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Influence of anisotropic pressure on the locking of 2/1 tearing modes in TEXTOR

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Abstract

A significant influence of anisotropic pressure induced by tangential neutral beam injection (NBI) on the locking of the m/n = 2/1 tearing mode has been observed in TEXTOR, where m, n are poloidal and toroidal mode numbers. A large 2/1 island (width ~8 cm; ~17% of plasma minor radius) near half plasma radius is seeded by application of a static (dc) or rotating (ac) perturbation field with the Dynamic Ergodic Divertor (DED) in 3/1 configuration on TEXTOR. The 2/1 island is locked to the external perturbation field, i.e. it has zero frequency when the DED is operated in dc. In the dc case, the island stays locked for a few hundred ms after switch off of the DED field, starting to spin up after co-NBI (P_{NBI}> 300kW) has been switched off. The persistent locking of the 2/1 island after switch off of the external perturbation field can be attributed to coupling with an *m/n*=1/1 internal kink mode enhanced by a significant anisotropic pressure in the NBI heated plasmas.

Introduction

Recently, DED on TEXTOR (R_0=1.75m, a =0.46m, where R_0 is the major radius and a is the radius of the last closed flux surface defined by the location of the ALT limiter on TEXTOR[1]) has been operated with m/n = 3/1 configuration for both, dc and ac at various fixed frequencies. For ac operation, the perturbation field can be rotated in co and counter current direction. A large 2/1 island with a frequency locked to the external perturbation field is seeded near half plasma radius by a strong m/n = 2/1 sideband of the DED perturbation field in a wide operation regime on TEXTOR[2]. A time delay (τ_{unlock}) until the previously locked mode spins up (so called unlocking) after complete switch off of the perturbation field has been observed in plasmas with dc DED[3]. A strong influence of anisotropic pressure induced by tangential NBI on the locking process of the 2/1 island has been experimentally observed.

Experimental setup

A plasma rotation scan by adjusting the balance of the input powers between co- and ctr-NBI, for constant total input power, P_{total}=1.3MW, has been performed for studying the stability of the 2/1 tearing mode on TEXTOR. A target plasma (I_p=300kA; B_t=2.25T) is produced with keeping a constant central line-averaged electron density at $2 \times 10^{19} m^{-3}$ by feed-back control.

Observation of locking of the 2/1 mode by co-NBI

Figure 1(a) shows the time evolution of radial line-integrated soft x-ray emission profiles measured by a vertical soft x-ray camera in a plasma with predominantly ctr-NBI heating ($P_{ctr\text{-}NBI}$=875kW; $P_{ctr\text{-}NBI}$=425kW). The coil current of DED was slowly ramped up to 3.75kA during 1.2s to 3.4s and ramped down to zero at 3.93s. When I_{DED} exceeds =0.75kA, the onset of a locked m/n=2/1 island at r=0.2m has been observed, where r is the geometrical minor radius without accounting for the effect of the Shafranov shift. The width of the m/n = 2/1 mode derived from the flattening of the x-ray emission profile is about 8 cm with I_{DED}= 3.75kA, which is 17% of the minor radius of the plasma. Once an m/n = 2/1 island has been created by the perturbation field, the sawtooth instability disappears, and a 1/1 internal kink mode coupled with the 2/1 mode is observed. No clear change in inversion radius of the sawteeth is seen before the 2/1 mode starts. The 2/1 island unlocks when I_{DED} is reduced to 0.1kA. The frequency of the 2/1 mode quickly increases up to 2.7 kHz before the NBI is switched off. However, when co-NBI heating becomes dominant, the mode will not spin up as long as the co injection is active (see Fig.1 (b)). In this discharge heated by co-NBI only, unlocking of the mode occurs after switching off the beam. There is no clear difference observed in the location and the width of the 2/1 island between co-NBI and ctr-NBI dominated plasmas.

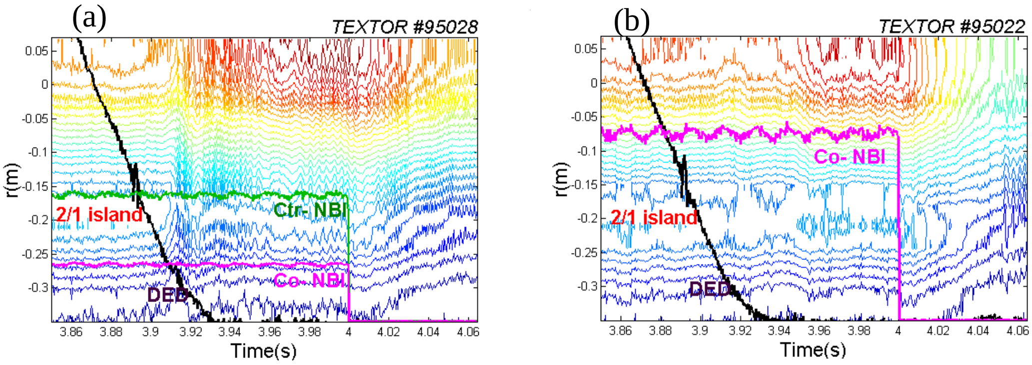

Figure 1 *Contour plot of line-averaged x-ray intensities (SXI) measured by a vertical soft x-ray camera in (a) ctr-NBI dominated ($P_{co\text{-}NBI}$=425kW; $P_{ctr\text{-}NBI}$=875kW;) and (b) co-NBI only heated plasmas. The flattening in the SXI profile near r=-0.2m at high field side is caused by a large 2/1 islands (width ~8 cm; ~17% of plasma minor radius). The timings of DED; co- and ctr-NBI are indicated.*

Observation of anisotropic pressure induced by co-NBI

Figure 2 (a) shows both, T_e and n_e profiles, at different times before and after the 2/1 island excitation in the plasma heated by co-NBI only. Before the 2/1 island sets on, the Shafranov shift, ΔS, determined from the T_e (ΔS^{Te}) and n_e (ΔS^{ne}) profiles, respectively, are similar, and is about 7cm. However, when the 2/1 island is seeded in the plasma, a clear drop in T_e has been observed, while the central n_e does not change much due to the density feed-back control. The flattening in the n_e profile at R=1.5m and R=2.0m indicates the location of the 2/1 island. No flattening is observed in the T_e profile measured by ECE. This is due to a difference in the toroidal angle of the diagnostic locations T_e and n_e. Here, the T_e profile is measured along a line of sight through two x-points of the locked 2/1 island while the sight lines of the n_e measurement pass two O-points. ΔS^{ne} observed at t=2.9s is little bit smaller than that before the island onset, which is in agreement with the decrease in β measured with the diamagnetic loop. However, a large increase of the outward shift of ΔS^{Te} (ΔS^{Te} = 13cm) has been observed even β is decreases due to the excitation of the 2/1 island in the plasma. It has been found that ΔS^{Te} decreases quickly from 13 to 10.2 cm when the co-beam fraction $P_{co\text{-}NBI}$/ P_{total} is reduced from 100% to 61%, and ΔS^{Te} saturates at 9.6cm when $P_{co\text{-}NBI}$ is only 32% of total input beam power as shown in Fig. 2(b). On the other hand, there is no clear change of ΔS^{ne} observed in the plasmas with a different $P_{co\text{-}NBI}$/ P_{total}. No data is available below 32% of $P_{co\text{-}NBI}$/ P_{total}, because the threshold for 2/1 mode onset is not reached at maximum DED current I_{DED} (3.75kA). The increase in ΔS^{Te} is considered to be due to anisotropic pressure ($P_{parallel}$>$P_{perpendicular}$) induced by NBI tangentially injected into a low density plasma.

Discussion and Conclusion

In the phase before the 2/1 mode onset, the direction of the toroidal plasma rotation, V_{tor}, strongly depends on the direction of the beam. However, once the 2/1 island is locked, the sawteeth are found to become stabilized and a 1/1 internal kink mode coupled with the 2/1 mode has been observed. The absolute values of V_{tor} in the plasma core and at the q=2 surface drop quickly, and the profile of V_{tor} inside of q=2 surface becomes more flattened due to the mode coupling. Furthermore, V_{tor} is equal to the diamagnetic rotation when the 2/1 mode locks and the difference in V_{tor} for plasmas with a different $P_{co\text{-}NBI}$/ P_{total} becomes negligible because the total input heating power is kept constant.

Once the perturbation field excites the 2/1 island in NBI heated discharges, the energy confinement time degrades from ~30ms to 18ms, which is much smaller than the beam slowing down time of about 50ms. On the other hand, the shape of the magnetic flux surfaces within the q=2 surface is significantly modified due to the large size of the 2/1 island. It is horizontally elongated at the toroidal position where one X-point is orientated towards the low field side (LFS), and vertically elongated where the O-point is located at the LFS. The measured Shafranov shift of the magnetic axis in the horizontally elongated section is much larger than that in the vertically elongated section due to a significant fraction of parallel beam pressure. Because of an increased orbit loss of fast beam particles in counter-NBI heated discharges, the pressure anisotropy is smaller than in the co-injected case, which agrees with the experimental observation as shown in Fig. 2(b). In ac 1kHz DED operation, the frequency of the 2/1 islands decays exponentially towards zero after switch off of the DED, and stays locked up to switch off of the co-NBI. The persistent locking of the 2/1 island after switch off of the external perturbation field can be attributed to a large destabilizing effect due to coupling with an *m/n*=1/1 internal kink mode enhanced by a large anisotropic pressure in the NBI heated plasmas.

On TEXTOR, the beam power scan has also been done with the same target plasmas heated by co-NBI only. The power threshold of $P_{co\text{-}NBI}$ for keeping the 2/1 island locked until switch off of the beam is about 300kW at a beam energy of 50keV. In plasmas heated by ICRH only, the 2/1 island always spins up after switch off of the DED, since there is no anisotropic beam pressure effect.

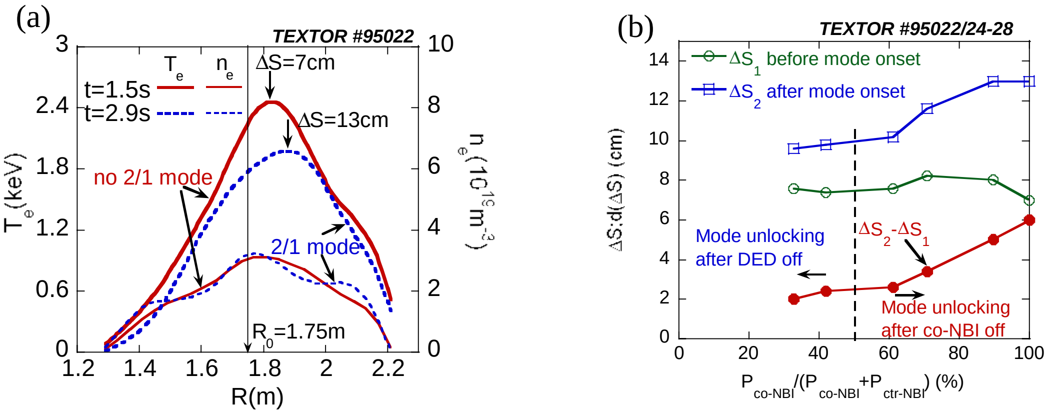

Figure 2 *(a) Radial profiles of T_e (thick) and n_e (thin) measured before (solid) and after (dashed) the 2/1 tearing mode onset in the plasma heated by co-NBI only ($P_{co\text{-}NBI}$=1.3MW). (b) Shafranov shift (ΔS) as a function of the ratio of input co-NBI power to the total beam power in the cases, before (open circle) and after (square) the 2/1 mode onset. Here, the total input beam power is kept constant (1.3MW). d(ΔS) is the difference in ΔS before and after the mode onset.*

These experimental results show a strong influence of anisotropic pressure on the stability of tearing modes, which should be accounted for when the (neo-classical) tearing mode scaling for future machines (e.g. ITER) is derived on present experiments.

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