

## Experimental observations of the X-point collapse and secondary islands with a resonant rotating perturbation field in TEXTOR

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**Abstract** The influence of a rotating external perturbation field induced by the Dynamic Ergodic Divertor (DED) on the mode locking and unlocking processes has been studied on TEXTOR. Internal plasma minor disruptions at  $q=2$  surface occurring during the process of locking of a  $m/n=2/1$  tearing mode has been observed. The plasma confinement collapses at the X-points (X-point collapse) of the  $2/1$  islands chain without much effect on the width of the islands (O-points). With an external rotating perturbation field, the locked mode disruption can be avoided. The width of the  $2/1$  island was reduced when the locked  $2/1$  mode was spun up by the external rotating perturbation field. Secondary islands around a large  $2/1$  island ( $>8\text{cm}$ ) have been observed by using ac DED on TEXTOR. The rotation frequency of the secondary islands is locked to the frequency of the external perturbation fields. The secondary island disappears when the  $2/1$  island becomes smaller (less than  $6\text{cm}$ ). The plasma confinement suddenly improved when the secondary islands vanished.

**Introduction** Experimental and theoretical studies of plasma disruptions caused by a locked mode have been investigated since the early stage of magnetically confined fusion plasma physics research, because the disruptions and related vertical displacement events induce many unacceptable problems (i.e. sudden thermal loading on the first wall, vessel halo currents and high energy runaway electrons) for future fusion reactors [1-3]. During the process of mode locking, internal plasma minor disruptions (where the plasma confinement is recovered after each collapse) at the  $q=2$  surface, have been often observed before a major disruption in many devices [4]. Suppression of a tearing mode has been performed experimentally with different methods, i.e. ECRH localized heating and current driving (ECCD) [5]. Recently, the influence of the electromagnetic torque induced by an external static/rotating Resonant Magnetic Perturbation (RMP) on the tearing mode rotation has been studied experimentally and theoretically [6-10].

On TEXTOR ( $R_0=1.75\text{ m}$ ,  $a=0.47\text{ m}$ , circular plasma cross section), the Dynamic Ergodic Divertor (DED) at the high field side produces either a static (dc) or a rotating (ac) helical RMP with frequencies of up to  $10\text{ kHz}$  in either co- or counter-direction with respect to the plasma current.

Previous experiments have shown that the DED in  $m/n = 3/1$  configuration (where  $m$  and  $n$  are the poloidal and toroidal mode numbers, respectively) is a good tool for the investigation of tearing mode related physics due to a large  $m/n = 2/1$  sideband perturbation [9 10]. In this paper we report on experimental observations of (i) internal plasma minor disruptions at the  $q=2$  surface occurring during the process of mode locking, (ii) secondary islands [11] generated around the large  $2/1$  island, and (iii) avoidance of plasma disruptions due to a locked  $2/1$  tearing mode by the application of a rotating RMP.

#### Experimental observations

Internal minor disruptions often happen when the  $2/1$  island grows and finally locks on TEXTOR. Furthermore, a major plasma disruption can be initiated by the locked mode. The experimental results are based on both, measurements of the soft x-ray emission profiles and  $T_e$  profiles, which shows that sudden collapse events occurring at the  $q=2$  flux surface without much influence on the  $2/1$  island, and there is strong evidence that these happen at the X-point of the island (X-point collapse). Figure 1 (a) and (b) show the time evolution and radial profiles of soft

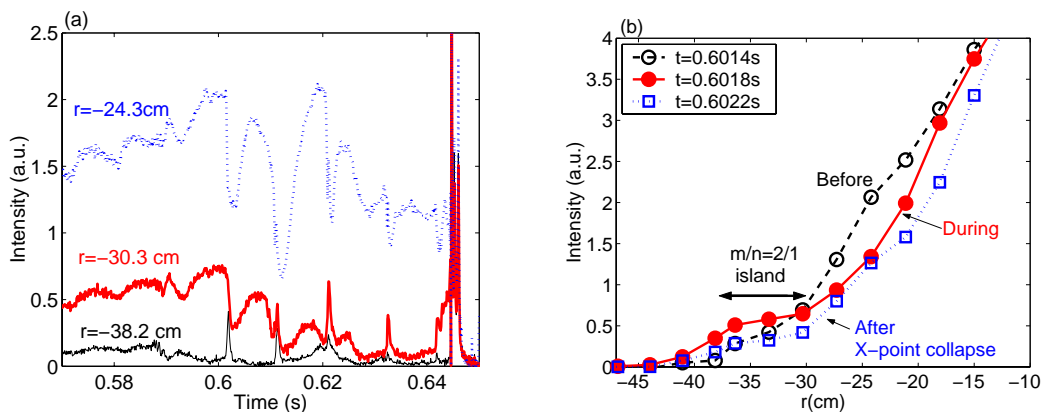


Figure 1 (a) Time evolution of line-integrated x-ray emission near the  $q=2$  surface and (b) radial profiles of x-ray emission measured by a soft x-ray camera viewing the high field side of plasma.

x-ray emission near  $q=2$  surface measured by a soft x-ray camera viewing the HFS in a discharge terminated after several internal minor disruptions due to a locked mode. The target plasma had a plasma current,  $I_p$ , of 400 kA and a magnetic field,  $B_t$ , of 1.9 T. A  $2/1$  island appears at  $t \sim 0.59$  s, and it is located at a plasma radius of  $r = 0.32$  m where a flattening in the x-ray emission profiles is observed. A non-linear growth of the island has been seen when the mode rotation frequency slows down to zero, and the sawtooth oscillation disappears. The x-ray emission profiles measured during one minor disruption clearly shows that the crash event happens at the  $q=2$  surface where a large  $2/1$  island is formed. There is no significant influence of the minor disruptions on the width of the  $2/1$  island observed. The loss of central plasma confinement due to the crash is relatively smaller than that near  $q=2$  surface.



the 2/1 island width down to  $\sim 6$  cm, and the secondary islands disappear as seen in Fig. 2 (e). A sudden increase in the plasma diamagnetic energy by  $\sim 13\%$  has been observed at the time when the secondary islands vanish. No significant further change of the width of the 2/1 island is observed even when  $I_{\text{DED}}$  is increased up to 3.75 kA. The plasma is stable during the application of the rotating RMP, however, it disrupts later due to a non-linear growth of the locked 2/1 mode after switch-off of the DED.

**Discussion and Conclusion** Spin-up of a locked 2/1 mode to the frequency of the external RMP induced by the DED is observed on TEXTOR. It is considered to be due to a toroidal momentum transfer through an electromagnetic torque  $J_{\phi} \times B_r$ , where  $B_r$  is the radial component of the external RMP and  $J_{\phi}$  is the toroidal component of plasma current flowing in the island region. Secondary islands rotating around the large locked 2/1 island have been observed when a low level of an external RMP is applied. The rotation frequency of the secondary island is locked to the frequency of the RMP, and it shows an evidence that a velocity shear could be generated near the resonant surface ( $q=2$ ) by the electromagnetic torque induced by DED when the frequency of the 2/1 mode is far below the frequency of the RMP ( $f_{2/1} < f_{\text{DED}}$ ). The reduction of island width during the process of mode unlocking with a rotating RMP has been observed, and it can be explained by a velocity shear near the resonant surface, which has a stabilizing effect on the island [7]. Secondary islands disappear when the width of the 2/1 island dropped down to  $\sim 6$  cm, and a sudden recovery of plasma confinement occurs. A similar observation has been also found by changing the rotation direction of the RMP from co- to counter-current direction. The experimental results also show that the plasma major disruption due to a locked mode can be avoided by active control of the frequency of the tearing mode with a rotating external RMP. This mechanism is of importance for active MHD control in future machines, e.g. ITER.

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