Nonlinear evolution of multi-helicity neoclassical tearing modes in the HL-2A low rotation plasmas

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Abstract. In HL-2A, Simultaneous onset and phase locking of multi-helicity tearing modes 2/1 and 3/2 NTMs seeding by the non-axisymmetric error field are always triggered in low density (line averaged density $n_e < 2\times10^{19}m^{-3}$) and low rotation discharges. The NTMs induced by error field penetration can be triggered in relatively low β plasmas. As the increase of plasma rotation arising from injected momentum, 2/1 island suppressed, and 3/2 island amplitude decrease. The results provide important evidence for NTMs stability predictions and their nonlinear dynamic in the low flow plasmas, such as ITER.

Introduction. Error fields due to PF and TF coils imperfections and misalignments, feeders and in-vessel ferritic material components, can lead to mode locking and rotation braking [1]. Reduction of error fields is a requirement for avoiding non-rotating magnetic island (neoclassical tearing modes) formation and for maintaining plasma rotation. Simultaneous onset and phase locking of different helicity neoclassical tearing modes (NTMs) can lead to the change of rotation profile [2,3], enhanced transport or even disruption. Understanding the nonlinear dynamics of coupled NTMs and interaction with sheared flow are important issues in future tokamak devices [4-6]. In HL-2A, non-rotation multi-helicity modes, m/n=2/1 and 3/2, formatted by error field have been observed in low density, low rotation plasmas. The results can provide evidences for NTMs stability predictions and their nonlinear dynamic in the low flow plasmas

Experimental results and discussion. In HL-2A, multi-helicity tearing modes, m/n = 2/1 and 3/2, have been observed in low rotation plasmas. The experiments were performed in L- or H-mode plasmas heated by electron cyclotron resonant heating (ECRH) and neutral beam injection (NBI), plasma current I_p~300kA, toroidal magnetic field B_T~2.4T. Figure 1 shows the typical discharge waveforms with multi-helicity islands. The typical H-mode plasma with type-III ELMs heated by 1.8 MW ECRH and 0.8 MW NBI. As shown in the frequency spectrum of the Mirnov coil in figure 1(d), rotating 2/1 and 3/2 modes are observed at t = 410 ms. The 2/1 mode is suppressed when the mode frequency increases. And the 3/2 island survives. After the ECRH is switched off at t = 610 ms, the amplitude of 3/2 island quickly drops and disappears following the decreasing of electron temperature and β. The 3/2 mode clearly shows the neoclassical nature driven by plasma pressure. The typical character of a neoclassical island is the linearly dependence between poloidal beta β_p and saturated island width.

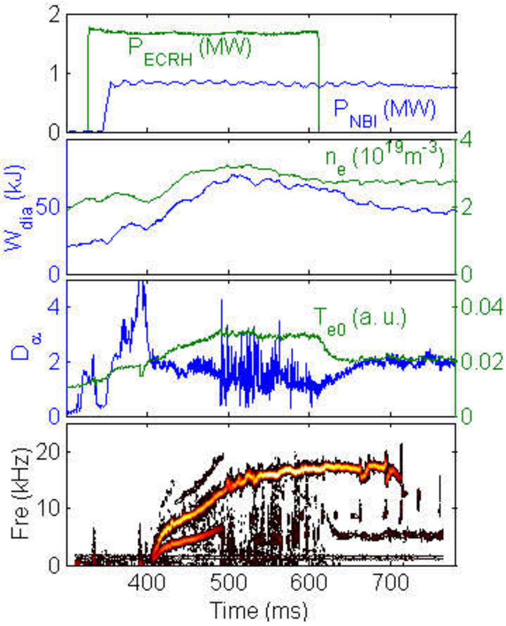

Figure 1. Typical experimental results with the multi-helicity islands, 2/1 and 3/2 onset in HL-2A.

For understanding the mechanism of the mode onset, the detail of the process has been surveyed. Firstly, we found the multi-islands are always triggered in low toroidal rotation plasmas. For the moderate density Ohmic plasmas in HL-2A, the intrinsic toroidal rotation is in the count-current direction. Balanced the intrinsic rotation by the co-current direction NBI, the plasma with a very low toroidal rotation can been carried out. As shown in figure 2, after the co-current NBI system turns on, the count-current rotation can reverse to co-current direction. The toroidal rotation was measured by a charge exchange recombination spectroscopy (CXRS). During this process, a very low rotation plasma can be obtained, as shown in the figure 2, t=510 ms, V_Φ < 10km/s. And the multi-helicity islands are always triggered during this low rotation phase.

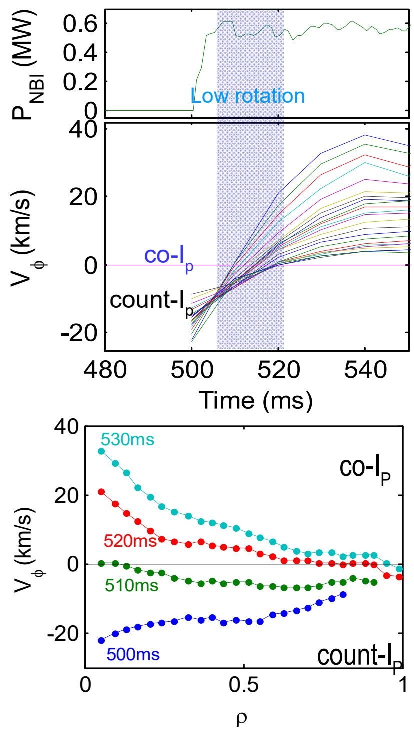

Figure 2. Typical toroidal rotation results with co-current NBI.

The development of a NTM requires a seed island whose island width must exceed a critical width. The seed islands can be generated by other MHD instabilities, such as sawtooth activities, ELMs, fishbones. However, as shown in figure 1(d), no visible MHD mode is observed before the 3/2 NTM onset. For understanding the role of

NTM onset, the detailed studies on development of the two modes have been performed. In the discharges with multi-helicity islands, a minor disruption during low rotation phase are always observed, sudden contraction of temperature profile T_e, soft X-ray sharply decrease and a spike in the total radiated power, as shown in figure 3. For investigating the role of the minor disruption, we calculated the amplitudes of the modes. It is found that the static 2/1 and 3/2 islands (frequency ~0) onset before the disruption, and the phase locked multi-helicity islands induce the disruption.

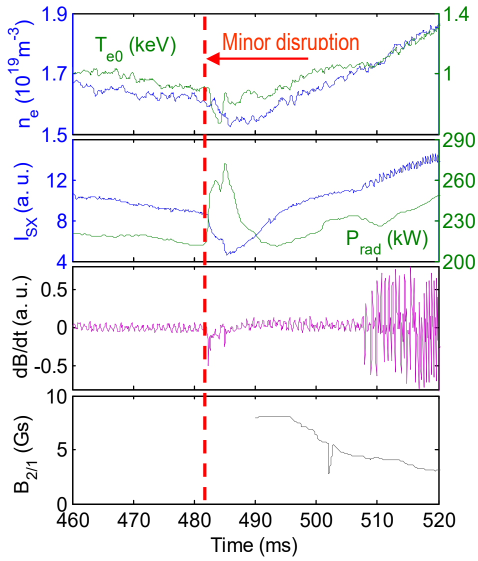

Figure 3. Time traces of signals show the minor disruption during multi-helicity islands existing in the plasma.

Another important character of the multi-helicity islands simultaneous onset is always observed at the relatively low density plasmas with the similar plasma parameters and heating power. As shown in figure 4, a set of similar discharges with different plasma density is compared. The result shows a clear critical value of density (line averaged density $n_e < 2.2\times10^{19}m^{-3}$) for the modes onset. Furthermore, the phase of the static islands can be determined by Mirnov coils. In varies plasma parameters, the spatial phases of 2/1 and 3/2 modes are exactly same, as shown in figure 5. As described above, the non-rotating multi-helicity islands have been

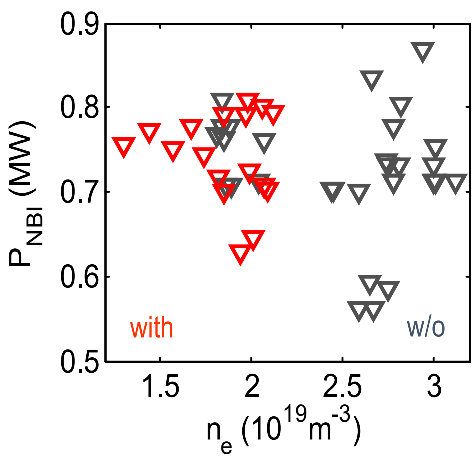

Figure 4. The critical plasma density at the modes onset versus the heating power, P_{NBI}.

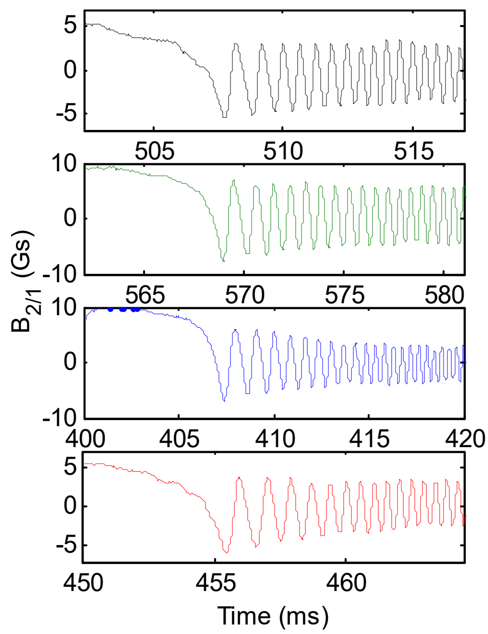

Figure 5. Static the multi-helicity islands with same locking phase in various discharges.

observed in low density, low rotation plasmas. The 3/2 island has the typical neoclassical character. And, the static islands onset with a same spatial phase. From there characters, the possible mechanism for the modes onset is induced by the non-axisymmetric error field. As we know, the threshold error field for generate locked modes decreases with decreasing plasma density and plasma rotation.

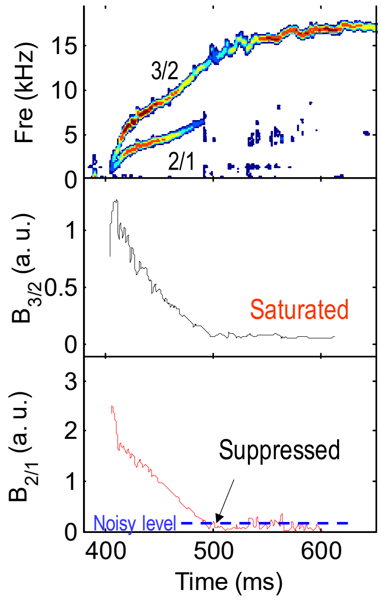

Figure 6. Time traces of 2/1 and 3/2 mode amplitude evolution influenced by the sheared flow arising from the momentum injection.

The influence of toroidal sheared flow arising from the co-I_p NBI on the nonlinear evolution of the multi-helicity NTMs has been investigated in HL-2A. The 2/1 mode is always suppressed due to the injected momentum. However, the 3/2 mode survives, as shown in figure 1 and figure 6.

Summary. In HL-2A low rotation and relatively low density plasmas, the critical threshold of the intrinsic error field penetration will be decreasing. And the multi-helicity islands can be seeded by the non-axisymmetric error field penetration, and lead to the change of rotation profile, enhanced transport or even disruption. Sheared flow arising from momentum injection can suppressed the coupled islands. For understanding the experimental results, numerical modelling will be carried out by means of reduced magnetohydrodynamic simulations. The results provide important evidence for NTMs stability predictions and their nonlinear dynamic in the low flow plasmas, such as ITER.

Reference.

[1] ITER Physics Basis 1999 Nucl. Fusion 39 2137

[2] La Haye R.J. et al 2002 Phys. Plasmas 9 2051

[3] Yu Q., Gunter S. and Lackner K. 2000 ¨ Phys. Rev. Lett 85 2949

[4] Sauter O. et al 2002 Plasma Phys. Control. Fusion 44 1999

[5] L. Wei et al 2016 Nucl. Fusion 56 106015

[6] Gerhardt S.P. et al. 2009 Nucl. Fusion 49 032003