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The influence of the Dynamic Ergodic Divertor on the MHD spectrum in TEXTOR

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Abstract *The Dynamic Ergodic Divertor (DED) was recently installed on TEXTOR. The influence of the DED created perturbation fields on the plasma were studied with a set of newly designed Mirnov coils. With operation of the DED in $m/n = 3/1$ configuration the following observations were made: (i) Above a critical coil current a 2/1 tearing mode was excited, (ii) broad bands of turbulence in the frequency range around 20 kHz appear, (iii) a coherent mode at 12 kHz, (iv) a $n = 1$ mode around 4 kHz, and (v) a strong coherent $n = 1$ mode at 36 kHz which was seen at high DED currents with dominant counter neutral beam injection.*

Introduction The DED consists of 16 helical coils which are aligned to the $q = 3$ magnetic field lines in the plasma [1]. The DED can be operated with toroidal and poloidal mode numbers $m/n = 12/4$, 6/2, and 3/1. In all these configurations the DED can be operated statically (dc) or the perturbation field can be rotated (ac mode) with very low (2 Hz) or high frequencies up to 10 kHz.

In this paper the results from the 3/1 configuration, which creates a strong 2/1 sideband, are presented. The influence of the DED generated error field on the plasma has been studied for various discharge conditions in DC and AC operation. In the chosen plasma scenario with an edge safety factor $q_a \approx 4.5$ ($I_p = 300$ kA, $B_t = 2.25$ T, $P_{NBI} = 300$ kW) the DED current was always ramped-up slowly in order to measure the threshold amplitude for mode onset triggered by the perturbation field.

Experimental Set Up One of the main diagnostic used to study the influence of the DED on the MHD spectrum of TEXTOR are Mirnov coils. Due to the integration of the DED a large part of the magnetic diagnostics, among them the sets of pick-up coils, had to be redesigned. The new coils consist of a high temperature spray ceramic, where a molybdenum wire is led in. Eight toroidal coils are installed at the top of the vessel for the determination of the toroidal mode number n. Another set of coils is located in a poloidal cross section for the m-number measurement of the MHD-instabilities. The coils are mounted close to the last closed flux surface of the plasma and are therefore shielded by two small graphite limiters (Fig. 1). The highest sampling frequency at the moment is limited to 100 kHz due to the data acquisition hardware. It is planed to increase the sampling rate to 2 MHz in the future.

Example for a Mirnov Coil measurement A typical discharge is shown in Fig. 2. A small amount of co-injected neutral beam heating ($P_{NBI} = 300$ kW) is applied from 1 to 3.6 s, mainly to serve as a diagnostic beam for charge exchange measurements. The current in the DED coils (red curve) is ramped-up to $I_{DED} = 2$ kA. In Fig. 2 the spectrogram of a Mirnov coil is shown. At the beginning of the discharge natural (weak) 3/1 and 2/1 modes are present. The 2/1 mode locks at a DED current of 0.4 kA, the 3/1 mode at 0.7 kA. Since these modes are quite weak the locking appears at rather large perturbation fields. There are several examples where large $m/n = 2/1$ modes exist prior to the switch-on of the DED. These modes typically lock at DED currents in the order of 100 A.

The dip in the density signal (blue line) at $t = 1.8$ sec is an indication for the creation of a locked 2/1 tearing mode [2]. The density recovers due to the action of the density feedback control. The 2/1 mode stays locked even when the DED current is switched off again. In this example the mode stays locked until the neutral beam heating was switched off. The time delay between DED switch off and unlocking depends on various plasma parameters and is discussed in [4]. Especially for the DC operation of the DED, where the 2/1 mode is created as a locked mode, the unlocking and spin-up of the mode after the DED phase allowed the determination of the mode numbers by comparison of the phases of adjacent pick-up coils. The 3/1 mode starts rotating immediately after the DED is switched off. The perturbation field to lock a pre-existing 2/1 mode is considerably smaller than the field which is required to generate the mode.

Correlated with the appearance of the locked 2/1 island, several modes appear. A $n = 1$ mode is visible in the spectrogram at a low frequency of about 4 kHz at a higher DED current of 0.85 kA.

At a frequency in the range from 12 to 15 kHz a $n = 2$ mode can be seen. The frequency of this mode seems to follow the temporal evolution of the DED current. A third observation is a broad band mode in the frequency range $20 - 22$ kHz. The interesting point is, that this broad band structures have a toroidal mode number of $n = -1$, i.e. that the mode rotates in the electron diamagnetic drift direction, wheres *normal modes* having positive mode numbers rotate in ion diamagnetic drift. A reflectometer system was used, trying to localize the radial position of these structures. At the $q = 3$ surface a change in the plasma rotation direction was found, indicating that the $n = -1$ broad band mode might be located outside of the $q = 3$ surface [3].

The onset threshold and frequencies of all the modes depend strongly on plasma parameters as studied by scans of various plasma parameters, e.g. n_e, B_t, v_{tor}, I_{DED}, β.

One example is the dependence of the new modes on the DED current. By increasing the DED current the $n = 2$ mode disappears at a critical DED current and the frequency of the 12 kHz mode increases in several steps from 12 kHz to 22 kHz, while the broad band structure disappears. Comparing the spectral range of the frequency response of the mode at $12 - 15$ kHz with different shapes of the DED current, shows, that they seem to follow the pulse shape of the DED current.

The 12 kHz and broad band structure appears also if an natural 2/1 tearing mode locks without DED. A possible explanation for these modes is, that they are driven by the increased pressure gradient between the mode and the plasma edge.

Plasma rotation effects on MHD spectrum with dc operation In order to investigate the influence of plasma rotation on mode onset, we modified the plasma rotation direction in a plasma by using various heating scenarios. Two different scans were performed: in one scan we replaced co-neutral beam injection heating gradually by ICRH, keeping the total heating power and thus plasma β constant. In a second scan we used both neutral beam injectors, keeping the total heating power constant. By varying the heating power of co- and counter injection, a full rotation scan was performed. In this experiment we were able to change he plasma fluid rotation, measured by charge exchange, from co to counter direction.

A comparison of co- and counter rotation is shown in fig.3 and fig.4. The total heating power in both discharges is the same ($P_{heat} = 1.6$ MW). At this heating power the measured signal looks different to fig.2. The 12 kHz mode has disappeared. The intensity and frequency of the $n = 1$ mode at 4 kHz shows a very strong dependence on the DED current and the temporal evolution of the density .

In the counter neutral beam dominated case (fig. 4) an intensive $n = 1$ mode appears at a frequency of 36 kHz . The mode appears at a DED of $I_{DED} = 2.3$ kA current and disappears if a critical value of $I_{DED} = 3.2$ is exceeded. The same effect is obtained for the $n = 1$ mode at 4 kHz. A possible explanation is, that the higher DED current results in a stronger ergodization of the plasma, which does not allow to build up coherent mode structures anymore.

A remarkable point is, that the onset of the locked 2/1 tearing mode is shifted with increasing ctr-NBI power to higher values. At pure counter injection 2/1 mode is not created at all. Fig. 6 shows the critical DED needed to create the locked 2/1 mode depending on the co-NBI heating power.

The second rotation scan using co-NBI heating (and ICRH to keep β constant) shows similar results (Fig. 5). By rising the NBI heating from 0 MW to 0.9 MW the critical DED current needed to generate the locked 2/1 mode is lowered from 1.2 kA down to 0.6 kA, decreasing by 50 %. The frequency of the former 12 kHz mode is increased to more than 15 kHz. The threshold of the DED current to create the $n = 1$ mode at 4 kHz is increased by 30 %, the 2/1 mode locks at 50% higher current.

Both scans clearly show, that the perturbation field required to create the locked 2/1 mode decreases with increasing co-rotation of the plasma.

Conclusion The DED is found to have a very strong influence on the MHD spectrum. Many new modes appear during the DED phase. Some of the modes only appear when the locked 2/1 tearing mode is present, others are caused by the perturbation field alone. With the DED the controlled excitation of different kind of modes is possible in a controlled way and will be utilized in further studies of mode properties and dependencies on plasma parameters.

[1] Special Issue, Fusion Eng. Design **37** 335 (1997)
[2] H. R. Koslowski et al., *this conference*, P1-124
[3] A. Krämer-Flecken et al., *this conference*, P1-120
[4] Y. Liang et. al., *this conference*, P1-126

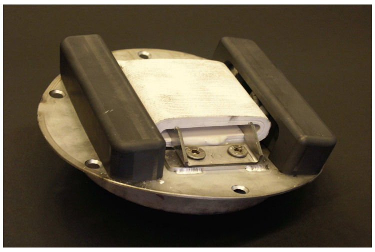

Figure 1: Mirnov-Coils, for measuring fluctuations in the poloidal magnetic field, shielded by two graphite limiters

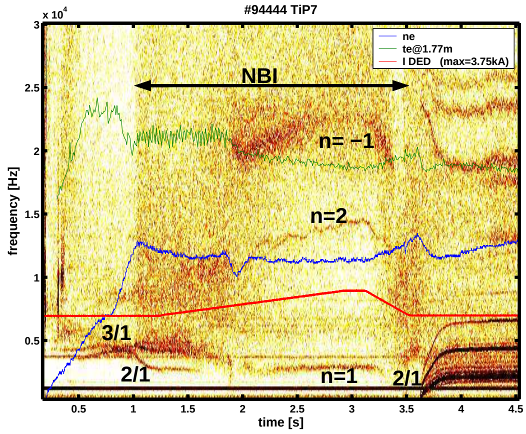

Figure 2: Typical spectrogram of the Mirnov coils during a static DED current ramp. During the DED phase the $n = 1$, a low frequency mode at 12 kHz increasing to 15 kHz and broad band structure at 22 kHz appear.

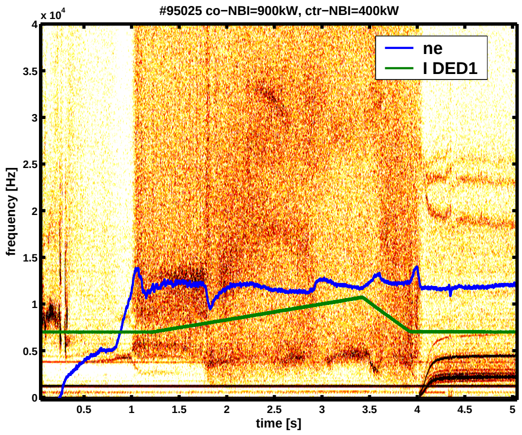

Figure 3: This plot indicates, that there is a strong influence of the ctr-NBI on the modes. The 1/1 mode at $4kHz$ is unstable, the LF mode has disappeared.

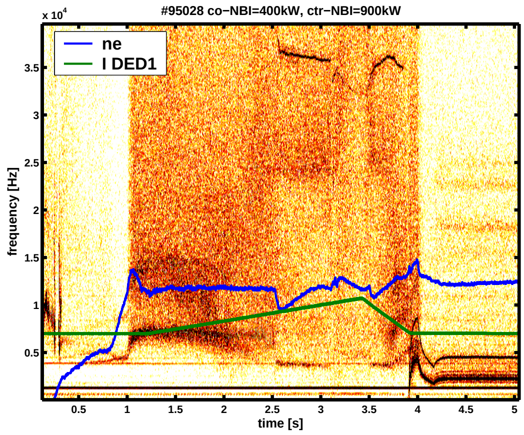

Figure 4: If the ctr-NBI power exceeds the co-NBI power a new strong $n = 1$ mode appears at $36kHz$.

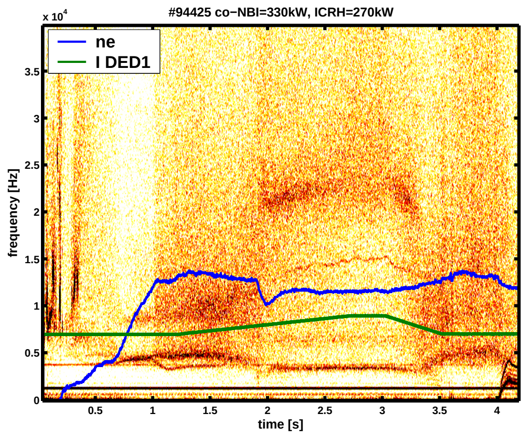

Figure 5: In this discharge sequence the total amount of heating power was kept constant by varying the co-NBI and ICRH power.

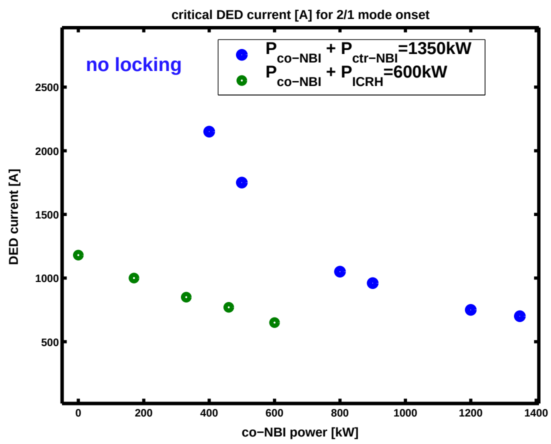

Figure 6: Both rotation scans show, that the onset of the 2/1 is delayed or even suppressed if the co-NBI heating is as low as possible and the ctr-NBI accelerates the plasma rotates in ctr-direction.