Observation of distinct ohmic plasma current evolution on EAST

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Introduction

A large plasma current at platform is of importance for the plasma with good confinement property in tokamak discharges [1], and meanwhile the current profile evolution is equally essential for operation and control due to its association with the equilibrium maintenance and Magneto-Hydro-Dynamic (MHD) instabilities avoidance [2]. In the past decades, it has been experimentally explored on many devices by the radially arranged magnetic probes that the evolution of current profile is associated with current ramp rate and meanwhile the current diffusion [3, 4], which is a function of electron temperature. Plasma current is initiated at a slower rate on the ITER-like experiment due to the limitation of superconducting coils [5], and this brings about new uncertainties for current evolution. Nevertheless, the measurements by material probes are no more accessible under the higher discharge performance, and the precise construction of the plasma shape also raises troubles for the regular line-integrated current profile diagnostics.

Electron Cyclotron Emission (ECE) and ECE-Imaging (ECEI) systems are widely used for the study of MHD instabilities which provide a spatial and temporal evolution and 2D fluctuations of the local electron radiation temperature as a function of flux surface [6]. In this paper, ECE and ECEI are adopted to trace the MHD modes and provide estimation on the core plasma behaviour during the current ramp-up phase and evolution of current density profile.

Experiment Observations

On the EAST tokamak, distinct MHD behavior during the current ramp-up phase are observed. Plasma current of the typical discharges are initiated fully by inductive drive. The evolutions of two referred discharges are displayed in Figure 1. Waveform of plasma current I_p are shown in Figure 1(a), and I_p of both discharges are raised at the rate of 200kA/s and reach the flattop of 400kA at 2s. Detailed time evolution of electron temperature, measured by self-calibrated ECEI [8] located in the core channel is presented Figure 1(b), and it can be found discrepancy of T_e is shown after 0.2s between the two discharges. Figure 1(c) and (d) show the spectrum of ECEI at $|R_0 - R|/a \sim 0.22$ of discharge # 42276 and #42289 respectively. No obvious MHD instability can be seen in the early period in #42276 until the spikes appears on spectrum at 0.8s, and the spikes refer to the sawtooth activities as shown by T_e signal displayed in the subgraph in Figure 1(b). And for the discharge #42289, a series of MHD activities appear sequentially during the current ramp-up from 0.4s till complete disappear at 1.28s, and no sawtooth can be seen during the analyzed period.

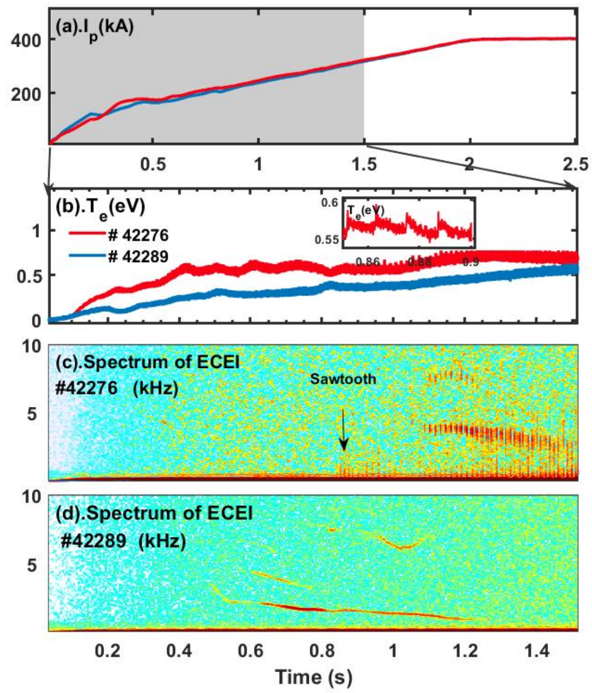

Figure 1 *Comparison of typical discharges performance during* I_p *ramp-up phase .*

The sawtooth activities at 0.8s in discharge #42276 illustrate the appearance of the q=1 surface, and hence indicating the formation of a peaked plasma current profile and steep plasma current gradient. While for the #42289 discharge, the trigger of MHD activities and development of the modes' structure and stability are associated with current profile evolution. In our experiments, the MHD modes located in the core plasma are too weak to be detected by the MHD probes which are mounted outside the vacuum to detect, and thus MHD features are investigated by the ECE and ECEI systems.

Figure 2(a) displays the modes radial positions with modes number. The poloidal mode number m is determined by the imaging of perturbed electron temperature (δT_e) provided by ECEI system as shown in the Figure 2(b~i), and the toroidal mode number n is determined by the cross-correlation between the toroidally separated ECE and ECEI system. It can be seen from the Figure 2(b)&(f) that during the coexistence of 3/1 and 2/1, 3/1 locates at inner side of 2/1, and the relative positions of the two modes are distributed as $r_s^{m/n=3/1} < r_s^{m/n=2/1}$. The reversed q profile indicates an off-axis q_{min} corresponds to an off-axis $j_{\varphi,max}$, and there exists a negative $\frac{dj_\varphi}{dr}$ at rational surface driving the unstable 3/1 mode according to the Tearing Mode equation $\nabla^2\psi = \frac{dj_\varphi/dr}{\frac{B_{\theta 0}}{\mu_0}(1-\frac{nq}{m})}\psi$ [7].

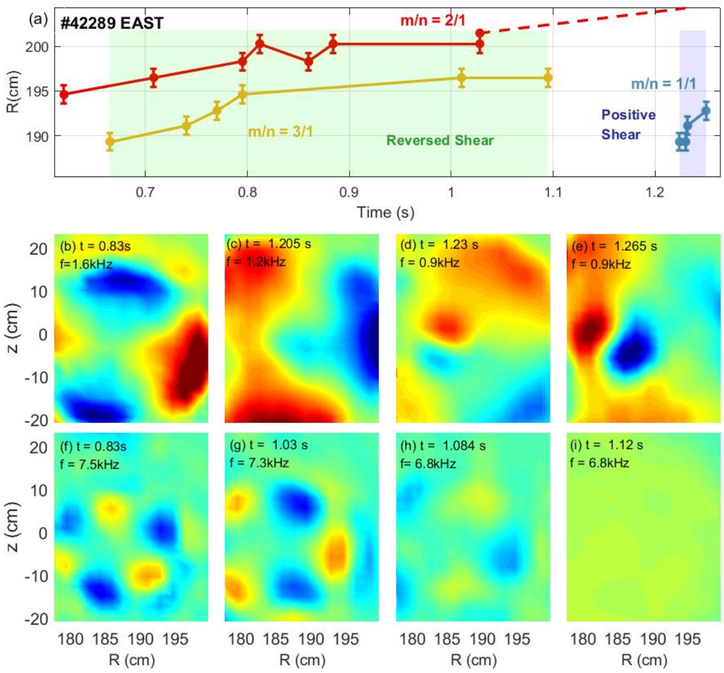

Figure 2 *MHD features: (a) mode traces, (b~h) imaging of* T_e *fluctuation provided by ECEI system.*

Plasma current density at core is accumulated by the stronger pinch effect with the current ramping. The negative current density gradient in the vicinity of $r_s^{m/n=3/1}$, which plays as the destabilizing drive for the 3/1 mode, decreases with the increasing current density in the core. 3/1 mode is gradually suppressed until it disappears completely at 1.1s, as displayed in Figure 2(f)~(i). Soon after the suppression of 3/1 mode, continuous increase of j_φ in the core makes the safety factor in the core dropping below the unit, and then the 1/1 mode emerges in the core at 1.2s by the toroidally coupling effect of 2/1 mode, keeping in the locked phase with 2/1 mode as shown in Figure 2(c)~(e). The relative radial position of 2/1 and 1/1 follows $r_s^{m/n=1/1} < r_s^{m/n=2/1}$ indicating the on-axis q_{min} and suggesting the formation of the peak current distribution.

Conclusion and Acknowledgments

In the ohmic current ramp-up phase of EAST, natural discharges with distinct MHD performance under the same plasma current ramp rate are observed. MHD features development are as the manifestation of current profile evolution. The direct burst of sawtooth indicates the early formation of the peak current profile. And the location of q_{min} moving from off-axis to on-axis illustrates that current is distributed from hollow to peak. Trigger and sustain of MHD modes can also show the evolution of current profile. The spatially and temporally resolved ECE and ECEI system measuring the local T_e perturbation and fluctuation can provide the new outlook for investigating the dynamical evolution of current profile. This work was supported by the National Natural Science Foundation of China (51821005).

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