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Study of ITB formation and sustainment with optimized current profiles in the high-performance steady state plasma on EAST

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Recently, improved high-performance plasma operation has been significantly extended towards more ITER and CFETR related high beta steady-state regime with optimization of current profile (βP ˜ 2.5 & βN ˜ 1.9 with ITB +ETB of using RF & NB and βP ˜ 1.9 & βN ˜ 1.5 with eITB + ETB of using pure RF) on EAST 1. The ITB formation and sustainment company with optimization of the current profiles, which seem to be due to different MHD-modes, similar with other devices 2. The mechanisms of linking the observed changes in MHD-behaviour and current profile seem to play an important role for ITB formation and sustainment in high beta steady state plasma on EAST.

First demonstration of a >100 s time scale long-pulse steady-state scenario with a good plasma performance (H98(y2) ˜ 1.1, with eITB) has been achieved on EAST using the pure radio frequency (RF) power heating and current drive. A typical discharge, with NB injection based on the >100 s long pulse discharge parameter, is shown in Figure 1. Better confinement was obtained with flat central safety factor q˜1 profile, with a flat boundary is about 0.2 m, and sawtooth-free in plasma discharges, accompanied by a long live mode (LLM) with a few times of current relaxation time. The LLM is localized in the core with the amplitude (10-20 Gauss) directly measured by Faraday-effect based polarimetry, and mode number (1,1) is determined by toroidally and poloidally separate diagnostics. The helical displacement of LLM is estimated to be as large as 2-3 cm, implying helical structure in the core may play an important role in current relaxation to sustain flat q profile. The measured local peaking radial magnetic fluctuation of LLM is ˜90 Gauss, which is at least 10% equilibrium poloidal magnetic field inside q=1 surface, suggesting a 3D equilibrium topology.

The ITB and ETB are both observed with an optimizied flat central q profile in the long-pulse high βN operation, as shown in Figure 2. The ITB of ion temperature, electron temperature and electron density has been obtained simultaneously during the fishbone event. And the ITB+ETB discharges sustain a few seconds with the long live fishbone in the H-mode discharge 80496, the central q profile is flat and q ˜ 1 inside ρ<0.3. The sustainment of internal transport barrier of electron density is accompanied with m/n =1/1 fishbone while it has no fishbone in the phase without ITB at t = 3.7 s. Further analysis shows that the m/n =1/1 fishbone signals located at the region of ρ=0.3 which is consistent with central flat q profile and ITB region of electron density. The formation and sustainment of the central flat q profile could be associated with the presence of the fishbone mode. Also, relationship between the formation of ITB and fishbone in EAST high βN ELMy H-mode discharge is confirmed in discharge 56933 in ref. 1. This current clamping effect is similar with other hybrid scenarios like in other devices. It suggests that some no-linear coupling exist between the MHD behaviors and the current profiles. The peak of the stored energy during the full shot revealed that the plasma was well constrained.

The 1/1 mode almost exists during the entire discharge period for improved H mode on EAST, and is a common phenomenon for many similar shots, which is similar to the LLM found on ASDEX-U and MAST 2. The over driven off axis current and fast transport of current from the core area give rise to larger difference between qmin and q=1 rational surfaces, which makes the internal mode with low m,n number more hard to be driven unstable. The combination of ECRH and LHCD plays an important role in sustaining flat q profile to avoid sawtooth crash. The 1/1 mode might play important role in shaping current density profile and sustaining the ITB in the high-performance plasma on EAST. The detailed process or mechanism based on internal measurements about how those modes can affect current profile is still missing. It is speculated that 1/1 modes may have interactions with background turbulence and play a role in current relaxation to sustain flat q profile and high-performance plasma with ITB..

1 X. Gao et al., Nucl. Fusion 57 056021(2017); B.N.Wan, et al., Nucl. Fusion 59 112003(2019); X. Z.Gong, et al., Nucl. Fusion 59 086030(2019).

2 J.Stober et al., Nucl. Fusion 47 728(2007); E. Joffrin et al., Nucl. Fusion 43 1167(2003); I Chapman et al., Nucl. Fusion 50 045007(2010).

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