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Characterization of the TEXTOR limiter H-mode and the impact of the Dynamic Ergodic Divertor on ELM-like relaxation events

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Because of its good confinement properties, the ELMy H-mode is the reference scenario for ITER. However, the best confinement regimes are connected with type 1 ELMs which bear risks for the machine integrity[1]. Therefore efforts are taken to mitigate the effects of ELMs, proposed mitigation schemes base on pellet injection[2], gas injection[3], plasma shaping[4] and edge perturbation[5]. It is questionable whether most of the proposals are compatible with the nearly steady state discharges of ITER. A significant progress on the ELM reduction has been performed at DIII-D by applying a perturbation field[6,7]. The perturbation field there is generated by currents in the I-coils which is a set of coils located above and below the equatorial mid-plane inside the vessel close to the plasma. The mitigation is attributed to an ergodization of the surfaces $q > 3$; the ergodization is a resonant process and therefore the mitigation works properly only in a limited range of q_{95}. The resonance means geometrically that the magnetic field line of the edge equilibrium field has to pass those upper and lower I-coils which carry the same current direction. The spectacular result of DIII-D was that it was possible to keep the good H-mode plasma confinement at suppressed ELMs for ITER relevant discharges (shaping and collisionality).

Since TEXTOR is equipped with the Dynamic Ergodic Divertor (DED), efforts were undertaken to obtain an ELMy-H-mode on TEXTOR and to investigate whether a reduction of the ELM activity can be achieved. The importance of the investigations lies in the different perturbation coil scenario and the related different perturbation spectrum as compared to DIII-D and to previous experiments on JFT-2M[5]. With respect to future JET or ITER applications it is in particular of interest whether it is better to use a perturbation field with high *m* and *n* mode numbers or with low ones. The advantage of low mode number device is the reduced requirement on the perturbation coil current which becomes in particular important for ITER where the coils have to be placed relatively far away from the plasma behind a neutron shield. On the other hand, perturbation field with the low mode numbers penetrate easily into the plasma and can interact with internal modes; this interaction leads beyond a certain threshold amplitude to the excitation of tearing modes[8] where in particular the m/n=2/1 modes can be triggered. This tearing mode reduces the otherwise good plasma confinement. The high *m, n* mode numbers do not show the problem of tearing mode excitation but require high coil currents for a sufficiently high perturbation amplitude at the plasma edge. In order to investigate the influence of the perturbation modes, the DED has been operated both in the fine m/n = 12/4 and the coarse m/n = 3/1 base mode.

For obtaining a limiter H-mode on TEXTOR the “normal” recipe has been applied as for other limiter tokamaks[9-12], namely by reducing B_t, plasma shift towards the high field side, and strong heating. The parameter range used so far is 1.2 T $\leq B_t \leq$ 1.4 T, 3 $\leq$ q(a) $\leq$ 4; $2{*}10^{19}$ m^{-3} $\leq n_e \leq 3{*}10^{19}$ m^{-3}; the power threshold of the H-mode amounts to about P = 2 MW. Typical for the limiter H-mode is the improved particle confinement and the small effect on the energy confinement.

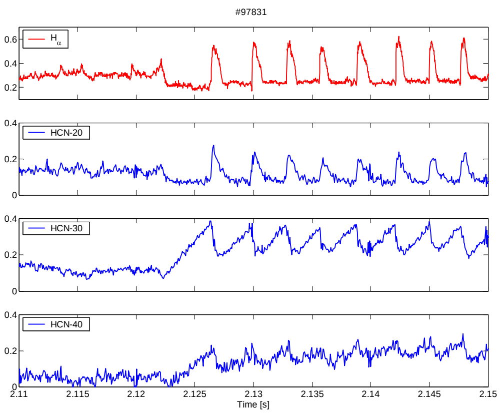

Fig. 1 *displays the transition from L-mode to the ELMy H-mode for an H_α channel and for three neighbouring HCN interferometer channels, one outside of the barrier edge, one at the barrier and one inside the barrier .*

Fig. 1 displays time trace of the transition from L-mode to the ELMy H-mode for an H_α channel and for three neighbouring HCN interferometer channels, one outside of the barrier edge, one at the barrier and one inside the barrier. At the onset of the H-mode, the H_α–signal drops by a factor of two and changes to the ELM phase. H_α channels located at different poloidal and toroidal locations show the same signal and transition character. The density - interferometer channels are normalized to 10^{18} m^{-3} and have all the same scale for all HCN channels; since some channels experience interferometer jumps, the lowest values are set close to zero. The outermost interferometer channel drops at the onset of the H-mode while the one at the pedestal is increases; the time trace of the central density channels are – as expected - little modulated.

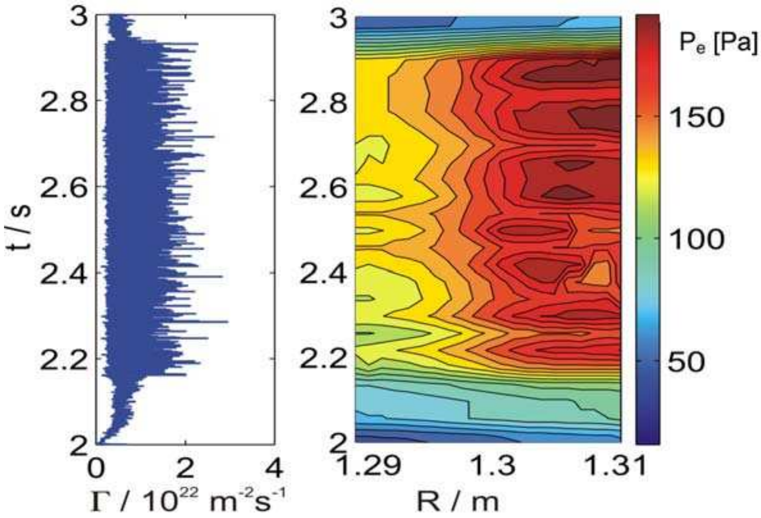

Figure 2: *Time trace of the H_a – signal and the evolution of the edge plasma pressure at the high field side for the TEXTOR discharge # 97315 in false colour technique. The time is represented as ordinate.*

In Figure 2, the time axis is displayed as ordinate; time increases from bottom to top and the phase of the strong plasma heating is displayed. The left subfigure represents the H_α time trace starting in the L-mode phase followed by a long ELMy phase. The local plasma pressure in front of the divertor target plate has been derived from atomic helium beam spectroscopy as a function of major radius and time and is shown in the right subfigure. The pressure is derived from the values of T_e and n_e assuming equal electron and ion temperatures. The strong increase of the pressure during the ELMy phase is obvious.

Since the B_t of the ELMy discharges is much lower than during the "normal" discharges in TEXTOR, the ECE channels are not available for the determination of the temperature profile. However, some preliminary Thomson scattering measurements have been performed which confirm the edge density build-up but no measurable temperature barrier. Consistently one sees an increase of the plasma energy by few percent only. Another topic of present research is the interaction of MHD modes with the plasma.

For investigating the interaction of the DED field with the ELMy plasma, the DED was switched on during different phases of the discharge. In Figure 3a and b, the DED in the *m/n* = 12/4 base mode was switched on before the application of the NBI. The curves from top to bottom are time traces of the injected power (NBI-co plus NBI-ctr), of the plasma current, of the line averaged density and of H_α. The discharges start with values of B_t = 1.7 T or 1.9 T and plasma currents of 300 KA. I_p and B_t are then ramped down at constant q(a). One sees clearly that the ELMs are reduced during the DED phase and that the ELMy phase sets in at the end of the DED-phase. The transition phase during the DED ramp down phase is shown in better time resolution in the lower set of figures. There as an additional time trace a Mirnov loop signal is plotted. During the DED-phase both the H_α signal and the Mirnov signal have a different character than during the ELM phase.

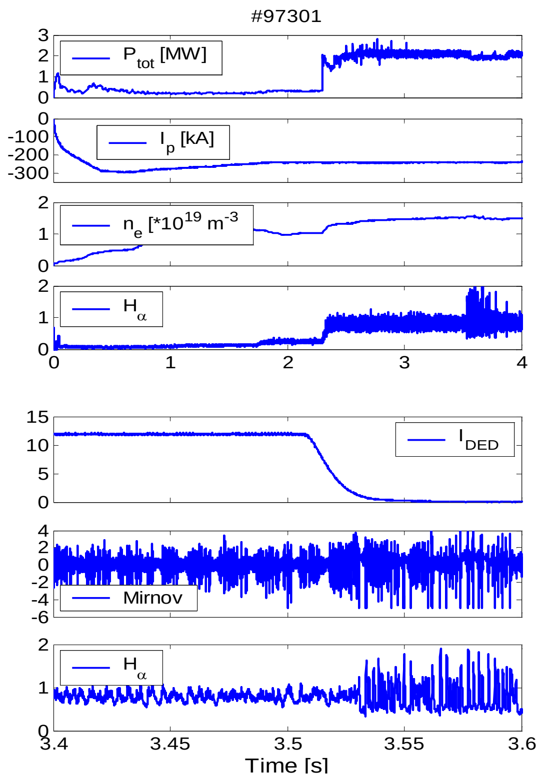

Fig. 3: *Different signal channels showing the ELM suppression by the DED. Top figure low time resolution and low figure with higher time resolution.*

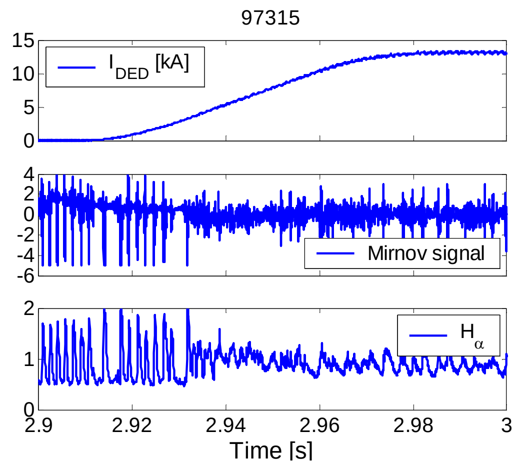

Fig. 4: *ELM reduction for increasing DED current.*

The comparison between fig. 3 and 4 shows that the ELM reduction does not depend whether the DED current is in the increasing or decreasing phase. For the m/n = 12/4 base mode the threshold is at about I_{DED}=3 kA. The density pedestal is reduced during the DED phase as well and it is not clear yet whether the edge density remains beyond the L-mode. In the *m/n* = 3/1 base mode of the DC-DED operation, the ELM reduction seems to be efficient as well; however, the plasma tends to disrupt easily because the perturbation field penetrates deeply into the plasma. During the AC operation of the DED, the stability of the plasma can be retained while the ELM activity was reduced.

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