 tokamak ($R_0 = 65\text{cm}$, $a = 20\text{cm}$, $B_T \leq 1.75\text{T}$). The r.f. power for LHCD is generated with a klystron amplifier ($\omega/2\pi = 2\text{GHz}$, $P_{\text{LHCD}} \leq 350\text{kW}$)

and injected into the plasma via two stacked four-waveguide launchers with a waveguide phasing of $\Delta\phi = 90^\circ$. The ECH system consists of an 89GHz gyrotron ($P_{ECH} \leq 220\text{kW}$) and a quasi-optical transmission system. Microwaves are injected into the torus from the low field side. The excited wave, propagating in the X-mode with nearly perpendicular angles to the toroidal field, is absorbed at the second-harmonic ECR layer. To investigate the internal MHD mode structure, five soft X-ray (SXR) detector arrays are installed in one poloidal cross-section and two SXR detector arrays at different toroidal sections. Each array has twenty detectors which are sensitive to SXR in the range 0.2-27keV. The time resolution is $5\mu\text{sec}$ and the spatial resolution is 1.8cm ($\Delta r/a = 0.09$) and the highest reconstructed poloidal mode number $m = 4$.

3. Experimental Results

In WT-3, coupled $m=1, n=1$ and $m=2, n=1$ MHD oscillations are observed in OH plasmas in the range $q_L = 2.7 - 3.2$, where q_L is the safety factor at the limiter. When the LH power ($P_{LHCD} = 100\text{kW}$) is injected into the OH plasma, the amplitude of the $m=2$ oscillation on the magnetic fluctuation signals begins to decrease and finally the $m=2$ mode become very weak or not present during LHCD. By SXR CT reconstruction, we investigate the time evolution and the internal structure of the MHD activities. The reconstructed SXR emissivity signals of the LHCD plasma at $R = 50.2, 58.4, 62.5$ and 67.1cm on the equatorial plane ($Z=0.0\text{cm}$) are shown by solid lines in Fig. 1.

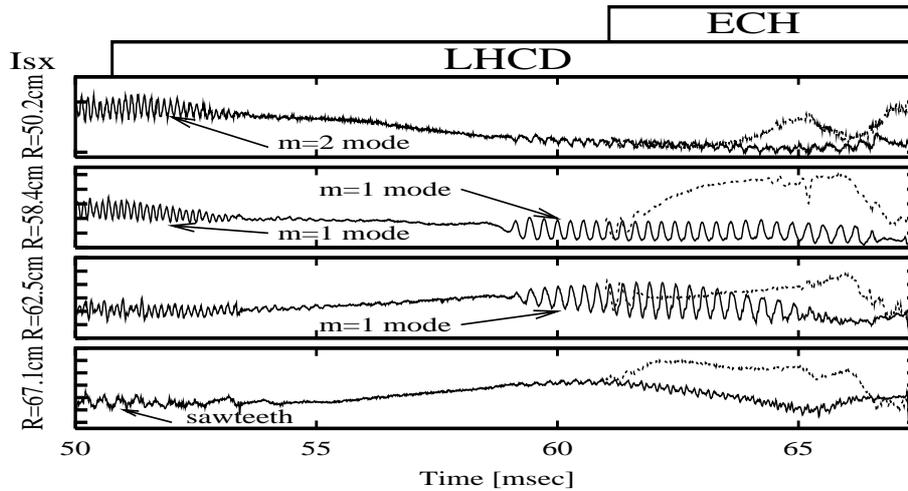


Figure 1. Typical temporal evolutions of reconstructed soft X-ray signals at $Z=0.0\text{cm}$ with (dashed line) and without (solid line) ECH.

It is found that both $m=1$ and $m=2$ modes are simultaneously stabilized. The sawtooth oscillation is also stabilized. Then (55-58msec), a double $m=1$ mode structure with quite small amplitude is observed on CT images. In addition, an $m=3, n=2$ oscillation is observed on magnetic fluctuation signals. These results suggest that the current profile is flattened in the plasma core region with slightly steepened at the $q=1.5$ surface. The SXR intensity at the plasma center is slightly increasing. Next (59msec \sim), the double $m=1$ mode disappears and in no time a new $m=1$ mode appears suddenly and grows quickly without sawteeth. Then, the amplitude saturates immediately. The time interval between the disappearance of the double $m=1$ mode and the excitation of the new $m=1$ mode is much shorter than the time scale of the change

of the overall current profile, suggesting that the excitation of the new $m=1$ mode can not be ascribed to the steepening of the current gradient at the $q=1$ surface. After the excitation of the $m=1$ mode, the increasing of SXR intensity at the center stops and begins to decrease. When ECH ($P_{ECH} = 100\text{kW}$) is applied at $R=59.7\text{cm}$ on the equatorial plane, the new $m=1$ mode is clearly suppressed very quickly (in only $600\mu\text{sec}$), as shown by dashed lines in Fig. 1. The SXR intensity is increased at the plasma center (see the waveform of $R=67.1\text{cm}$ in Fig. 1) in addition to near the ECR surface ($R=58.4\text{cm}$ in Fig. 1).

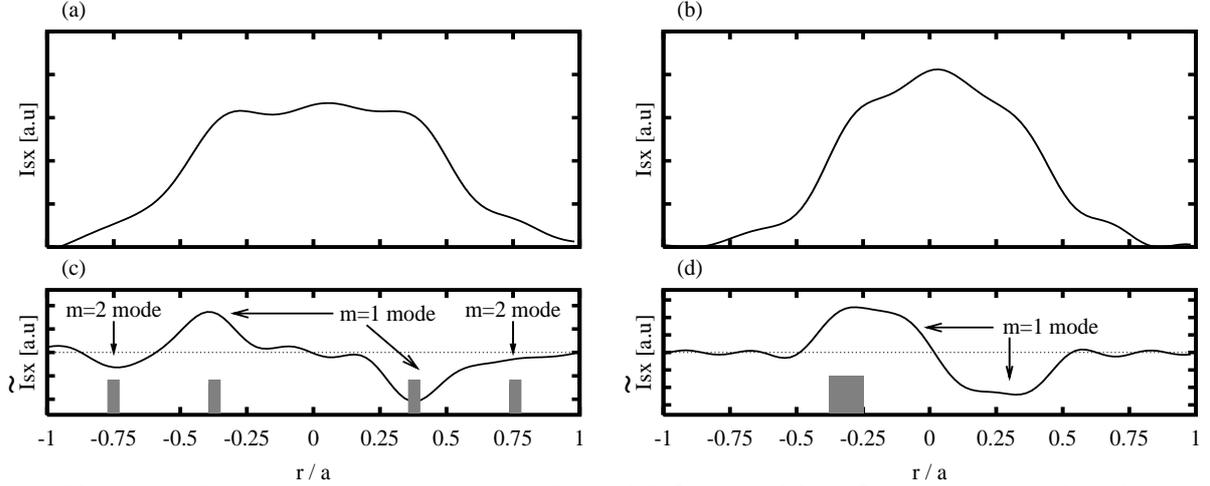


Figure 2. Reconstructed soft X-ray profile in (a) OH and (b) LHCD plasma. Profile of fluctuation components of soft X-ray emissivity in (c) OH and (d) LHCD plasma. The hatched regions represent the width of ECR layer effective for the suppression of the $m=1$ and $m=2$ modes.

The reconstructed SXR profiles for the OH (averaged from 50 to 51msec for the sake to remove fluctuation components) and the LHCD (averaged from 60 to 61msec) plasmas along r -axis, where $r = R - R_0$, are shown in Fig. 2(a) and (b), respectively. At the time of the appearance of the new $m=1$ mode, the SXR profile become fairly peaked (Fig. 2(b)) compared to that in the OH plasma (Fig. 2(a)), suggesting that steep pressure gradient is formed around the $q=1$ surface in contrast to the flattening of the current profile. The fluctuation profiles on the SXR signals for the OH and LHCD plasmas are shown in Fig. 2(c) and (d), respectively. In the OH plasma, the $m=1$ mode is localized in the range $r/a = 0.3 - 0.5$. The inversion radius of the sawtooth crash is nearly equal to the radius of the peak of the $m=1$ mode structure. In the OH plasma, we assume that the $q=1$ and $q=2$ surfaces are the locations of the peak amplitude of the $m=1$ ($r_{q=1}/a = 0.38$) and $m=2$ oscillations ($r_{q=2}/a = 0.75$), respectively. The amplitude of the $m=1$ mode is comparable to that of the $m=2$ mode ($A_{m=1} \simeq 2.5A_{m=2}$). Both $m=1$ and $m=2$ modes are completely suppressed in about 2msec after applying ECH onto a narrow ($\Delta r/a \simeq 0.05$) region (the hatched region in Fig. 2(c)) near the $q=1$ or the $q=2$ surfaces [1,2]. On the contrary, the internal structure of the new $m=1$ mode in the LHCD plasma is quite different from that in the OH plasma. Fig. 2(d) show that the new $m=1$ mode shares the entire interior domain of the original $q=1$ surface. This feature is consistent with that reported in PLT [5,6] and ASDEX [7]. An $m=2$ mode is also excited, however, the amplitude is quite small compared to that of the $m=1$ mode ($A_{m=1} \gg A_{m=2}$). We investigate the responses of the $m=1$ mode for various locations of the ECR layer systematically only in the high field side. When the ECR layer is located in the relatively wide ($\Delta r/a \simeq 0.15$) region (the hatched region in Fig. 2(d)),

the $m=1$ mode is completely suppressed.

The reconstructed SXR profiles with (dashed line) and without (solid line) ECH are shown in Fig. 3. The location of the ECR layer is indicated by an arrow ($r/a = -0.315$). The local enhancement and the local flattening of SXR profile at the ECR surface is clearly seen. During ECH, the majority of the microwave power is found to be absorbed by bulk electrons. Because SXR signals, sensitive to 0.2-27keV and 0.9-27keV, increase, while almost no responses of the SXR signals, sensitive to 1.7-27keV and 2.5-27keV, and hard X-ray signals are observed. Furthermore, no decrease of loop voltage is observed.

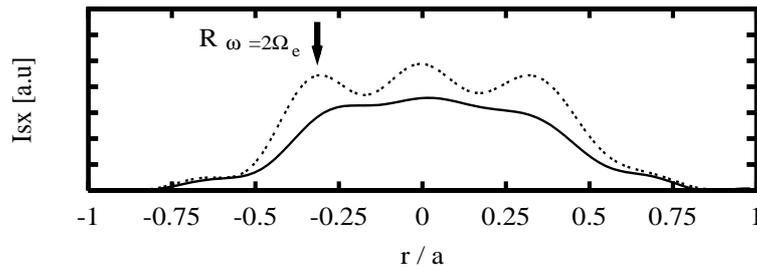


Figure 3. Reconstructed soft X-ray profile with (dashed line) and without (solid line) ECH.

These results on the suppression of the new $m=1$ mode by ECH are quite different from the previous experiment on the $m=1$ and $m=2$ modes in the OH plasma [1,2]. Therefore, the suppression of the new $m=1$ mode seems not to be due to the current profile modification by ECH nor by electron cyclotron current drive but to be due to a flattening of pressure gradient around the $q=1$ surface. In Fig. 3, central SXR emissivity is also increased, suggesting that the confinement is improved by the removal of the $m=1$ mode.

4. Summary

The $m=1$ and $m=2$ modes are simultaneously suppressed by LHCD. A double $m=1$ mode is observed after the suppression, suggesting that the current profile is flattened in the plasma core region. Then, new $m=1$ mode with large amplitude and wide width compared to that in the OH plasma is excited. Just before the mode excitation, steep gradient is formed on the SXR profile near the $q=1$ surface. By applying ECH, the local enhancement of SXR emissivity at the ECR surface is observed and the $m=1$ mode is suppressed. The time scale of the suppression is fast and the width of the ECR layer effective for the suppression is wide compared to the case of ECH on the $m=1$ and $m=2$ modes in the OH plasma, suggesting that the suppression mechanism is different. The suppression seems to be due to the flattening of the pressure gradient around the $q=1$ surface. After the suppression, the central SXR intensity increases.

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