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Density dependence of the tearing mode threshold

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Abstract - The excitation threshold of the m/n=2/1 tearing mode has been studied by applying the external perturbation field induced by the Dynamic Ergodic Divertor (DED) on TEXTOR. A sudden drop in the threshold dependence on the density has been observed for the first time. Present scalings of the error field mode threshold do not explain the observed behaviour.

Introduction - The TEXTOR tokamak is equipped with the Dynamic Ergodic Divertor (DED) which consists of 16 helical coils mounted at the high-field side of the torus. The DED can generate either static or rotating perturbation fields with frequency up to 10 kHz with the fundamental mode numbers $m/n = 12/4, 6/2$ or $3/1$, here m and n are the poloidal and toroidal mode numbers. Previous experimental results show that the DED in the 3/1 configuration is a good tool to study the excitation of the 2/1 tearing mode due to the presence of a large 2/1 sideband [1]. Additionally, two neutral beam injectors provide momentum input in co-current as well as in counter-current direction allowing to disentangle rotation and beta effects. The established scaling of the locked mode threshold scales proportional to the density with a slightly different exponential depending on the machine, e.g. 0.58 at JET [2] or 1 at Alcator C-Mod [3]. The error field correction coil system on ITER is based on the dependency of the mode threshold.

Experiment - Recently the dependencies of the threshold of the 2/1 tearing mode excitation on the plasma density, rotation velocity and beta have been studied systematically by applying the DED on TEXTOR. The m/n=2/1 mode excitation threshold has been determined by a current ramp-up of the DED in an ohmic heated plasma with densities between 0.8 and $4 \cdot 10^{19}\text{m}^{-3}$. The experimental results from this density scan show a sudden drop of the mode threshold at an electron density of $n_e = 2 \cdot 10^{19}$ m^{-3} indicated in Fig. 1. The first branch at lower density is comparable to the scaling of JET in L-mode plasmas at low density [2]. The second branch at higher density, the linear rise, resembles the results from Alcator C-Mod [3]. In between both regimes is a sudden drop in the excitation threshold. The dependence of the excitation threshold on the density has been investigated in detail by adding small amounts of co- and/or counter neutral beam injection while keeping a constant total input power of 250 kW, thus only

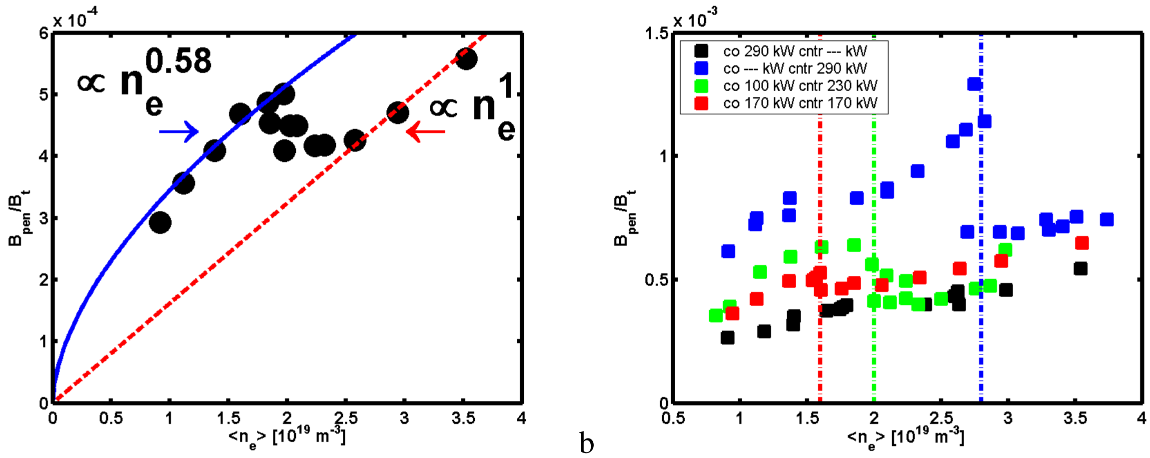

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Figure 1: a)The calculated critical fraction B_{pen}/B_t which excites the 2/1 mode depends on the plasma density and shows a drop at the density of $2 \cdot 10^{19}$ m^{-3}, in contrast to previously published scalings. b) The dashed lines indicate the sudden drop in the mode excitation threshold that is shifted to the left or right depending on the direction of the momentum input by the neutral beam injectors. It doesn't occur with only momentum input in co-current direction.

focusing on the toroidal plasma fluid rotation. The resonance behaviour has been found in each case, except for the density scan with momentum input in only co-current direction. However, the corresponding electron density for the largest drop in the threshold changes depending on the plasma rotation and has its maximum with only counter-current beam injection shown in Fig. 1. The threshold behaviour has been also investigated in plasmas with different normalized beta values β_n while keeping the toroidal plasma rotation constant with balanced neutral beam injection. The experimental results from two density scans at total NBI powers of 250 kW and 950 kW, respectively, show a shift of the threshold resonance with electron density. In Fig. 2 the excitation threshold is plotted versus the line averaged density and versus the toroidal plasma rotation frequency. When the excitation threshold suddenly drops the toroidal rotation also increases in the counter-current direction. No drop of this threshold is found with only momentum input in the co-current direction.

The toroidal plasma fluid rotation (f_Φ) and electron diamagnetic drift frequency (f_e^*) determine the frequency of the 2/1 mode $f_{2/1}$ [4]. The excitation threshold reaches a minimum when the frequency of the applied perturbation field f_{DED} equals the frequency of the 2/1 mode [5]:

$$f_{\text{DED}} \propto f_{2/1} = f_\Phi - f_e^\star \qquad (1)$$

Different rotation scans on TEXTOR have proven that the excitation threshold of the mode is lowest when the toroidal rotation in co-current direction equals the absolute value of the electron diamagnetic frequency [1]. Then the resonance condition, eq. 1, for a static perturbation

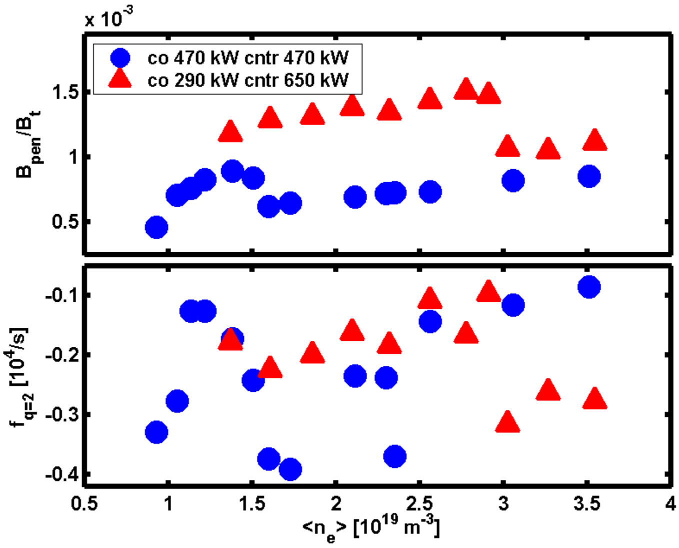

Figure 2: When the excitation threshold suddenly drops at the density of $1.5 \cdot 10^{19}$ m^{-3} (circles) and at $3 \cdot 10^{19}$ m^{-3} (triangles) the toroidal plasma rotation velocity at the q=2 surface also changes to further counter-rotation. No drop is found in the scan with only momentum input in co-direction.

field, is fulfilled.Whereas the new results of TEXTOR, the plasma fluid rotation increases in the counter-direction when the excitation threshold drops cannot be explained by eq. 1 since the rotation of the 2/1 mode differs further from the rotation of the applied perturbation field.
During the discharge after the DED has been switched off, the 2/1 mode quickly unlocks and its rotation frequency $f_{2/1}$ saturates. The dependency of the excitation threshold on the 2/1 mode rotation frequency is shown in Fig. 3. The points of the frequencies measured before the drop are marked by open symbols. A critical frequency occurs at which the excitation thresholds accumulate and this is exactly the frequency when the threshold drops. This critical frequency remains the same for scans with constant total heating power.

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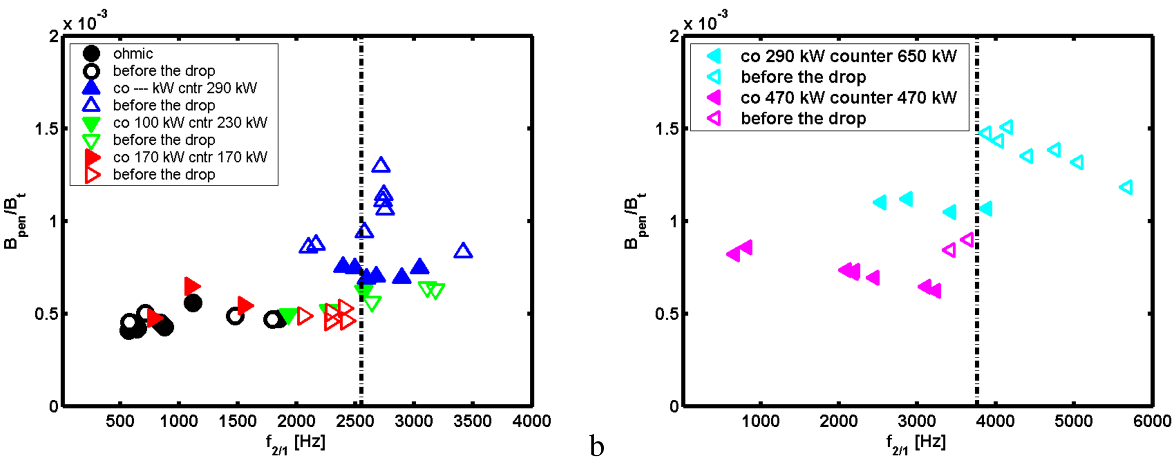

Figure 3: The dependency of the excitation threshold on the $f_{2/1}$-frequency a) with low neutral beam heating power and b) high neutral beam heating power. There is a critical frequency (marked as a dashed line) in each scan the frequencies accumulate at.

Discussion and Conclusion - This critical 2/1-frequency at the density at which the mode threshold drops depends linearly on the total heating power, i.e. ohmic and neutral beam heating in these experiments. This critical frequency and the corresponding neutral beam fraction $\eta = (P_{co} - P_{counter})/(P_{co} + P_{counter})$ are given in Fig. 4. This neutral beam fraction η doesn't influence the critical 2/1 frequency which only depends on β_n.

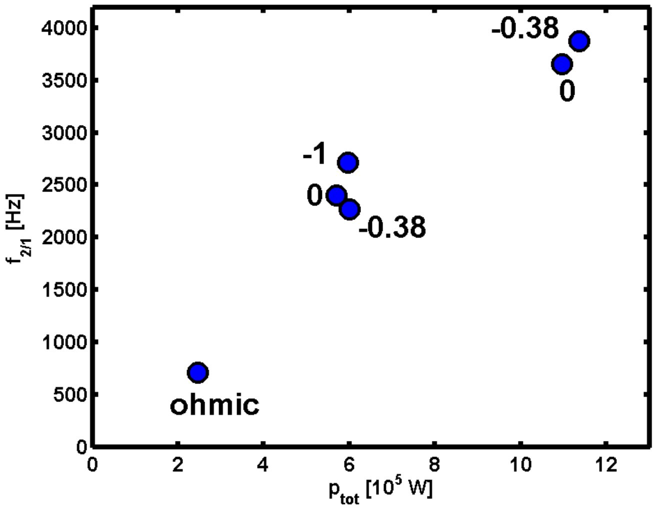

Figure 4: The frequency of the 2/1 mode before the sudden drop of the excitation threshold is plotted versus the total heating power (ohmic and neutral beam heating). The dependency is linear and independent of the neutral beam fraction η (indicated with the numbers)

Various scans with different beam fractions and with different β have been performed in L-mode plasmas. This L-mode regime is also envisaged for the start-up of an ITER discharge. The drop in the density dependence described here happens in the transition from low to high density and therefore links both density regimes. This transition only depends on the toroidal plasma fluid rotation and β_n.

There is a critical frequency of the m/n=2/1 tearing mode at which the sudden drop occurs. This critical frequency doesn't depend on the neutral beam fraction, but only on the total heating power.

When the mode threshold drops the plasma fluid rotation frequency increases to further counter-current direction. This behaviour - unlike in the experiments investigating the rotation dependence with constant density [1] - cannot be explained by the matching condition, eq. 1.

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