Kink Mode Study in EAST High β_p Plasma

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1. Introduction

High-performance steady-state, hybrid scenarios with core q-profile is relatively flat and qmin close to unity are proposed as one of ITER's advanced modes of operation [1]. The high β_p and core q -profiles of hybrid discharges are also favorable for destabilizing of 1/1 internal kink mode [2].

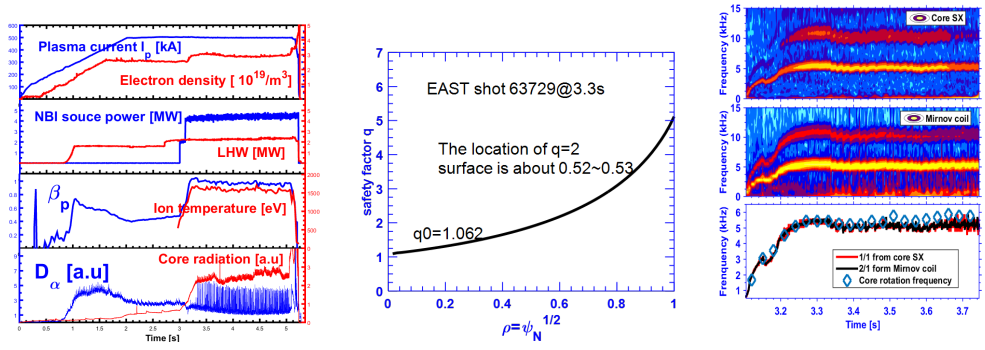
Saturated 1/1 mode with helical cores have been found to impact confinement in both positive and negative ways. Theoretical predictions and supporting experimental observations from MAST find that fast ion confinement degrades significantly with helical cores [3] and data from EAST show 2/1 neoclassic tearing mode (NTM) trigger by 1/1 mode via mode coupling [4]. On the other hand, the flux pumping mechanism [5] keeps the q profile above unity without sawteeth crashes and is beneficial for maintaining high performance hybrid discharges [6] and is helpful for avoiding of high-Z impurities accumulation [7].

In this work, two types of kink modes, fishbone and long-lived mode are experimentally and numerically studied at EAST tokamak. In high β_p plasma, sawtooth instability was replaced by a saturated 1/1 internal kink mode which either manifests itself as a periodical burst energetic ion related fishbone or as a long-lived mode which is associated to the core safety factor at $q_0 \sim 1$. The present of those1/1 internal modes are beneficial to the sustain of hybrid scenario with extended regions of low-magnetic shear profile and $q_0 \sim 1$, because of that they can expel high-Z impurity and can make flux pumping. The presence of 1/1 internal kink mode without sawtooth crash and the nature of ideal mode of 1/1 kink instability have been reproduced by 3D magnetohydrodynamic nonlinear simulations with the M3D code. And, M3D+K code hybrid simulation shows a good agreement to the fishbone activity in EAST [8].

2. Experimental observations in EAST high β_p plasma

Hybrid scenarios with weak of revised shear in the core is thought to be a strong candidate for ITER operation, due to its high-performance steady-state and endurable impurities accumulation level. However, hybrid scenarios regular exhibiting with 1/1 helical modes due to the core safety factor only slightly above unity. A long-lived mode (LLM) was found in EAST high β_p hybrid plasma. Typical plasma parameters are shown in figure1 (a). The LLM appear after the increase of β_p due to the heating of neutral beam injection (NBI). Figure 1(b)

shows the minimum q in the core is 1.062 which is very close to unity. Two important features of LLM can be drawn from the data shown in figure1(c). 1. The frequency of LLM is close to the plasma toroidal rotation at magnetic axis, 2. Harmonic of 1/1 LLM so-called 2/2 mode is usually present together with 1/1, and a mode with mode number 2/1, can be detected by edge Mirnov coils. The second feature is not surprise, since the m=2 component of 1/1 kink mode is not small in torus configuration due to the toroidal effect. The first feature implies that LLM could be an ideal mode. Note that sawtooth crashes are absent during LLM process.



(a) (b) (c)

Figure 1. Long lived mode in EAST plasma with $q_0 > \sim 1$

With the increase of the power of NBI, the periodical sawteeth crashes can be replaced by shortly bursting fishbone due to the raising of both $\boldsymbol{\beta_p}$ and $\boldsymbol{\beta_{hot}}$, as shown in Figure 2. Again, harmonic mode 2/2 is also present. It is known that the high-Z impurities accumulating in the core in ITB plasma could be a big issue for next fusion device like ITER. EAST data show the presence of fishbone can mitigative high-Z impurities in the plasma core, as shown in Fig 3.

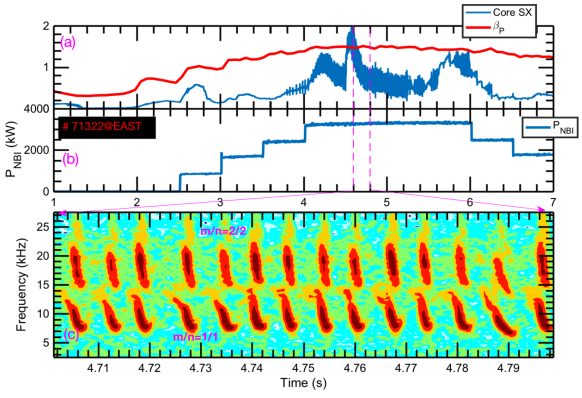


Figure 2. Fishbone in high β_p plasma at EAST.

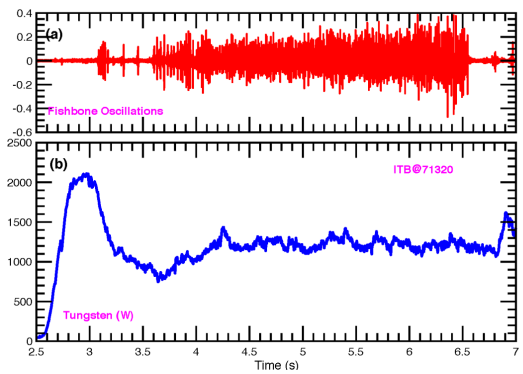


Figure 3. Tungsten expelled by fishbone in ITB plasma.

3. M3D simulation

Nonlinear MHD simulation code M3D with realistic tokamak geometry was used for LLM simulation. The experiment magnetic equilibrium and $\boldsymbol{T_e}$, $\boldsymbol{n_e}$ profiles are employed. 1/1+2/2 mode structures are found, which is consistent with experiment and theoretical predictions.

The nonlinear running of M3D code also confirm the absences of sawteeth crashes. The initial mode structures are plotted in Figure 4.

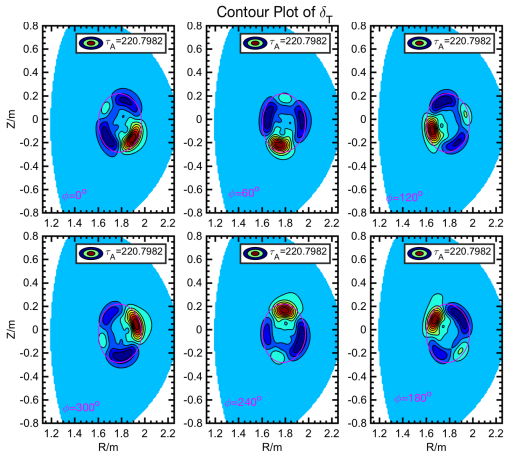
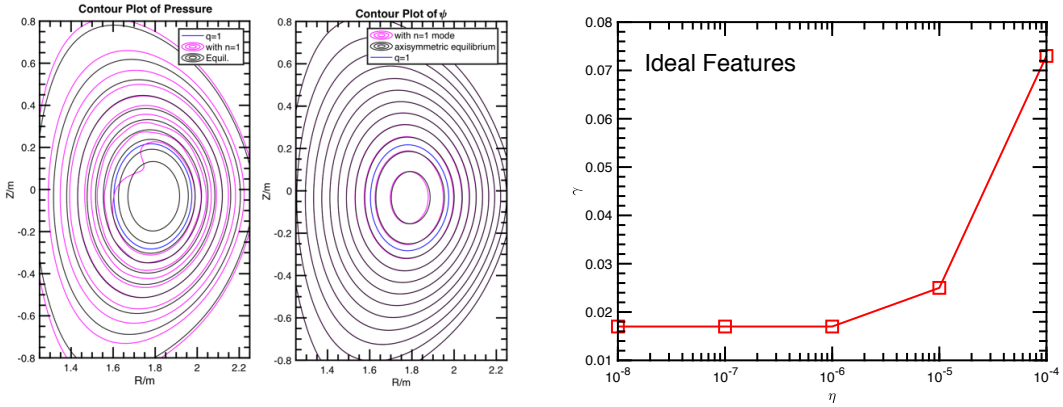


Figure 4. 1/1+2/2 mode structures and sawtooth-free helical state simulated by M3D code.

M3D nonlinear results show that the growth rate of LLM are independent to resistivity respect to the experimental value region ($\eta = 10^{-9} - 10^{-7}$), as plotted in Figure 5(b). This is a very strong evidence of the ideal nature of LLM. Furthermore, a clear shift of pressure axis, but no clear shift of magnetic surface is found during LLM process, which is also support that LLM have ideal feature (See Figure 5(a)).



5(a) 5 (b)

Figure 5. Ideal features of helical 1/1 kink mode

Hybrid simulations with the global kinetic-magnetohydrodynamic (MHD) code M3D-K also have been carried out to investigate the linear stability of beam-driven fishbone EAST experiment. Linear simulations show that a low frequency fishbone instability is excited at experimental value of beam ion pressure. The mode is mainly driven by low energy beam ions via processional resonance. The results are consistent with the experimental measurement with respect to mode frequency and mode structure. The linear results of M3D-K code are shown in Figure 6.

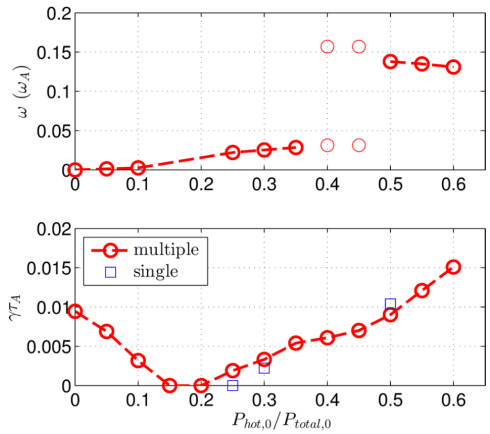


Figure 6. Fishbone frequency and linear growth rate associated with P_{hot}/P_{total} predicted by M3D+K. The simulated frequency $f_{sim} = 6.99kHz$ with P_{hot}/P_{total} ~0.25 for EAST shot 48605 is consistent with the experiment measured mode frequency value [9].

4. Summary

Two types of kink modes, fishbone and long-lived mode are experimentally and numerically studied at EAST tokamak. In high β_P plasma, sawtooth instability was replaced by a saturated 1/1 internal kink mode which either manifests itself as a periodical burst energetic ion related fishbone or as a long-lived mode which is associated to the core safety factor at $q_0 \sim 1$. The present of those1/1 internal modes are beneficial to the sustain of hybrid scenario with extended regions of low-magnetic shear profile and $q_0 \sim 1$, because of that they can expel high-Z impurity and can make flux pumping. The mechanism responsible for the flux pumping caused by kink mode was numerically in nonlinear 3D magnetohydrodynamic simulations using the M3D code. Furthermore, M3D+K code hybrid simulation shows a good agreement to the fishbone activity in EAST. This work was performed under National Nature Science Foundation of China with Grant No. 11505226.

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