29th EPS Conference on Plasma Phys. and Contr. Fusion Montreux, 17-21 June 2002 ECA Vol. ***26B****, P-1.039 (2002)*

Observations of the Onset of the Energy Quench in ASDEX Upgrade Density Limit Disruptions

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Plasma disruptions limit the range of plasma parameters used in the operation of a Tokamak and have pernicious effects on the machine. In particular density limit disruptions restrict the maximum usable plasma density. So it is very important to understand the physical causes of density limit disruptions in order to clearly define the operation boundaries of Tokamaks.

Major density limit disruptions are usually preceded by a $m/n = 2/1$ tearing mode, that may or may not lock to the vessel wall. The complete destruction of energy confinement in these major disruptions is known to have a characteristic $m/n = 1/1$ form. Initially only a small degradation of the confinement occurs, as is observed by the slow increase of the electron temperature at the plasma edge. But at some stage of the evolution of the 2/1 mode the degradation of the energy confinement shows an abrupt increase that quickly leads to a cold plasma. It was observed in circular plasmas [1] that this abrupt increase of the degradation of the energy confinement starts at the low field side, in the neighborhood of the core facing side of the O point region of the 2/1 mode. At this position a region with electron temperature similar to the temperature in the 2/1, O point region, is observed to expand quickly towards the plasma core. Thomson scattering showed that at the time the electron temperature profile is flat over the plasma radius, the electron density is $\approx 50\%$ higher inside the 2/1 mode, compared at the onset of the 2/1, O point T_e erosion.

In this paper we report on the 2/1 T_e erosion that we also observed in ASDEX Upgrade major density limit disruptions. The evolution of the temperature profile is measured with a heterodyne radiometer with 60 channels and 32 μs time resolution. The evolution of the density profile is also investigated both from the high field (HFS) side and from the low field side (LFS) measured with a broad band multi channel reflectometer, with 35 μs time resolution.

These experiments where performed in lower single null diverted ohmic plasmas with $I_p = 1$ MA and $B_\phi = 2.4$ T in order to obtain $q_{95} = 4$. A ohmic density limit of 6×10^{19} m^{-3} was achieved by puffing Ne gas on a D plasma, in order to lower the density limit, relatively to a pure D plasma. Such procedure allowed to optimize the use of the reflectometer which in these experiments had a maximum probing frequency of 73.1 GHz that corresponds to a density of 6.64×10^{19} m^{-3}.

The ohmic density limit disruptions here studied showed typical features of other ASDEX Upgrade density limit disruptions [2]. In the precursor, a MARFE is observed at 2.632 s forming in the divertor region and moving up towards the mid-plane via the HFS. At approximately 3.000 s it eventually decays into a poloidally symmetric radiation shell. The increased edge radiation leads to an unstable current profile that destabilizes an $m/n = 2/1$ tearing mode, see Fig 1(g) at $R_{LFS} \approx 2$ m. At 3.060 s the 2/1 mode locks to the wall and 7 ms latter a minor disruption occurs. When the 2/1 mode locks to the wall the mode O point is in front of the ECE radiometer antenna. So the cold plasma region expanding from the LFS mode's O point towards the plasma core is very similar to the 2/1, O point T_e erosion previously observed in RTP [1], see arrow A in Fig 1(g). However since there are no T_e measurements in the X point region, due to the mode locking, we will refer to this erosion simply as the 2/1 T_e erosion. After this minor disruption there is one other smaller minor disruption at 3.090 s before the major disruption at 3.103 s.

The reflectometer was triggered by a magnetic derived signal monitoring the locked mode. Due to an intrinsic delay in the trigger the n_e profiles could only be measured starting at 3.070 s, missing the first minor disruption. The evolution of the density profiles measured with the reflectometer, shows that the start of the 2/1 T_e erosion, occurs together with an abrupt and consistent increase in the density profile around the $q = 2$ surface on the LFS, starting from the core facing side of the rational surface, see arrow B in Fig 1(e). The final T_e collapse occurs when n_e at the LFS peaks even further (arrow C Fig 1(e)). At this time it is observed a peak in the H_α emission at the divertor (Fig 1(d)) and also in the SXR emission (Fig 1(b)).

On the HFS only the neighborhood of the $q = 2$ surface could be probed and no such sustained abrupt increase of the density was observed. Despite the abrupt

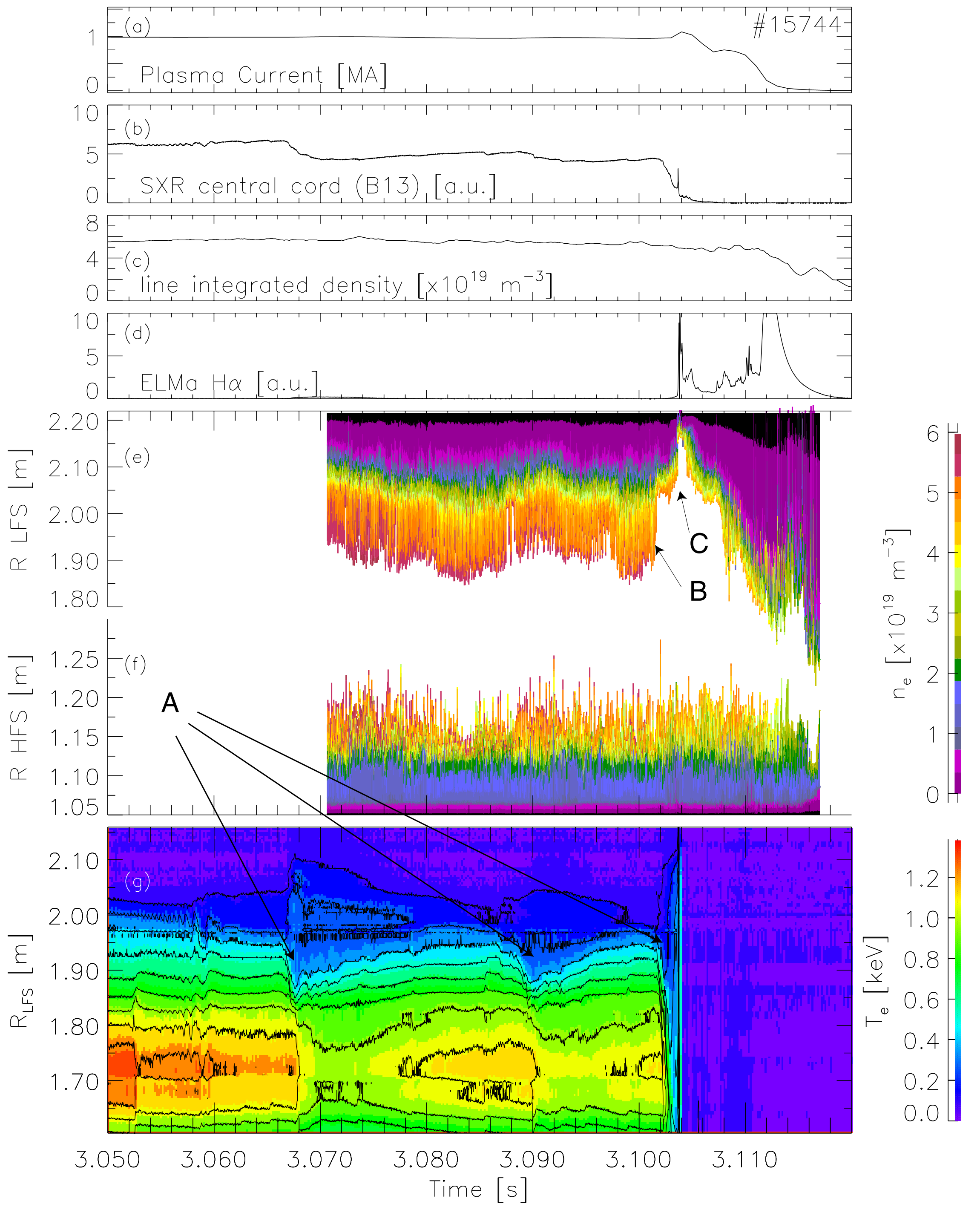

Figure 1: Synchronized plots of plasma parameters. (e) and (f) are Low Field Side and High Field Side n_e profiles measured with a broad band reflectometer, with 35 μs time resolution. (g) are T_e profiles measured with a 60 channels ECE reflectometer, 32 μs time resolution. Arrow A indicates the $2/1$ T_e erosion. Arrows B and C indicate the abrupt increase in n_e occurring in the major energy quench.

changes in the electron density LFS profiles, and concomitant abrupt changes in the electron temperature LFS profiles, the line average electron density practically does not change during the energy quench while the T_e profile collapses completely and the plasma loses its kinetic energy.

The reflectometer measures the density along an horizontal cord, or more precisely it measures the position of the cut-off layer for the probing frequency. This prevents any detection of a density decrease behind the cut-off layer. However comparing these observations with those at RTP [1] (where the energy quench shows comparable and very similar features) it is presumed that these abrupt changes in the density profile are local perturbations moving radially out-wards, at least, since this diagnostic is not sensitive to any non-radial (poloidal) component that this displacement may contain. Further experimental support for this assumption should be obtained in ASDEX Upgrade disruptions.

These abrupt changes in the electron density seem to be local and poloidally asymmetric, mixing cold with hot plasma as they propagate out-wards.

It should be investigated if this behavior is the result of a convective motion of the type predicted in [3]. The poloidal asymmetry of this event is at variance with the model of field line stochastization supposed to take place in between the $q = 2$ and the $q = 1$ surfaces, since such a change in the field line topology should produce observable effects both in the HFS and in the LFS.

References

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