*31st EPS Conference on Plasma Phys. London, 28 June - 2 July 2004 ECA Vol.**28G**, P-1.124 (2004)*

Investigation of the excitation of error field modes using the Dynamic Ergodic Divertor at TEXTOR

H. R. Koslowski[1], A. Krämer-Flecken[1], Y. Liang[1], O. Zimmermann[1], K. H. Finken[1], M. von Hellermann[2], R. Jaspers[2], E. Westerhof[2], R. Wolf[1], and TEXTOR-team

[1] *Forschungszentrum Jülich GmbH, Institut für Plasmaphysik, Association EURATOM-FZJ, 52428 Jülich, Germany**

[2] *FOM-Institute for Plasma Physics Rijnhuizen, Association EURATOM-FOM, PO Box 1207, 3430 BE Nieuwegein, The Netherlands*, www.rijnh.nl*

Abstract. *The Dynamic Ergodic Divertor (DED) on the TEXTOR tokamak has been operated in the $m/n = 3/1$ configuration. In this mode of operation the perturbation field penetrates deeply into the plasma and has a strong $m/n = 2/1$ sideband. Above a critical threshold for the DED coil current a $m/n = 2/1$ tearing mode is excited. Systematic investigations of the required error field strength for mode excitation are presented. The critical field increases with plasma density and beta, when ICRH is used to heat the plasma. Counter rotation by tangential neutral beam injection opposite to the plasma current direction stabilizes the tearing mode, too, whereas neutral beam co-injection decreases the threshold for mode onset.*

Introduction. The TEXTOR tokamak ($R = 1.75\,\text{m}$, $a = 0.46\,\text{m}$) is equipped with two tangential neutral beam injectors (1.5 MW each), one injecting in direction of the plasma current (co), the other one in opposite direction (counter). The injected power of each of the neutral beams can be precisely controlled by means of an aperture in the beam line. In addition, ion and electron cyclotron heating systems are available.

The dynamic ergodic divertor (DED) on TEXTOR consists of a set of 16 helical coils mounted on the high field side of the torus [1]. The pitch of the coils corresponds to the $q = 3$ surface in the plasma. Depending on the wiring of the coils to the power supplies magnetic perturbations with poloidal and toroidal mode numbers $m/n = 12/4$, 6/2, and 3/1 can be produced. The DED can be operated statically (dc) or with rotating perturbation field (ac) at various frequencies. The rotation of the external perturbation field in ac mode can be selected to be co or counter with respect to the plasma current direction.

The DED along with the flexible heating systems allows to perform detailed studies of the dependence of the critical error field on plasma rotation, beta, and collisionality.

When the DED is operated in the 3/1 mode a strong $m/n = 2/1$ sideband is created due to toroidal effects. This 2/1 error field induces a 2/1 mode in the plasma. The experiment shows that at some critical level of the external perturbation coil current the error field penetrates and a $m/n = 2/1$ tearing mode is formed. This behavior is found

*partners in the Trilateral Euregio Cluster

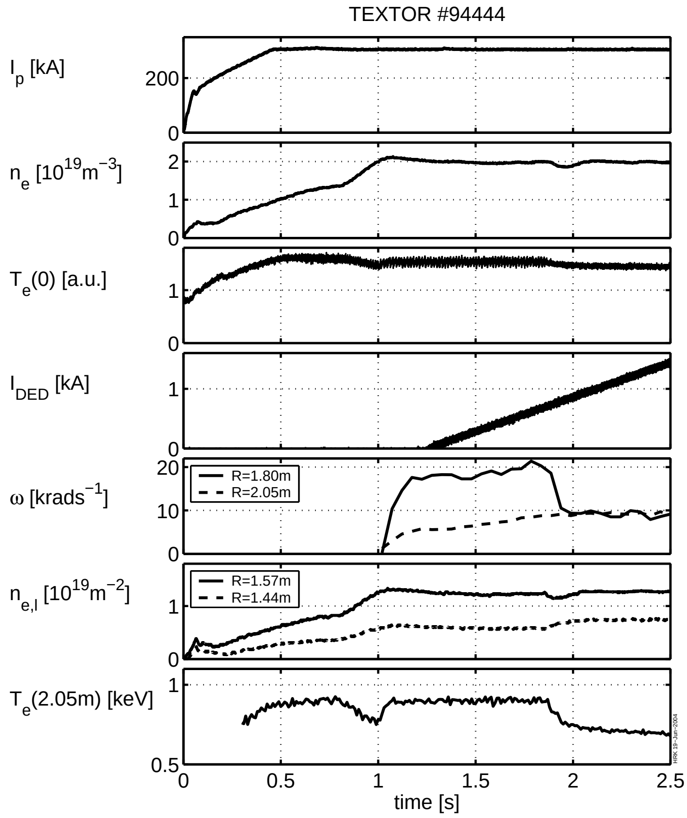

Figure 1: Time traces of various signals showing the time evolution of an experiment with slow DED ramp-up in dc mode. The signals from top to bottom are: plasma current, line-averaged electron density, central electron temperature, DED coil current, toroidal plasma rotation frequency (core and edge), two line-integrated electron density measurements close to the $q = 2$ surface, and the electron temperature at the $q = 2$ surface.

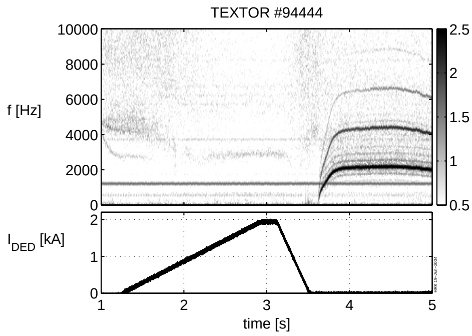

Figure 2: Spectrogram of a magnetic pick-up coil (top), and DED coil current (bottom). The 2/1 tearing mode excited by the error field is locked and starts rotating when the external field is switched off.

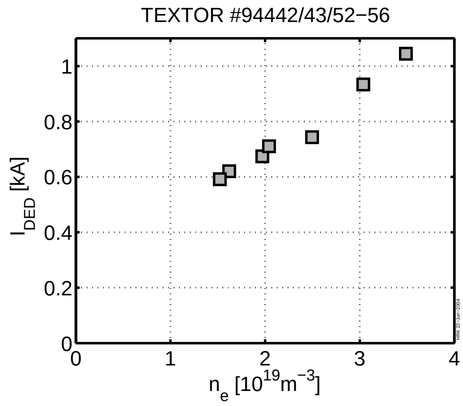

Figure 3: Critical DED coil current at mode onset versus the line-averaged electron density.

to be extremely reproducible and the threshold for mode onset depends on the plasma parameters and the heating scenario. In this paper the dependence of the critical error field amplitude on plasma density, beta, and plasma rotation will be presented.

Description of the error field experiment. The time traces of various signals for a typical discharge where a $m/n = 2/1$ tearing mode is excited by the external perturbation field are shown in figure 1. The experiments are performed at a toroidal field of $B_t = 2.25\,\mathrm{T}$. The plasma current is ramped up to 300 kA. This corresponds to a cylindrical edge safety factor of $q_a = 4.5$. For these plasma conditions the DED can be operated up to the maximum current of 3.75 kA/coil. At lower edge safety factors the induced mode leads to a disruption. The line-averaged electron density has been chosen to be $2 \times 10^{19}\,\mathrm{m}^{-3}$ and is ramped-up to this value before $t = 1\,\mathrm{s}$. At the same time neutral beam co-injection with about $P = 300\,\mathrm{kW}$ is applied, mainly to serve as a diagnostic beam for the charge exchange diagnostic. Electron density and temperature are stable during the flat-top of the discharge and regular sawtooth oscillations are present. At $t = 1.3$ s the slow current ramp-up in the DED coils starts. When the DED coil currents reach a critical value of 700 A at 1.87 s a $m/n = 2/1$ tearing mode is excited and grows rapidly to its saturated size. The mode onset is clearly visible in the drop of the line-averaged electron density (which is only transient because the feedback system reacts in order to restore the density value prior to the tearing mode). The local electron temperature at the $q = 2$ surface (located at $R = 2.05$ m at the low field side) decreases due to the enhanced transport caused by the mode. The line-integrated electron density measurements at the high field side show a drop inside the $R_{q=2}$ and an increase outside. The most striking feature is the sudden modification of the toroidal rotation frequency which shows a drop in the center and indicates rigid body rotation of the plasma inside the $q = 2$ surface after the mode has formed [2]. This braking of toroidal rotation [3] which coincides with the penetration of the externally applied error field is similar to the effect found on e.g. JET [4, 5], DIII-D, and COMPASS-D [6].

Figure 2 shows a spectrogram from a magnetic pick-up coil. Before switch-on of the DED perturbation field no mode is visible. After switch-off the mode, which was created as a locked mode, spins up and can be detected by the pick-up coil. Mode number analysis based on phase comparison of adjacent toroidal and poloidal coils yields the mode numbers $m/n = 2/1$ [7]. There is a slight time delay between switch-off of the DED and the spin-up of the mode. This is discussed in more detail in [8].

Results of parameter scans. The same discharge conditions as shown in figure 1 were applied to investigate the threshold for mode onset as a function of the electron density. The results are summarized in figure 3. The required critical perturbation field strength (which is simply proportional to the coil current plotted in the figure) increases with plasma density. Since the total heating power was kept constant an increase in density corresponds to a decrease in electron temperature. The mode threshold does therefore

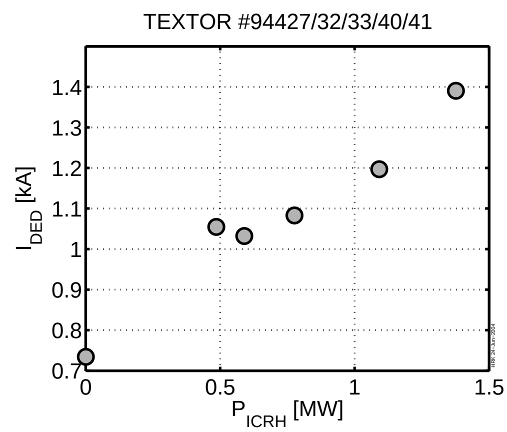

Figure 4: Increase of the threshold for mode onset with ICRH heating power.

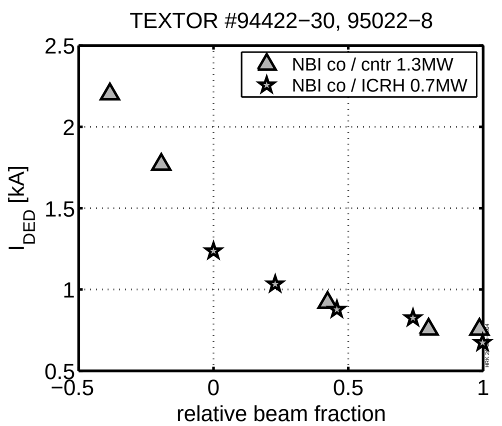

Figure 5: Critical DED current versus the relative fraction of co and counter neutral beam heating.

increase at higher collisionality.

The dependence of the critical perturbation field on plasma beta is illustrated in figure 4. Here a set of similar discharges with various amounts of additional ICRH heating is compared. The data show a clear stabilizing effect of ICRH heating, i.e. an increase of beta. At the highest ICRH power the mode onset threshold is doubled compared to the Ohmic reference case.

In order to investigate the influence of toroidal plasma rotation on the mode threshold (i) a scan of the relative beam power distribution between co and counter neutral beam injection and (ii) a scan where NBI co injection was gradually replaced by ICRH were performed. The results are plotted in figure 5. The total heating power of both beams was kept constant ($P_{NBI} = 1.3\,\mathrm{MW}$), only the relative fractions were varied. The relative beam fraction is defined as $(P_{co} - P_{cntr})/P_{aux}$. A value of 1 corresponds to pure co-injection, -1 means pure counter injection. The electron density and electron temperature at the $q = 2$ surface and β_N were constant within a few %. All data from both experiments line up nicely on a common curve. Any difference in mode excitation threshold may be therefore attributed to the influence of plasma rotation. The data covers a range from $\omega \approx 35\,\mathrm{krads}^{-1}$ for pure co-injection to $\omega \approx -30\,\mathrm{krads}^{-1}$ at a beam fraction of -0.4. The lack of data points at strong counter-injection is due to the fact that even at the maximum DED current no mode onset was observed. The data clearly shows that co-injection is destabilizing whereas counter-injection increases the mode threshold. Experiments where the DED was operated in ac mode with a frequency of 1 kHz gave quantitatively similar result.

Summary and conclusion. Recent results from DED operation in $m/n = 3/1$ mode show that above a critical threshold of the external perturbation field 2/1 tearing modes are excited. Because a static DED field was applied these modes are formed as locked modes and start spinning up when the DED is switched off. A density dependence weaker than linear for the mode threshold is found, in good agreement with JET results [4, 5]. The beta dependence seems to be stronger than determined on JET, whereas the influence on co-injected neutral beam power is opposite. Only counter-injection increases the mode threshold on TEXTOR. The reason for this different behavior is still unclear and further investigations and analysis will be performed in the future.

[1] Special Issue, *Fusion Eng. Design* **37** (1997) 335
[2] M. de Bock et al., this conference, P1-117
[3] R. Fitzpatrick, *Nucl. Fusion* **33** (1993) 1049
[4] R. Buttery et al., *Nucl. Fusion* **40** (2000) 809
[5] E. Lazarro et al., *Phys. Plasmas* **9** (2002) 3906
[6] R. Buttery et al., *Nucl. Fusion* **39** (1999) 1827
[7] O. Zimmermann et al., this conference, P1-123
[8] Y. Liang et al., this conference, P1-126