31st EPS Conference on Plasma Phys. London, 28 June - 2 July 2004 ECA Vol.**28G**, P-1.117 (2004)

Plasma rotation during operation of the dynamic ergodic divertor in TEXTOR

M. De Bock[1], R. Jaspers[1], M. von Hellermann[1], K.H. Finken[2], A.L. Rogister[2]

1. FOM institute for Plasma Physics Rijnhuizen, Association EURATOM-FOM, Trilateral Euregio Cluster, Nieuwegein, The Netherlands, www.rijnh.nl
2. Institute für Plasmaphysik, Association EURATOM-FZJ, Trilateral Euregio Cluster, Forschungszentrum Jülich GmbH, Germany

1. INTRODUCTION

At the TEXTOR tokamak a Dynamic Ergodic Divertor (DED) has recently been installed [1]. The main purpose of the DED is the generation of an ergodic layer at the plasma edge by an externally induced dynamic perturbation field. An effect on the plasma flow velocity might therefore be expected and this is the subject of the present paper.
Three questions will be addressed here:

1. Does the DED give rise to a change of the plasma rotation?
2. What is the mechanism leading to the changed rotation?
3. How do excited modes and their suppression effect the angular rotation?

2. THE EXPERIMENTAL SETUP

The main tool used for the experiments is the DED. The DED consists of a set of helical coils located inside the vacuum vessel of TEXTOR at the high field side [1]. The current that is fed through the coils can be DC, AC^+ and AC^-. AC^+ and AC^- are so called co- and counter rotating scenario, i.e. the currents induce a rotating perturbation field of which the toroidal projection lies along or opposite to the plasma current, respectively, the poloidal projection is in the direction of or opposite to the ion diamagnetic velocity. If the relative velocity between the plasma and the DED field is non-zero, the ponderomotive force will exert a torque on the plasma [2]. The AC operation can be done at different frequencies. We have looked into the effects on toroidal rotation due to DED in DC operation, 1 kHz and 3.75kHz AC^+ and AC^- operation, all in the so called 3/1 configuration.
In order to measure the rotation profiles we use Charge Exchange Recombination Spectroscopy (CXRS). The current CXRS system at TEXTOR (R_0 = 1.75m, a = 0.46m) has 9 lines of sight in the equatorial plane, approximately tangential to the magnetic flux surfaces. With this setup we can measure the toroidal rotation. The observation volumes of the CXRS system are distributed over an area from the plasma centre to 60% of the plasma radius.

3. SPINNING UP OF THE PLASMA ROTATION WITH DED

Upon switching on the DED, regardless of the mode of operation (DC, AC^+ or AC^-), the rotation increases. The plasma always spins up in the co-direction and the increase of rotation is constant over the whole rotation profile. The torque applied to the plasma by the (rotating) ergodic field – the ponderomotive force [2] – cannot explain such a behaviour. The plasma rotation is – due to momentum input by the neutral beam – positive for the presented discharges. This means that, apart from AC^+ operation with a sufficiently high frequency, the ponderomotive force is expected to decrease the plasma rotation. Experiments however show only an increase in co-rotation. This indicates that a second mechanism is influencing the plasma rotation and is dominant over the ponderomotive force.
A completely satisfactory explanation for the increase of toroidal rotation during DED operation has not yet been found. However, using a neoclassical approximation for the change in toroidal velocity [3], it may be shown that a change of the temperature of 50 eV over a region of 5 cm in the plasma edge is sufficient to lift up the entire toroidal velocity profile, including in the plasma core, by 20 km/s, which is the maximum observed increase. On the other hand, one could expect non-ambipolar plasma flow along open magnetic lines in the ergodic layer (i.e. a faster drain of electrons than of ions out of the plasma). This would cause the build up of a local, positive (i.e. outwards pointing)

radial electric field in the plasma edge. A radial electric field of 2.5 kV/m could explain to an increase of the local toroidal velocity of 20 km/s in the correct direction.

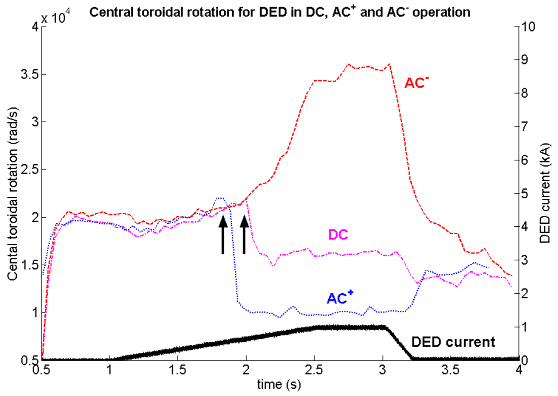

Figure 1 *Increase in rotation is seen in DC, AC^+ and AC^- operation. For DC and AC^+ operation mode excitation occurs which breaks down the rotation (black arrows), for AC^- excitation of the 2/1 mode is avoided and the rotation increases as long as the DED current increases (and decreases when de DED current decreases again)*

When ergodization is the dominant driving force of the increased rotation caused by the DED, it could be expected that increasing the amplitude of the perturbation field – i.e. increasing the current in the DED coils - will increase the rotation. As seen in figure 2 this is indeed the case. Fitting a monotonous function to the data we find an almost cubic relation. Once the DED current reaches a certain value the perturbation field is large enough to excite a 2/1 tearing mode. This is accompanied by a sudden collapse of the rotation (figure 1).

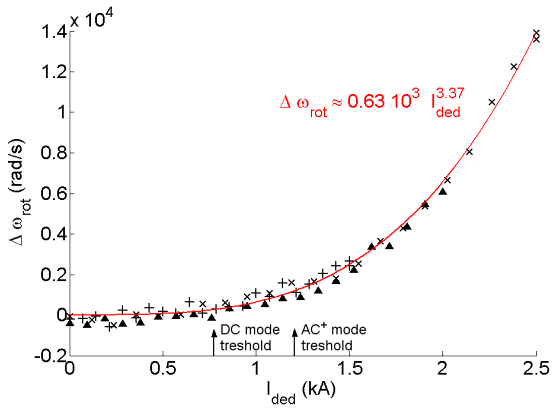

Figure 2 *The increase in rotation plotted against the DED current. A fit to the data with a monotonic increasing function shows approximately a cubic relation. (the different symbols represent different plasma discharges)*

4. MODE EXCITATION

The threshold for excitation of the 2/1 mode depends on the plasma conditions. It increases with β_p, counter-rotation and n_e [4]. For the parameters here investigated the threshold lies around 10^{-3} T for the spatial m/n=2/1 Fourier component of the DED field in DC and AC^+ operation. For AC^- operation the threshold is not very well defined, but in any case lies much higher and mode excitation is usually avoided. On mode excitation the central rotation suddenly collapses, while generally at half radius only a slight or even no decrease of the plasma rotation is observed (figure 3.b). In some specific cases a further increase of rotation at half radius is observed even after the decrease of rotation in the centre. This further increase of the rotation for the outer channels in only temporary. The rotation rapidly decreases again to the value it had at the moment of the mode onset. This temporary increase of the rotation at half radius was observed for DC DED operation where the DED current was slowly ramped to a value close to the excitation threshold (figure 3.a). The drop in rotation is stronger for higher DED frequencies. For AC^+ operation at 3.75 kHz even a change in the direction of the rotation is observed (figure 3.c).

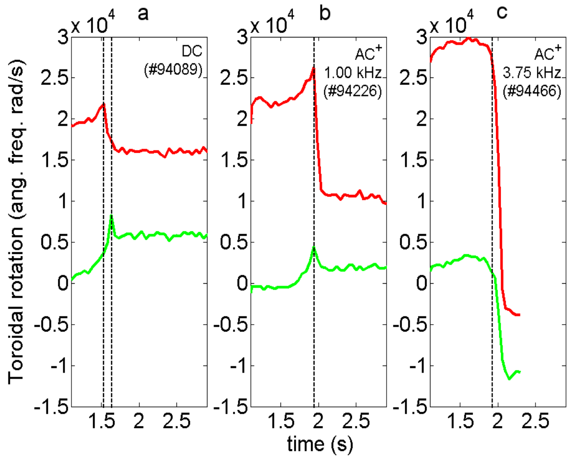

Figure 3 *The effect of mode excitation on the central rotation (red trace R = 1.74m) and on the rotation more towards the edge (green trace R = 2.0 m).*
a) DC operation with a slow current ramp of the DED towards a value close to the excitation threshold. the outer channels still increase while the center has already a decreased.
b) AC+ 1.00 kHz operation. Simultaneous drop of the rotation for central and outer channels. Rotation after mode excitation lower than in the DC case.
c) AC+ 3.75 kHz operation. Rotation drops below zero (rotation changes direction). A disruption follows.

Looking at the rotation profiles one sees a flattening of the profile over an area between 1.84 m and 2.00 m, while the gradients of the profile stay more or less constant over the other parts of the profile (figure 4). The region of constant rotation extends from the experimentally derived position of the 2/1 island (position of q=2) and the area where we determined q=1 before the excitation of the mode (using sawtooth inversion). Although sawteeth disappear when the 2/1 mode is excited, on preliminary MSE data no change of the central q is observed. Moreover, on switching off the DED, the sawteeth immediately reappear with the sawtooth inversion radius at the same position as it had before the mode. This indicates that the position of q=1 is not changed on mode excitation. It is reasonable to believe that the flattened area of the rotation profile lies in between the q=1 and q=2 surfaces. This suggests a coupling between the 2/1 mode and a 1/1 mode. Both on ECE as on soft X-ray signals fluctuations near the q=1 surface are observed; it is however uncertain whether these can be attributed to the presence of a 1/1 mode.
It is important to note that, although the plasma rotation is clearly influenced by the MHD mode, the frequency of the plasma rotation differs from the mode frequency. As seen on Thomson Scattering data for DC [5] and on Mirnov, ECE and soft X-ray signals for AC^+ operation [6,7] the mode frequency is locked to the external DED frequency.

5. ISLAND SUPPRESSION WITH ECRH

Tearing modes jeopardize plasma stability. Therefore island suppression and/or avoidance is an important issue in tokamak physics. On TEXTOR electron cyclotron heating (ECRH) is used to suppress the 2/1 islands that are excited by the DED [8]. As was shown above the excitation of the 2/1 mode has a drastic effect on the rotation. It is expected that suppression of the 2/1 mode will also influence the rotation.

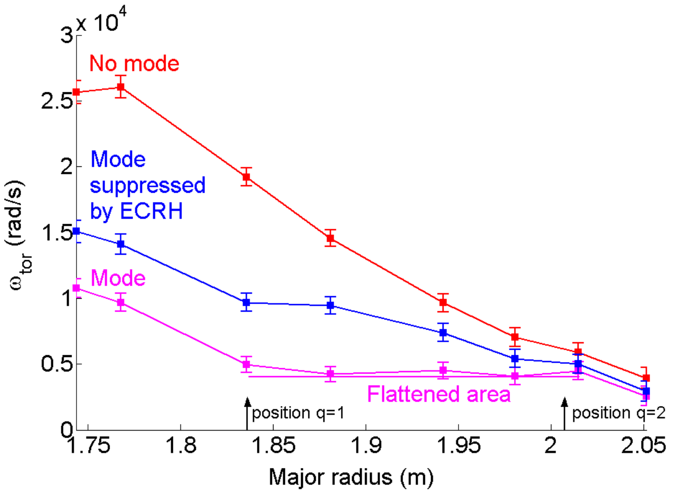

Figure 4: *Rotation profiles before the mode, during the mode and during mode suppression by ECRH. When the mode is present a large area of the rotation profile, extending from the position of q=2 to q=1, is flat.*

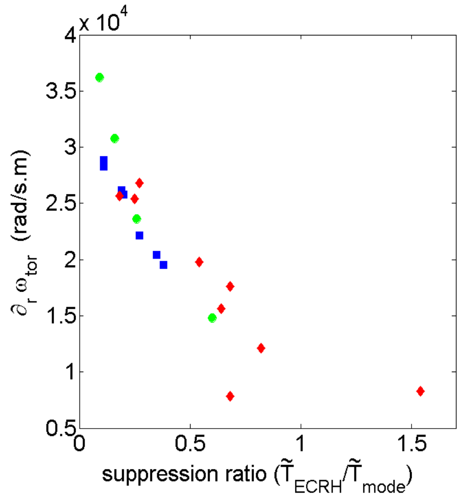

Figure 5: *The gradient of the rotation profile plotted against the suppression ratio determined from ECE signals The green circles are data from an ECRH power scan, the blue squares from a phase scan (relative to the DED) and the red diamonds from a deposition radius scan.*

Experiments done at TEXTOR show that the flat area in the rotation profile gets steeper during the island suppression, leading to a higher central rotation (figure 4). As a measure for the suppression of the 2/1 mode the ratio of fluctuation amplitudes of magnetic (Mirnov coils) and temperature (ECE) signals during and before suppression was taken [8]. Figure 5 shows the average gradient of the rotation profile in between the q=1 and q=2 surfaces against this suppression ratio. It is clearly seen that a lower suppression ratio (i.e. better island suppression) coincides with a larger gradient.

6. CONCLUSIONS

Before the threshold for mode excitation is reached, the dynamic ergodic divertor enhances plasma rotation. The shape of the rotation profile in the plasma core does not change. A more than linear relationship between the strength of the DED field and the increase of rotation has been observed. The observed increase in rotation cannot be explained by the expected torque of the DED field. A satisfactory explanation for the increase in rotation during DED has not yet been found.
The enhanced rotation reaches a limit when the perturbation field of the DED excites a 2/1 tearing mode in the plasma. When this mode is excited the rotation profile is flattened over an area that extends from the q=2 to the q=1 position. This suggest a mode coupling of the 2/1 mode with a 1/1 mode. The frequency of the plasma rotation differs from the rotation frequency of the 2/1 island that is locked to the DED frequency. On suppressing the 2/1 island with ECRH, the gradient of the region that had constant rotation during the mode increases again.

Acknowledgement

This work, supported by the European Communities under the contract of the Association EURATOM/FOM, was carried out within the framework of the European Fusion Programme with financial support from NWO. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

References

[1] K. H. Finken et al., this conference, I2-06
[2] K. H. Finken et al., Nuclear Fucion 41 (5), p. 503 (2001)
[3] Claassen et al., Physics of Plasmas 7 (9), p. 3699 (2000)
[4] H. R. Koslowski et al., this conference, P1-124
[5] S. K. Varshney et al., this conference, P1-127
[6] O. Zimmermann et al., this conference, P1-123
[7] Y. Liang et al., this conference, P1-126
[8] E. Farshi et al., this conference, P1-12