On the Genesis of Closed Current Filaments in the Edge of JET

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Introduction

Experimental observations show that ELMs lead to the ejection of a number of current carrying filamentary structures into the scrape-off layer (SOL) [1]. ELMs generate structures with excess energy and density and it can be conjectured that they leave corresponding holes behind. In contrast to blobs/filaments, holes are usually quickly filled by parallel motion along the magnetic field and therefore exhibit a restricted lifetime. If such a hole, however, is in the vicinity of a resonant surface it closes on itself and increases its lifetime. We suppose that the Palm Tree Mode (PTM) is a signature of such an event and therefore a current hole in contrast to e.g. outer modes [2]. The PTM is an ELM post-cursor, which was until now only detected in JET type-I ELMy H-mode plasmas as long as the rational $q = 3$ surface is close to the edge pedestal [3]. Understanding PTMs enhances thus our knowledge of ELM and edge physics and contributes to the refinement of ELM models.

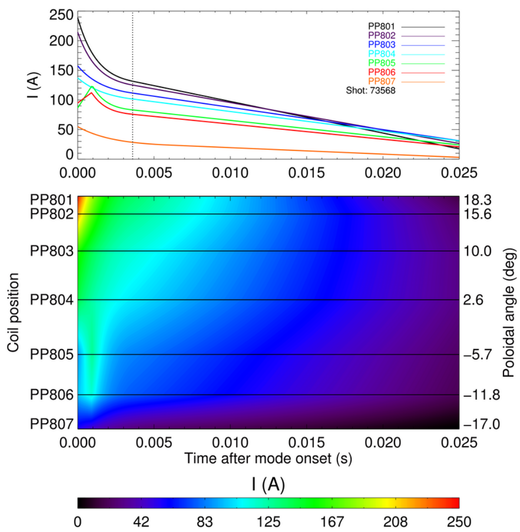

Figure 1: Evolution of a PTM (JET pulse: #73568, $t_0 = 12.996$ s) as seen by the poloidal limiter coil array in quadrant eight.

*see the appendix of F. Romanelli et al., Proceedings of the 22nd IAEA Fusion Energy Conference 2008, Geneva, Switzerland

Results and Discussion

Fig. 1 shows the evolution of the current, proportional to the magnetic perturbation of a PTM (JET pulse #73568, $t_0 = 12.996$ s) as measured by the outboard poloidal limiter coil array in quadrant eight (Fig. 2). The magnetic signals were calibrated, filtered by a Butterworth high-pass filter with a cut-off frequency of 1 kHz and integrated in order to compute the magnetic field B. Using ECE data the radial location of the mode was determined at the outboard midplane. Under the assumption of equidistance of the mode to all limiter coils, the distance to coil PP804 ($d = 0,19$ m) and Biot-Savart's law was used to calculate the current carried by the filament [4]. The signals of the coils PP801-PP804 show an initially rapid decay, followed by a linear decay phase. In contrast coils PP805 and PP806 show a current growth in the beginning. Coil I802 in Fig. 3b) at the inboard side shows a fast growth phase presumably starting at $I_0 \approx 0$ A. However, PTMs without a rapid decay phase or even with a constant initial phase can be observed.

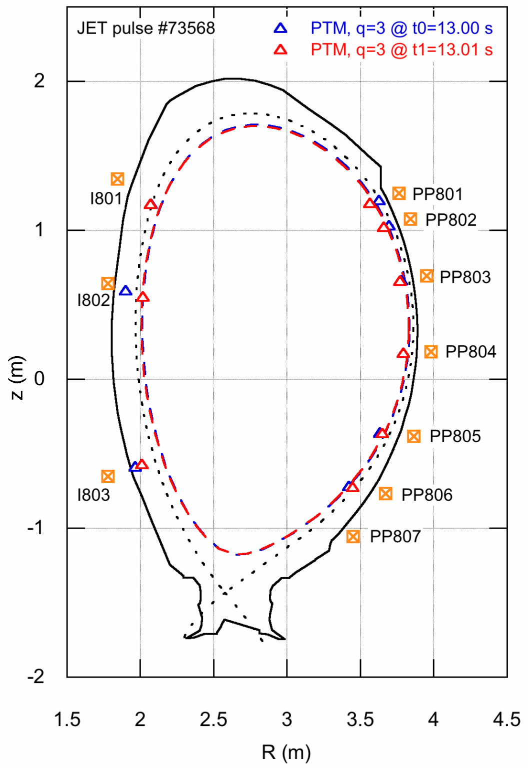

Figure 2: Computed location of a PTM filament and the $q = 3$ surface for two different time steps with respect to coil PP804. JET pulse: #73568, $t_0 = 13.00$ s (blue), $t_1 = 13.01$ s (red).

Apparently all signals show different currents and even different decay rates. In a closed current filament one would expect the same current everywhere after formation. That means that the first assumption of equidistance to all pick-up coils at the limiter is not valid. The first problem can be overcome if one assumes that the current is the same everywhere after the rapid decay phase (dashed line in Fig. 1). The signal from PP804 can then be used to calibrate the others and to find the corresponding distance of the mode to each coil. The different decay rates give insight into the deformation of the filament due to plasma shaping and control, recovery of the pedestal etc. just to mention a few. This means that the decay rates are a combination of the "physical" current decay and the relative motion of the filament to each coil. Figure 2 shows the computed positions of a PTM filament at two different times using the methods explained above. The PTM is indeed close to the $q = 3$ surface (JET pulse: #73568, blue: $t_0 = 13.0$ s, red: $t_1 = 13.01$ s).

The redistribution of current observable at various positions in JET gives rise to the assumption that an initially poloidally peaked current distribution spreads out and transforms into a uniform current distribution as the filament is formed. Neglecting perpendicular dynamics this behavior can be described by Eq. (1) where e designates the elementary charge, m_e the electron mass and n the plasma density. An initially peaked current density distribution j diffuses along a closed magnetic field line at a rate given by the parallel diffusion constant $\tilde{D}_{\|}$. Additionally current density is lost due to parallel Spitzer resistivity $\eta_{\|}$.

$$\frac{\partial j}{\partial t} = \tilde{D}_{\|} \nabla^2 j - \eta_{\|} \frac{e^2 n}{m_e} j \tag{1}$$

This simplified model was solved numerically. A Gaussian current density distribution with a maximum current density of $j_0 = 4.2 \cdot 10^5\, A/\mathrm{m}^2$, $\sigma = 1.2$ m and a filament cross-section of $A_0 = 1.8 \cdot 10^{-3}\,\mathrm{m}^2$ [3] was placed in the middle of the domain. The initial width was set according to results from Tore Supra which give an estimate for the toroidal length of a ballooning perturbation in Tokamaks [5]. The domain length is 56.0 m, depicting the approximate length of a filament on a $q = 3$ surface in JET. Periodic boundary conditions were chosen to reflect a closed current filament.

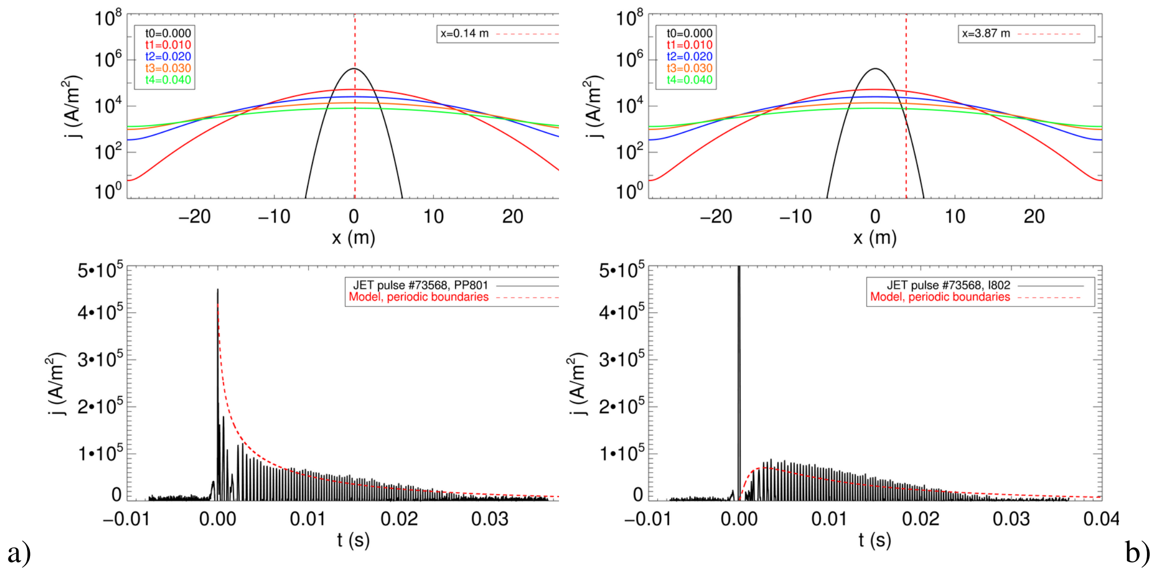

Figure 3: Comparison of measured and simulated current densities for the outboard a) and inboard side b) of JET (JET pulse: #73568, $t_0 = 12.9936$ s).

Geometrically strongest ballooning is expected at the outboard midplane [6]. It can therefore be assumed that also the biggest holes are created in that region. Surprisingly it seems that the current begins to spread somewhere near PP801 and therefore near the top of JET (Fig. 1). The location of PP801 is therefore associated with the center of the domain in the model (Fig. 3a).

The fit of the experimental data is in a good agreement with the measurement from coil PP801 at the outboard side of JET (Fig. 3a). The region of current influx (Fig. 3b) show approximately the same current density rise time. After the growth phase the current density is underestimated. The electron temperature at the location of the PTM after the collapse of the pedestal is roughly $T_e \approx$ 280 eV. The parallel Spitzer resistivity is therefore around $\eta_{\|} = 7.0 \cdot 10^{-8}\,\Omega$m. The resistivity which we obtain from the simulation is $\eta_{\|} = 6.5 \cdot 10^{-8}\,\Omega$m. MHD stability analysis of diagnostic optimized configuration shots (JET pulse: #55986, $q_{95} = 3.0$) yield $0.36\,\mathrm{MA/m^2}$ for the toroidal edge current density [7]. One would expect at maximum a total loss of edge current density which is indicated by the result from the model too (JET pulse: #73568, $j_\phi = 0.42\,\mathrm{MA/m^2}$).

Conclusion

Decay and evolution of a PTM was studied at several positions in JET. Signal strengths and decay rates give insight into location and the movement of the mode. The dynamics of current redistribution indicate a transition from a poloidally peaked to a uniform current distribution as the filament is formed. A 1D model was presented resembling parts of the experimental data, validating the assumption of periodic boundaries and therefore of a closed current filament. The obtained parallel resistivity is in a good agreement with the local Spitzer resistivity. Current diffusion and resistivity are therefore two important effects in the genesis and evolution of the PTM. The obtained results support the assumption that ELMs create holes in the edge plasma. Implications on ELM models should therefore be discussed in future.

Acknowledgement

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