CHANGE OF PLASMA PROPERTIES PRIOR TO HIGH DENSITY DISRUPTIONS IN ASDEX

H. Niedermeyer and K. Behringer, K. Bernhardi, A. Eberhagen, G. Fussmann,
O. Gehre, J. Gernhardt, G. v. Gierke, E. Glock, G. Haas, F. Karger,
M. Keilhacker, S. Kissel[+], O. Klüber, M. Kornherr, G. Lisitano, J. Massig,
H.-M. Mayer, K. McCormick, D. Meisel, E.R. Müller, H. Murmann, J. Neuhauser,
W. Poschenrieder, H. Rapp, B. Richter, F. Schneider, G. Siller, P. Smeulders,
F. Söldner, K. Steinmetz, K.-H. Steuer, Z. Szymanski[++], G. Venus, F. Wagner

Max-Planck-Institut für Plasmaphysik, EURATOM Association, D-8046 Garching

I. INTRODUCTION

In the ASDEX divertor experiment, as in all major tokamaks, any increase of the plasma density during a discharge by means of programmed or feedback-controlled gas puffing is limited by a disruptive instability. The disruption is preceded by a strongly growing MHD mode. In a wide parameter range, however, the first indications of the density limit being reached are observed a few tens of milliseconds before the MHD instability appears: the line-averaged electron density increases faster than programmed via a fast gas valve, the loop voltage increases, the intensity of H_α increases by a factor of 2, the bolometer signals increase by a factor of 2 to 3, and the intensity of CIII and OIII lines increases by about two orders of magnitude. By skilful programming of the density increase it was possible to sustain this pre-disruptive plasma state for about 600 ms while n_e was steadily growing even above the normal density limit (Fig. 1).

In discharges with a "mushroom" limiter on the outer periphery of the torus a similar state automatically develops at density plateaus slightly below the limit. As shown in the following, the pre-disruptive (p.d.) state is characterized by a strong poloidal asymmetry of plasma parameters near the boundary, namely a belt-shaped strongly radiating high-density region near the inner periphery of the torus.This region is probably identical to the "marfes" observed in ALCATOR C /1/. In ASDEX the phenomenon was mainly investigated because there is a strong suspicion that when this state becomes unstable it triggers MHD instabilities and thus determines the density limit. Moreover, it may be of interest with respect to a radiating plasma mantle and also for basic transport studies.

2. EXPERIMENTAL FINDINGS

ECE, Thomson scattering, spectroscopic and electromagnetic measurements show that the hot plasma core ($r < 0.3$ m = 0.75 a) changes only slightly during the transition to the p.d. state. T_e on axis is reduced from 550 eV to 500 eV, the profile becoming slightly narrower, n_e on axis increases from 4.5 to 5.6×10^{19} m^{-3}, and Z_{eff} stays essentially = 1. The observation of sawtooth activity with only a slight change in frequency and amplitude, the measured increase of V_L from 1.4 to 1.8 and of l_i from 1.5 to 1.7, and the nearly constant value of $\beta_p = 0.3$ are consistent with the measured ne and T_e measurements. The numerical values mentioned above are for the best investigated divertor discharge type at $I_p = 250$ kA, $q_a = 4.3$. Limiter discharges

---

[+] On leave from Massachusetts Insititute of Technology, Cambridge, USA

[++] On leave from Institute of Fundmanental Technological Research, Warsaw show twice the value for T_e, half the value for n_e and a much higher Z_{eff}, but behave qualitatively similarly.

A drastic change of the plasma boundary must, however, be concluded from HCN interferometer measurements. While the density integrals through the plasma center along a horizontal and a vertical chord agree well in the normal state (with divertor discharges a correction has to be made for the divertor plasma, which contributes to the line integral along the vertical chord), both differ by about 6 to 10 % in the p.d. state (Fig.2), which can only be explained by a poloidally asymmetric density distribution. The same behaviour is found in limiter discharges (Fig.3). Because of pressure constancy on flux surfaces a corresponding poloidally asymmetric temperature distribution must be concluded. Poloidal T_e and n_e gradients at reasonable energy fluxes and flow velocities are only possible in low temperature regions, i.e. at the boundary.

Neither with the Li-beam diagnostic nor with Thomson scattering is an appreciable change of plasma parameters at the outer plasma edge detected. The high density zone has obviously to be identified with the bright zone at the inner plasma edge seen in pictures in the light of visible OII and CII radiation (Fig. 4). With the width of this zone estimated to be at maximum 5 cm the peak density in the hump as calculated from the difference of the density integrals is at least equal to the peak density of the hot plasma column, i.e. 5.6×10^{19} m^{-3}. Photographic observation in the visible at 4416 Å (OII), 5133 Å (CII), at H_α and H_β is complemented by vertical scans in the VUV range for lines of nearly all ionization stages of carbon and oxygen. The location of the bright zone is very sensitive to the vertical plasma position. A shift of $\Delta z = \pm 2$ mm of the plasma column leads to a displacement of the bright zone of about $\pm 60^o$ in the same direction.

During the normal state all ions up to OVI and CIV radiate only in thin shells near the plasma boundary (hydrogen lines, CII and OII, however, are even stronger inside the divertor throats). In the p.d. state only hydrogen radiates in the divertor throats. OIV, OV, OVI still radiate in shells, but all carbon ions observed, the lower oxygen ions and hydrogen show a peak of the intensity near the midplane (Fig. 5). The peak must be radially localized near the boundary. The spatial integrals of all lines observed increase during the transition to the p.d. state by a factor that is the larger the lower the ionization state of the ion is (OVI: 3, CII: 30).

An absolute measurement of the highest ionization states observed (O VIII, Fe XVII), which radiate near the plasma center, gives absolute values of the impurity concentration of the order of 10^{-4} for oxygen and 10^{-5} for iron that are nearly constant from before the p.d. state to its end. From this we conclude that there is essentially no change in impurity influx. An additional impurity influx should also have been detected with the mass spectrometer in the divertor chamber, into which nearly all particles finally flow. In pictures, also taken from protruding structural elements, there is no evidence for enhanced plasma wall interaction during the p.d. state.

A calibration of a VUV spectrometer near 1000 Å shows that the total radiation loss is dominated by light impurity radiation. The lowest ionization states only contribute significantly during the p.d. state. A slight peaking of the total radiaton profile in the midplane during the p.d. state is also observed from vertical bolometric scans.

Many signals show strong fluctuations during the p.d. state. Horizontal interferometer channels at $z = \pm a/2$ are correlated with 180 ° phase difference. Soft X-ray diodes and also CIII signals taken along chords at about half radius in nearly horizontal direction fluctuate in phase with the corresponding interferometer signal.The correlation is explained by a stochastic motion of the high-density zone in the vertical direction, which is also seen on high-speed films. The motion seems to be in phase in the toroidal direction, as the diagnostics are at different toroidal positions.

More experimental results are reported in Ref. /2/.

3. DISCUSSION

The pre-disruptive state is most probably the result of a thermal poloidal instability on closed flux surfaces near the plasma edge. Below a certain electron temperature (depending weakly on the impurity content) the heat conduction time along field lines is longer than the local cooling time via radiation. Without perpendicular transport the plasma is then unstable against poloidal electron temperature variations, if the local cooling rate increases slower than T_e^2 /2/. For oxygen this will be true above a few electron volts (depending slightly on the radiation model). Particle and heat transport across magnetic field lines tend to stabilize this mode. Since the radial transport and especially its poloidal variation is not yet understood, a quantitative descripton is not possible at present.

The nonlinear equilibrium, sustained for many global energy or particle confinement times, is possible only if the local particle transport is extremely low and if there are appropriate sources and sinks. In fact, there are indications /3/ that the perpendicular transport is quite small near the inner periphery, where the poloidal anomaly occurs. Also clasical parallel heat and particle transport along field lines is strongly inhibited by collisions in and near this low temperature region. But a weakly anomalous cross diffusion and diffusion plus thermal forces (directed towards high temperature at low impurity concentration /4/) along field lines would restrict the local confinement of the cool plasma ring to less than 100 ms compared to 600 ms in the experiment.

With respect to local sources we may rule out external impurity sources as pointed out above. Because of high n_e and low T_e, however, local recombination together with an appropriate mass flow could explain the observed spectral line intensities from low ionization states. A flow pattern similar to that in Pfirsch-Schlüter diffusion would probably be adequate.

In summary, the poloidal asymmetry is most probably the result of a thermal instability in the low temperature edge. The mechanisms involved are not yet understood in detail, but, in turn, could provide important new information about tarnsport in tokamaks and about the sequence of events necessary to trigger a major disruption.

References

/1/ Pickrell, M.M., Massachusetts Institute of Technology, Rep. PFC/RR-82-30

/2/ Niedermeyer, H. et al., Max-Planck-Institut für Plasmaphysik, Report IPP III/90 (1983).

/3/ Keilhacker, M., Max-Planck-Institut für Plasmaphysik, Report IPP III/72, p. 1 (1982)

/4/ Neuhauser, J. et al. (this conference)

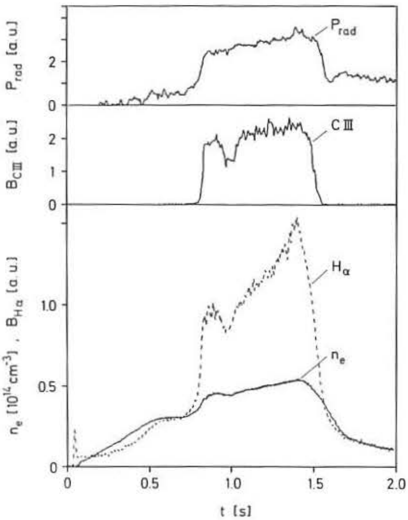

Fig. 1: Increase of line density and radiation in a tokamak discharge close to the onset of the disruptive instability.

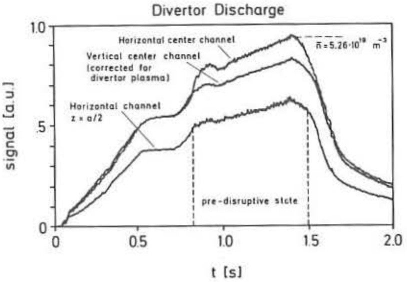

Fig. 2: Line density integrated along horizontal and vertical chords during a divertor discharge near the density limit.

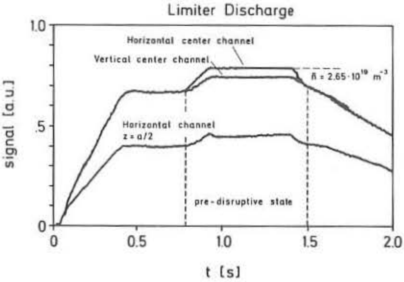

Fig. 3: Same signals as in Fig. 2 for a limiter discharge near the density limit.

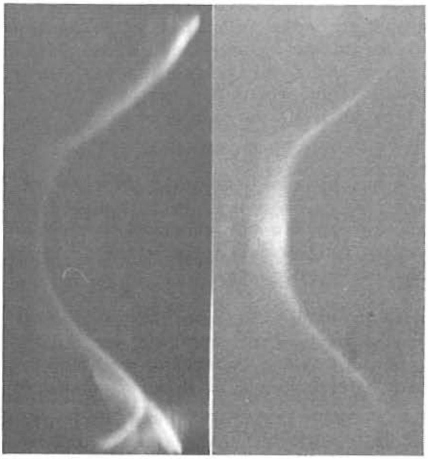

Fig.4: Photographs of the inner plasma boundary in tangential view in the light of a CIII-line (λ = 5133 Å).
a) before b) during the p.d.state.

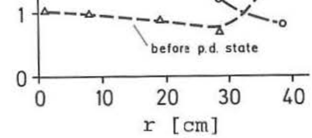

Fig. 5: Line integrated spatial profiles of the CIV line emission scanned in vertical direction before and during the p.d. state.