*31st EPS Conference on Plasma Phys. London, 28 June - 2 July 2004 ECA Vol.**28G**, P-1.126 (2004)*

Observation of mode structure and mode locking using the Dynamic Ergodic Divertor on TEXTOR

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Abstract

The m/n=2/1 and 3/1 tearing mode structures generated by the dynamic ergodic divertor (DED) perturbation field on TEXTOR have been investigated using the soft x-ray pin diode arrays, SXR. When the DED coil current, I_{DED}, overcame a critical value, I_{DED}^{C}, the m/n=2/1 mode with a width Δd ~ 8cm could be observed near half radius (a=46 cm). The I_{DED}^{C} for the onset of the 3/1 mode is found to exceed that of the 2/1 mode, and the island is located near the plasma edge r_{eff} ~0.8 having a width of ~2 cm, where r_{eff} is the effective minor radius. The phase for both, the 2/1 and the 3/1 modes, is locked to the external perturbation field; the islands are stationary in the DC case. In the DC case, the island may stay locked for a few hundred ms after switch off of the DED, starting to spin up after the co-NBI has been switched off. These experimental results suggest that in TEXTOR the ctr-NBI beam can stabilize the 2/1 tearing mode whereas the co-beam destabilizes.

Introduction

Recently, DED on TEXTOR has been operated with poloidal (m) and toroidal (n) mode numbers m/n = 3/1 for both, DC and AC and for various frequencies. For AC operation, the perturbation field can be rotated in co and counter current direction. A strong influence of a large m/n = 2/1 sideband, created by DED, on the MHD behaviour has been observed.

Experimental setup

On TEXTOR, four soft x-ray pin diode cameras SXR, viewing the plasma in a poloidal plane from top (2 × 20 channels) and from the low field side (2 ×16 channels), are used to study MHD phenomena. Assuming the x-ray emission to be constant on a magnetic flux surface, the shapes of the internal flux surfaces can be inferred from the emission profiles measured by SXR. The spatial resolution in each soft x-ray camera is about 2 cm within the plasma.

Observation of the 2/1 and the 3/1 modes generated by the DED perturbation field

Figure 1(a) shows the time evolution of radial line-integrated soft x-ray emission profiles measured by a vertical soft x-ray camera for a co-NBI heated plasma with Ip=300kA; n_e ~ $2x10^{19}m^3$; Bt=2.25T; DC DED. I_{DED} was slowly ramped up to 3.75kA during 1.2s to 3.4s and ramped down to zero after 3.9s. When I_{DED} exceeds I_{DED}^{C}=0.75kA, the onset of a locked m/n=2/1 island at r=0.2m has been observed, whereby r is the minor radius calculated without counting the effect of a Shafranov shift. The location of the two O-points of the locked 2/1 island depends on the toroidal angle (Φ=292 degree) and the phasing of DED. They are observed by SXR at θ~210 and ~30 degree, which is consistent with the DED design data and results from other diagnostics (i.e. T_e and n_e measurements located at different toroidal position). A non-linear growth of the 2/1 island has been observed when

$I_{DED} > I_{DED}^{C}$; the width of the m/n = 2/1 mode derived from the flattening of the x-ray emission 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 central line integrated electron density, the central electron temperature and β suddenly drop, likely due to a loss of confinement within the plasma core. At the same time, the sawtooth instabilities disappear. No clear change in inversion radius of the sawteeth is observed before the 2/1 mode appears. Radiation peaking inside the island has been found for strong gas puffing or high-Z impurity injection. This indicates an accumulation of impurities or bulk particles inside of islands [1].

When I_{DED} is increased further, the onset of a locked m/n=3/1 island is observed in the DC mode. Figure 1(c) shows the time evolution of the radial line-integrated x-ray emission, measured at the plasma edge (r/a=0.3/0.46 to 0.44/0.46m) in a discharge with Ip=300kA; $n_e \sim 2x10^{19}m^3$; Bt=2.25T. Here, a =0.46m is the minor radius of plasma, defined by the location of the ALT limiter in TEXTOR. I_{DED} was ramped up to 3kA from 1.52s to 1.73s, kept constant until 3.7s and switched off at 3.93s. To enhance the x-ray emission at the plasma edge, neon gas was puffed from 1.3s to 1.7s. For I_{DED} in excess of 2.8kA, a 3/1 island is observed at r ~0.37cm with a width of ~2cm at the HFS, as shown in Fig.1 (c) (d). The effects of the 3/1 tearing mode on the central T_e and n_e are less pronounced as the effect of the 2/1 mode. However, a remarkable increase from 40% to 60% in the radiation fraction, $\gamma = P_{rad}/P_{total}$, has been observed when the 3/1 mode formed at the plasma edge. When I_{DED} is ramped down below I_{DED}^{C} of the 3/1 mode, γ drops back to the original level [2]. Here, P_{rad} and P_{total} are the total radiation power and total input power, respectively. This result suggests that the 3/1 mode does only appear if $I_{DED} > I_{DED}^{C}(3, 1)$ and it is more stable than the 2/1 mode.

Operating DED with a frequency of 1 kHz in co rotation can induce a rotating m/n=2/1 mode which is phase locked to the external perturbation field. The rotation of the mode both, in poloidal and toroidal direction as measured by SXR and sets of fast Mirnov-coils coincides with the DED rotation. The location of the 2/1 mode is not much different from that in DC mode, but it is slightly smaller ~5cm with I_{DED}=2kA. In 1 kHz counter rotating DED, the onset of the 2/1 mode is rarely observed with I_{DED} below 2.5kA. In few discharges, the 2/1 mode appeared, triggered by accidental impurity influx. The value of I_{DED}^{C} for the onset of the 2\1 tearing mode in both DC and AC DED strongly depends on plasma parameters such as plasma density, toroidal rotation, β, and plasma current [3].

Observation of unlocking of the 2/1 mode

The time delay (τ_{unlock}) of the spin-up the previously locked mode (so called unlocking) after complete switch off of the perturbation field has been observed in the plasmas with DC DED. Both, β and the plasma rotation scans, have been performed. For a target plasma (Ip=300kA; Bt=2.25T), the central line-averaged electron density is kept constant at $2x10^{19}m^{-3}$ by feed-back control. For the β scan, the plasma pressure is changed by using ICRH (0.8-4.5s) with different powers (P_{ICRH}) levels of 500kW, 800kW, 1100kW and 1400kW, respectively. Co-NBI is applied with a power of 180kW for diagnostic purposes. DED is on from 1.26s to 3.52s with I_{DED}=2.0kA. The experimental results show that τ_{unlock} is decreasing with increasing P_{ICRH}, which agrees to theoretical predictions [4].

In a plasma rotation scan, the plasma toroidal rotation is changed by adjusting the balance of the input powers between co- and ctr- NBI, for constant total input power. DED is on from 1.2s to 3.9s with maximum I_{DED} of 3.75kA. Figure 2(a) shows the frequency spectrum of an SXR channel near the q=2 surface measured in a plasma with predominantly ctr-NBI heating. The mode unlocks 33ms after DED is switched off. The frequency of the

2/1 mode quickly increases up to 2.7 kHz before the NBI is switched off. τ_{unlock} decreases when the contribution from ctr-NBI increases. However, when co-NBI becomes dominant, the mode will not spin up as long as the co injection is active (see in Fig.2 (b)). In the discharge heated by co-NBI only, unlocking of the mode occurs 52ms 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 (see in Fig. 2 (c)). Figure 2(d) shows the difference in toroidal rotation (v_{tor}) profiles measured by charge exchange spectroscopy between the two discharges shown in Fig. 1(a) (b). In the phase before the 2/1 mode onset, the direction of the central v_{tor} strongly depends on the direction of the beam. However, once the mode is locked, the difference in the v_{tor} profiles between these two cases becomes negligible.

Summary

The structure of the m/n=2/1 and 3/1 islands generated by DED perturbation fields have been measured by SXR cameras on TEXTOR. The survival of a locked island during a few hundred ms after DED switch off has been observed in co-NBI heated plasmas. The experimental results suggest that ctr-NBI can stabilize the 2/1 tearing mode whereas it is destabilized by co- injection.

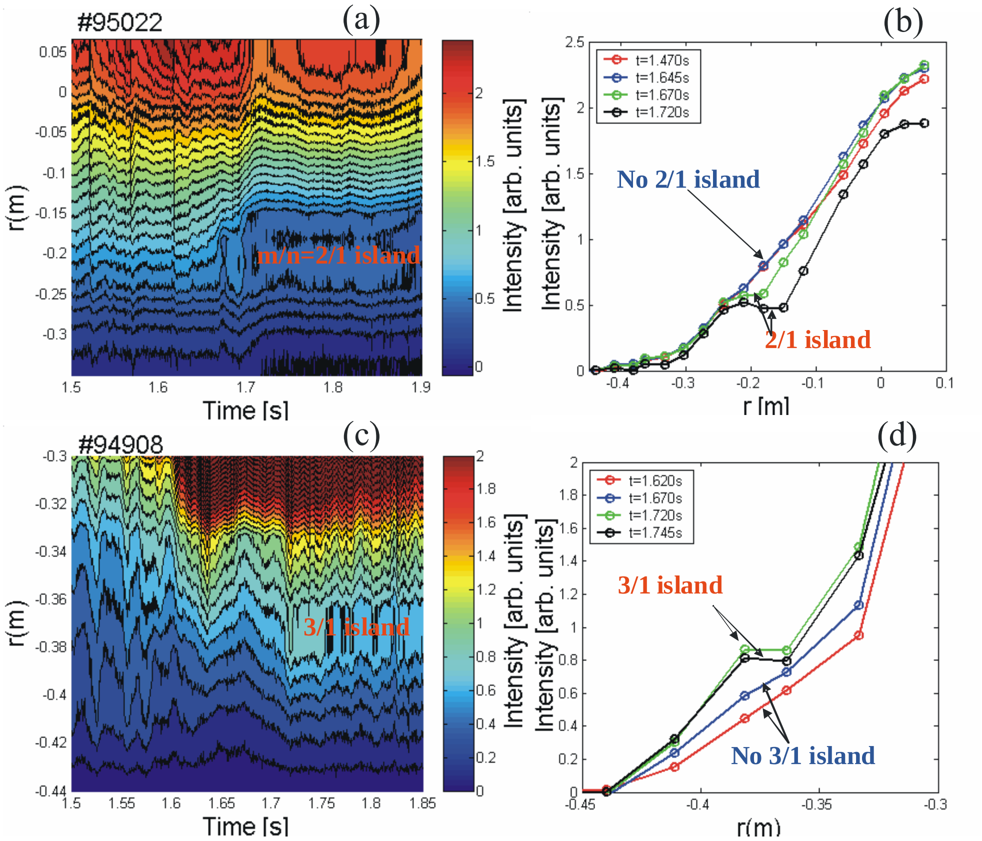

Figure 1 Contour plot of line-averaged x-ray intensities (SXI) at (a) plasma core and (c) at plasma edge measured by a vertical soft x-ray camera in DED plasmas. (b) and (d) radial profiles of SXI measured in the time interval for the plasmas shown in (a) and (c), respectively. The flattening of SXI indicates the location and the width of (b) the 2/1 and (d) the 3/1 islands. To enhance the x-ray emission at the plasma edge, neon gas was puffed [(c) and (d)] from 1.3s to 1.7s.

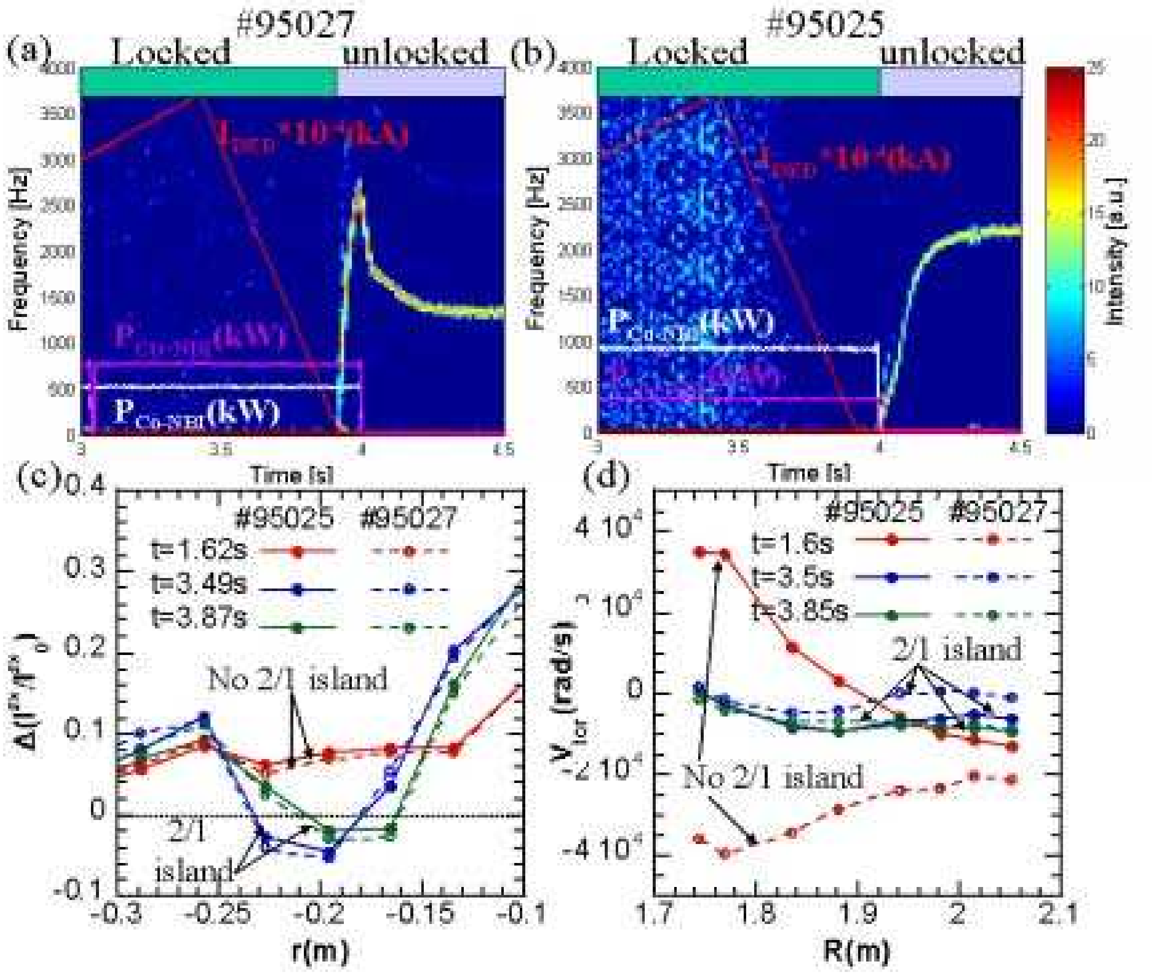

Figure 2 Spectrogram of one line-averaged x-ray intensities (SXI) near the q=2 surface measured in (a) Ctr-NBI dominated (#95027) and (b) co-NBI dominated (#95025) plasmas. Radial profile (c) of gradients of SXI and (d) plasma toroidal rotation velocity in the time before onset of the 2/1 mode (t=1.62s); with maximum DED current (t=3.5s) and just before DED switch-off (t=3.85s) are compared for the two plasmas shown in (a) and (b). All time durations of DED; co- and ctr-NBI are indicated in figure (a) and (b).

References

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