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# Effects of ECRH on magnetic islands created by the TEXTOR Dynamic Ergodic Divertor

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## I Introduction

A Dynamic Ergodic Divertor (DED) has been installed in TEXTOR (R = 1.75 m, a = 0.46 m) for manipulation of the magnetic topology [1]. The DED system consists of 16 coils plus two compensation coils with helicity q=3. It can be operated either in DC mode, or in AC mode at different frequencies up to 10 kHz. The individual coils can be powered in such a way as to produce a dominantly m/n=12/4, m/n=6/2, or m/n=3/1 magnetic perturbation. The experiments described in this paper, employ the DED in the AC mode of operation at 1 kHz and in 3/1 configuration. In the 3/1 configuration, a strong m/n=2/1 sideband is created due to toroidal effects. Above a critical field this induces a 2/1 magnetic island in the plasma [2]. This way the DED provides a controlled manner to create magnetic islands, which then form an ideal model system to study the manipulation of magnetic islands by localised heating or non-inductive current drive as affected, for example, by electron cyclotron resonance heating (ECRH) or current drive (ECCD). Localised heating or current drive is expected to affect the mode stability both through changes in the equilibrium temperature and current density profile, thus changing the tearing mode stability parameter Δ’ [3], as well as through heating or current drive inside the island. Heating or co-current drive near the O-point of a magnetic island will suppress the island, whereas heating or co-current drive near the X-point are expected to have the opposite effect [4]. The latter effect will benefit from modulated ECRH or ECCD in phase with the mode rotation.

## II Experimental conditions

The target plasma is fixed with a toroidal field of $B_T = 2.25$ T, plasma current $I_p = 300$ kA, and line averaged density $n_e = 2.0\ 10^{19}\ m^{-3}$. Neutral beam injection (NBI) at a power of 300 kW is applied mainly for diagnostic purposes. The AC (+1 kHz) DED current amplitude is ramped to 1.4 $kA_{rms}$ in the individual coils and held constant during a ≥ 1 s plateau phase. A 2/1 magnetic island, locked to the DED perturbation, is formed at a DED current of typically 1 $kA_{rms}$. Midway the DED plateau phase an ECRH pulse is applied and the effects on the 2/1 mode are diagnosed from 2/1 oscillations observed on magnetic pick-up coils, the

ECE radiometer at 141 GHz, as well as the soft x-ray camera (SXR). The position of ECRH deposition is varied by changing the vertical injection angle.

## III Experimental results

The discharge scenario is illustrated in Fig. 1 for discharge #94727 in which the ECRH depositon, $\rho_{dep} = r_{dep}/a$, coincided with the 2/1 magnetic island, i.e. with the position of the q=2 surface, $\rho_{q=2}$. Shown are the plasma current, density, heating powers, and current in one of the DED coils, as well as the resulting evolution of the ECE signal at 141 GHz, the magnetic perturbation measured on one of the magnetic pick-up coils, and the toroidal rotation velocity in the plasma centre as obtained from charge exchange recombination spectroscopy (CXRS). The creation of the 2/1 magnetic island at 1.57 s is clearly seen in the sudden increase of both the 141 GHz ECE oscillations and the amplitude of the magnetic perturbations. The creation of the 2/1 mode is accompanied by a sudden drop in toroidal rotation over the whole plasma cross-section [5]. In the plateau phase of the DED current, the full width of the magnetic island is $w/a \approx 0.13$. When ECRH is applied at 2.20 s, both the ECE oscillations and the magnetic perturbations are significantly reduced: other measurements confirm that the 2/1 magnetic island is virtually reduced to zero. Also the central plasma rotation is seen to increase again, but does not recover its value from before creation of the 2/1 mode. The central plasma rotation only recovers fully after switch-off of both the DED and ECRH. When the DED is switched-off before ECRH the 2/1 mode also does not reappear. Without suppression by ECRH the 2/1 mode unlocks when the DED is switched-off, but a finite amplitude mode remains in the plasma [2]. The effect of ECRH or ECCD on the mode amplitude will be characterised by the ratio of the 1 kHz temperature fluctuations in the plateau phase of the DED with ECRH over those before ECRH: $\tilde{T}_{141,ECRH} / \tilde{T}_{141,DED}$. Apart from changes in the 2/1 mode amplitude, the ECE fluctuations may be affected by changes in the $T_e$ gradient or a shift in the position of the q=2 surface. However, the ECE data are consistent with changes in the 2/1 mode amplitude as observed on other diagnostics such as magnetic pick-up coils, or SXR.

Figure 2 shows the rate of mode suppression, $\tilde{T}_{141,ECRH} / \tilde{T}_{141,DED}$, as a function of the normalised deposition radius, $\rho_{dep}$, for two series of discharges with ECRH, and co-ECCD, respectively. In case of ECRH the width (FWHM) of the deposition profile is $\Delta\rho_{dep} = 0.02$. Co-ECCD is affected by selecting a toroidally oblique injection angle of $-15^{o}$. A linear adjoint calculation [6] predicts a driven current of about 8 kA, with a deposition profile width of $\Delta\rho_{dep} = 0.07$. As can be seen in Fig. 2, co-ECCD is more effective for mode suppression than ECRH only. In the co-ECCD case, the broader deposition profile also results in a proportionally broader range over which the mode is suppressed. In order to obtain the minimum required power to stabilise the mode, a power scan has been performed for ECRH, and co-ECCD at the optimum $\rho_{dep}$. As shown in Fig. 3, the maximum available power of 800 kW has been just sufficient for stabilisation in the case of co-ECCD (#94988), although this result could not be reproduced in a later series of discharges. In the figures, different symbols are used to indicate data taken on different days: although reproducibility during the day is very good, small differences in discharge conditions – for example, in the exact location of the q = 2 surface – occur between different days of operation. This hampers detailed comparison of data taken on different days.

ECRH/ECCD has been operated under feedback control from the DED current: the gyrotron power is modulated in phase with the rotation of the DED magnetic perturbation and, consequently, in phase with the locked 2/1 magnetic island. ECRH power is switched between high, 800 kW and low power, 150 kW with a 50% duty cycle. The phase between the DED current and the ECRH power modulation has been varied in order to scan the ECRH power deposition through the magnetic island. Figure 4 shows the results obtained with modulated heating and current drive at the optimum $\rho_{dep}$ for mode suppression.

## IV Conclusions

The 2/1 tearing mode triggered by the DED induced magnetic perturbations, has been suppressed by 800 kW of ECRH or co-ECCD. When the mode has been suppressed by ECRH and the DED current is switched-off during the phase of mode suppression, the mode does not reappear after the ECRH pulse. Although complete suppression of the 2/1 tearing mode has only been obtained with co-ECCD, more detailed analysis is required to assess the relative merits of localised current drive and heating. Modulated co-ECCD centred at the O-point is seen to be more effective than CW current drive at the same power, whereas modulation centred at the X-point is less effective than CW current drive at the average power. It is expected that these studies will eventually provide information on the effectiveness of localised heating and current drive for the suppression of naturally occurring magnetic islands as with (neoclassical) tearing modes. In particular, the results will help to specify the required ECCD power to control and suppress neoclassical tearing modes in ITER [7].

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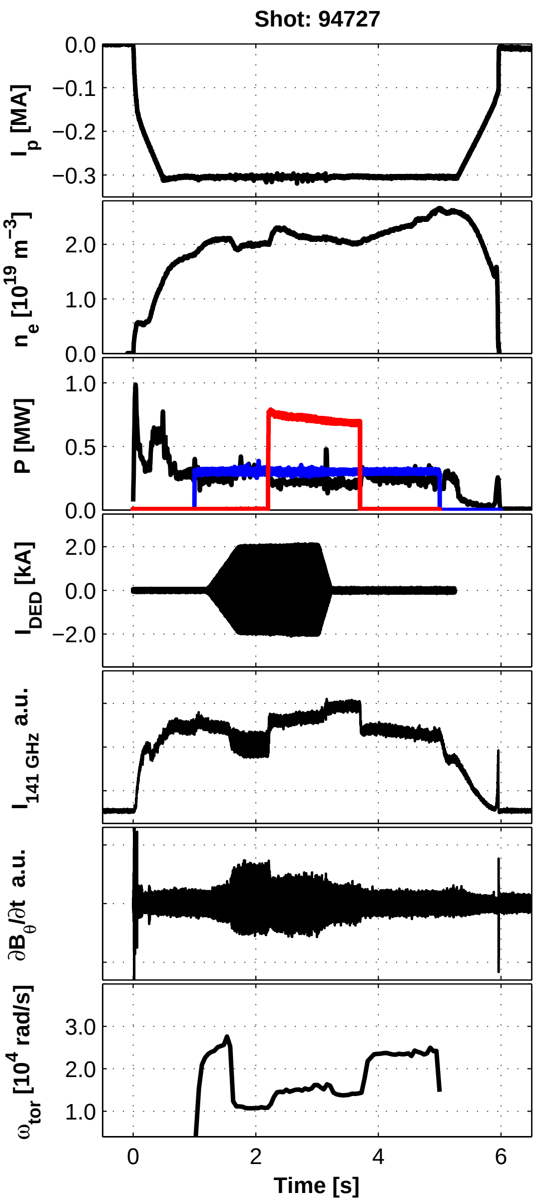


Figure 1. The discharge scenario illustrated by time traces of (from top to bottom) plasma current, density, heating (black: ohmic, blue: NBI, red: ECRH), DED current, 141 GHz ECE emission, the signal from a magnetic pick-up coil, and the toroidal rotation in the plasma centre as obtained from CXRS.

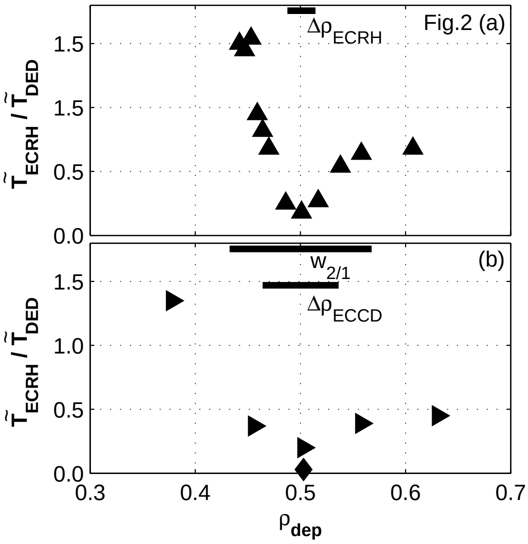


Figure 2. The rate of mode suppression is shown as a function of the normalised ECRH / co-ECCD deposition radius for (a) ECRH and (b) co-ECCD. Symbols indicate data from different days.

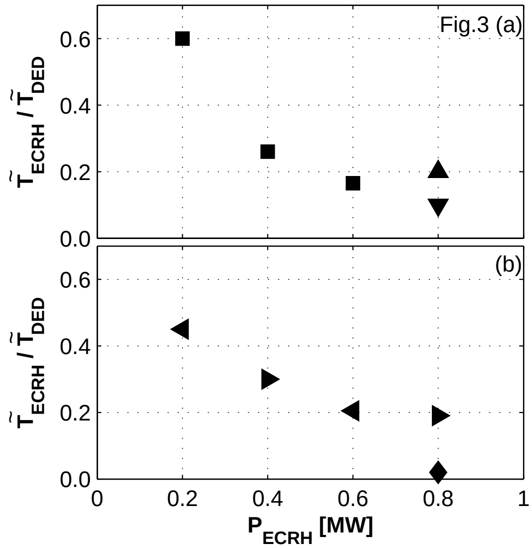


Figure 3. Ibid as a function of the injected power for (a) ECRH, and (b) co-ECCD.

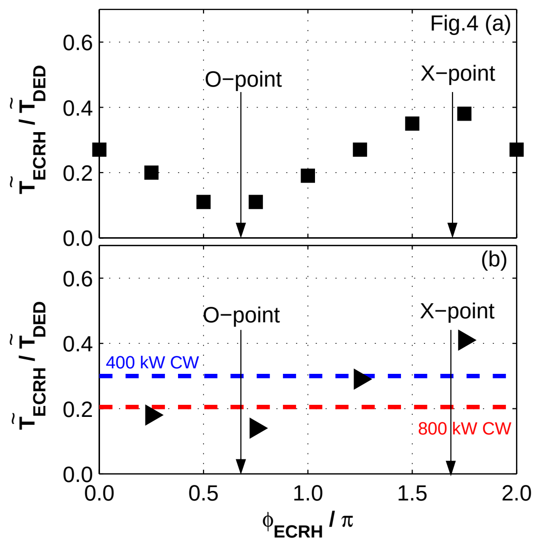


Figure 4. Ibid as a function of the phasing, $\phi_{ECRH}$, between the modulated (a) ECRH or (b) co-ECCD. The arrows indicate the phasing for which the high power phase is centred around the O- or X-point.