31st EPS Conference on Plasma Phys. London, 28 June - 2 July 2004 ECA Vol.**28G**, P-1.171 (2004)

# Separatrix instabilities and ELMs

Emilia R. Solano[1], F. Villone[2]

[1]Asociación EURATOM/CIEMAT para Fusión, Avda. Complutense, 22, 28040 Madrid, Spain
[2]Assoc. EURATOM/ENEA/CREATE, DAEIMI, Universitá di Cassino, Via Di Biasio 43, I-03043, Cassino, Italy

## Introduction

Experimental observations in JET indicate that type I ELMs are associated with rapid movements of strike points [1,2,3]. In [2,3] strike positions are identified with 2 different diagnostics: as the position with maximum ion saturation current, measured with divertor target Langmuir probes, and as the position of highest temperature and/or heat flux measured with an infrared camera. The apparent strikes often shift as much as 20 cm in 100 μs or less (limit of temporal resolution), but in the next data point the strikes settle nearer their original position, displaced toward the plasma centre by 2-5 cm from the pre-ELM position. Here we consider a possible explanation for the apparent sudden strike jump, although we must acknowledge that it may or may not be real, as during the ELM the ion saturation current profile becomes rather flat, and the position of its maximum is difficult to determine.

In an H-mode plasma strong edge pressure gradients indicate the likely presence of non-zero current density at the separatrix. This means that at the X-point there is a flux tube with toroidal current, which we assume to be parallel to the core plasma current. A new instability mechanism for the plasma can then be considered, associated with position stability of the current-carrying X-point toroidal current filament. If the X-point current carrying flux tube is displaced towards the private flux region, it will be accelerated further in that direction, as the attractive j×B force from the core plasma decreases while the force from the divertor coils increases. This flux tube would then tear, opening up the separatrix. Transiently, a new X-point would form, closer to the core plasma, as the externally imposed diverting fields are increased by the field produced from the detached current carrying flux tube. Plasma would flow along previously closed field lines, both in public and private scrape-off layer regions. As the current in the private flux region reaches the targets, it would dissipate, leading to yet another new equilibrium, with a new X-point forming at an intermediate position between the previous two.

## Vertical instability of current-carrying X-point, and strike movements:

We consider the stability of a current carrying filament in a diverted plasma in a magneto-static model of the tokamak. The divertor is represented by straight circular coils of radius 0.1 m, placed at (R,Z)=(±0.2, ±2.0) and (±0.3,±1.8) (metres), divertor target tiles are assumed to be vertical, at R= ±0.2 m, plasma centre at R=0. Initially the double null plasma is modelled as a straight circular coil of radius 0.5 m, immersed in the divertor field, leading to an X point height of $Z_X$= ±1.47 m, and strikes at $Z_S$=±1.618 m, as shown in Fig. 1a. At the X-point the force on a current filament would be zero, such equilibrium is vertically unstable. There is a secondary null at $Z_{X2}$=±1.77 m, a filament placed here would be vertically stable and horizontally unstable. Removing 5% of the plasma current and placing it in 2 filaments (1 cm radius) at ±$Z_f$, above and below the plasma centre, leads to a displacement of the strike points, as shown in Figs. 1.b, 1.c and 2. As the X-point is approached from inside, the strikes are pushed away from the plasma centre, "down", the evolving H-mode. Beyond a critical value, $Z_s$ =±1.68 m, strikes are swept "up", as filaments cross into new private region, the transient ELM phase. For $Z_s$= $Z_{X2}$, the highest strike position, ±1.58 m is reached, equivalent to a "peeled" plasma with extra divertor current. Whenever current in the private flux region dissipates, strikes would move to "peeled" position without extra divertor current, Zs=±1.60 m. About 10 cm of the divertor target area are swept in this process. Qualitatively, this is as we expected: if X-point current filaments were to be displaced from the main plasma towards the divertor coils, they would "fall" vertically in a fast time-scale until the secondary X-point is reached. There the filaments would drift horizontally towards inner or outer target plates: we must study in more detail the magnetic topology in the divertor region.

With different tools, we studied a JET equilibrium reconstruction [4,2,3] of shot 58837, at 61.39 s. Peeling from it 5% of current, we computed induced eddy currents (from instantaneous current loss), and added current to divertor coils to represent filament current (but not computing eddy currents for this change). Results are shown in Fig. 3. The strikes move as follows: before peeling, $Z_{Sin}$=-1.69, $Z_{Sou}$t=-1.65; after peeling, with extra divertor, $Z_{Sin}$=-1.58, $Z_{Sout}$=-1.54; after peeling, no extra divertor, $Z_{Sin}$=-1.61, $Z_{Sout}$=-1.60. The behaviour very much matches what the naïve tokamak model shows. This will permit us to carry out more detailed calculations with the simplistic model, to study time evolution of eddy currents and their effect on falling filament, not consistently considered here.

In reality, the effect of falling current filaments on strike point position is overestimated in both of the above calculations: it is unlikely that all of the current lost from the plasma at an ELM would appear in the private flux region after separatrix breakage, and eddy currents induced in divertor conducting structures would transiently oppose strike movements. But even if only 10% of the effect survives it could still induce ~1 cm vertical displacements. The more tangentially the targets are designed, the larger the effective target sweeping would be during such transient phase.

For realistic tokamak geometry and current profile details we should search for an equivalent instability associated with progressive transfer of current density from plasma core to edge, as probably occurs when pedestal pressure gradients increase before an ELM.

**Toroidicity effects**

When toroidal effects are taken into account, the toroidal plasma current density in a tokamak equilibrium is given by $j_t = Rp' + FF'/R$, where p is the pressure, F the poloidal current density, and prime is the poloidal flux derivative, $p' = dp/d\Psi$. As p and F are flux functions, if F' has opposite sign to p' (diamagnetism), in the high field side the toroidal density reverses. This is common in H-mode plasmas, near the edge, as was pointed out in [5]. Fig 4. shows a JET reconstructed equilibrium, just before an ELM, in which the region with negative current density is marked in red. The variation of $j_t$, Rp' and FF'/R along the lower half of the separatrix is shown in Fig. 5.

Increasing $\beta_{poloidal}$ and triangularity increases diamagnetism and reduces the toroidal current density at the X-point, increasing the stability of the current-carrying X-point. At extreme triangularity and $\beta_{poloidal}$, the toroidal current density at the X-point might reverse, thereby completely modifying its stability conditions (from “pulled” to “pushed” at field null).

The toroidal negative current in the HFS may itself de-stabilize the separatrix, as opposing currents repel each other, and might contribute to peeling of the outer surfaces.

**Conclusions**

Experimental observations are compatible with the hypothesis that an ELM is a peeling of flux surfaces near the boundary, which open into the scrape-off layer, and the formation of a new separatrix, inside the previous one. In the transitional phase, the strike points may sweep a large area while current that became trapped in the new private flux region drifts deeper into it and dissipates. The stability of a current-carrying X-point may play a role in ELM dynamics, as shown with a simplistic model. Toroidicity effects may relate $\beta_{poloidal}$ and triangularity to X-point stability. Separatrix instability could provide an ELM trigger.

*Acknowledgements*

This work has been conducted under the European Fusion Development Agreement, and has been funded in part by a Ramón y Cajal grant from the McyT, Spain.

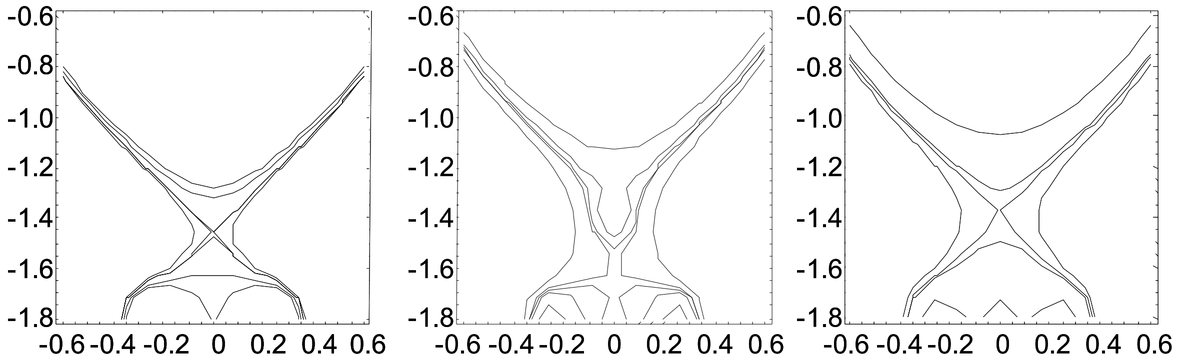


Fig. 1.a) Plasma, no filament 1.b) Filaments at $Z_f$= ±1.4 m. 1.c) Filament at $Z_f$=±1.77 m.

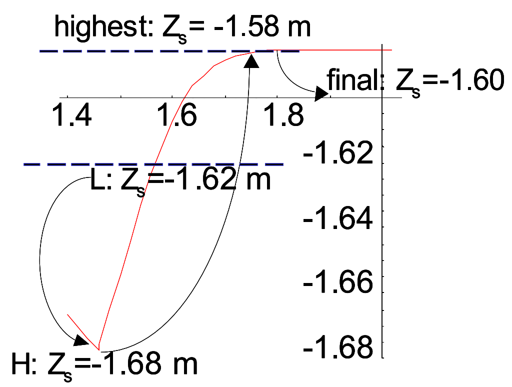


Fig. 2: Strike position *vs.* filament position: from L-mode to H-mode, to extra high, to final?

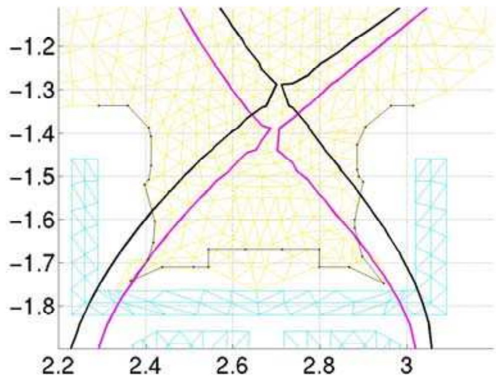


Fig. 3: JET equilibrium reconstruction: before peeling (magenta); after peeling, with extra divertor current.

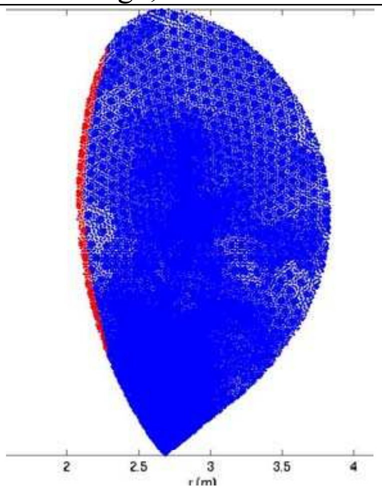


Fig.4: Reconstructed equilibrium, region with negative current density marked in red; JET 58837, 61.4 s.

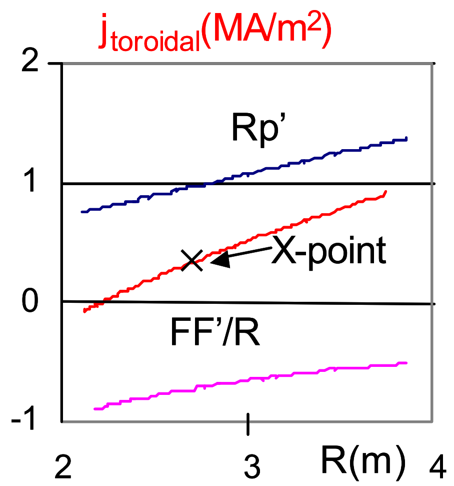


Fig. 5: toroidal current density along bottom half of separatrix, and its two components.

[1] J. Lingertat et al, Journal of Nuclear Materials vols.241-243 February II, 1997, p.402.
[2] Emilia R. Solano et al., 30th EPS Conf. on Contr. Fusion and Plasma Phys., St. Petersburg, 7-11 July 2003 ECA Vol. 27A, P-1.106.
[3] E. R. Solano, Y. Corre, F. Villone et al., Proc. of 16th Plasma Surface Interactions, Portland, USA. May 24–28, 2004, P1-57, to be published in Jour. Nucl. Matt.
[4] R. Albanese, F. Villone, Nuclear Fusion, Vol. 38, no. 5, pp. 723- 738 (1998)
[5] L. Lao, et al., Nuclear Fusion vol.30 no.6 June 1990 p.1035.