Role of m=0 magnetic perturbations in the crash phase of the pulsed poloidal current drive regime in the TPE-RX device

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The reversed-field pinch (RFP) is a magnetic configuration for thermonuclear fusion plasma, characterized by the toroidal (B_ϕ) and poloidal (B_θ) magnetic fields with comparable amplitudes and by the reversal of B_ϕ near the edge. The radius at which B_ϕ reverses is called reversal radius. The RFP configuration is sustained by the dynamo mechanism, via the non-linear interaction of m=0,1 tearing modes; this mechanism produces the dynamo electric field, E_d, necessary for the sustainment of the configuration. However, the interaction of several tearing modes produces high stochasticity in the plasma core and high radial transport. A technique to reduce the transport and to increase the plasma properties is the PPCD [1]. The application of PPCD stabilizes the tearing modes, reduces the core stocasticity [2], and increases the plasma confinement properties. It is shown in Ref. [3] that the improvement of the plasma performance is tightly correlated with the increase of $E_\parallel$, the component of the electric field parallel to the magnetic field. However, the improved confinement regime (ICR) generated by the PPCD is transient and it suddenly terminates. In this paper we described the dynamics of magnetic modes at the termination of the ICR in the RFP device TPE-RX.

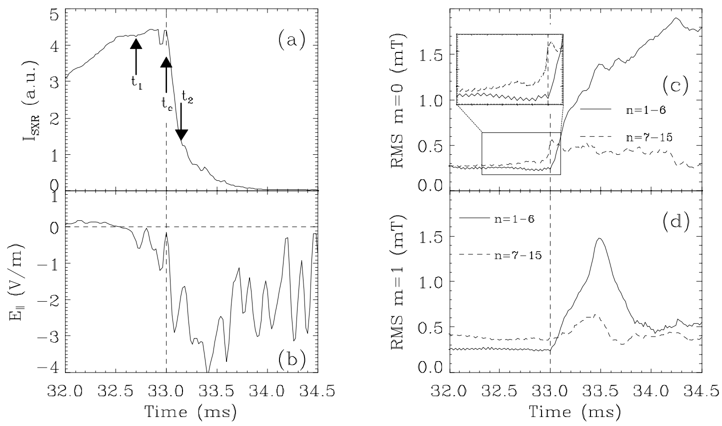

Figure 1: Time evolution of I_{SXR} (a), $E_\parallel$ (b), m=0 (c) and m=1 (d) modes around the termination of the ICR.

Figure 1 shows the waveforms of soft X-ray intensity, I_{SXR} (a), $E_\parallel$ (b), m=0 (c) and m=1 (d) modes. At the termination of the ICR, $t=t_c$, I_{SXR} suddenly crashes and $E_\parallel$ decreases to –3V/m, a value comparable to that before the PPCD application. Note that $E_\parallel$ starts to decrease before t_c. As far as the behaviour of tearing modes is concerned, both low-n (n≤6) and high-n (n≥7) m=0 modes grow during the crash. On the contrary, the resonant m=1 modes (n≥7) are constant during all the time of the crash mechanism, and the non-resonant m=1 modes grow only after the crash. This behaviour is in contrast with the conventional picture of the sawtooth crash mechanism, in which the peaking of the current produces the growth of m=1 modes and subsequently, through the non-linear interaction of these modes, the growth of the m=0 modes.

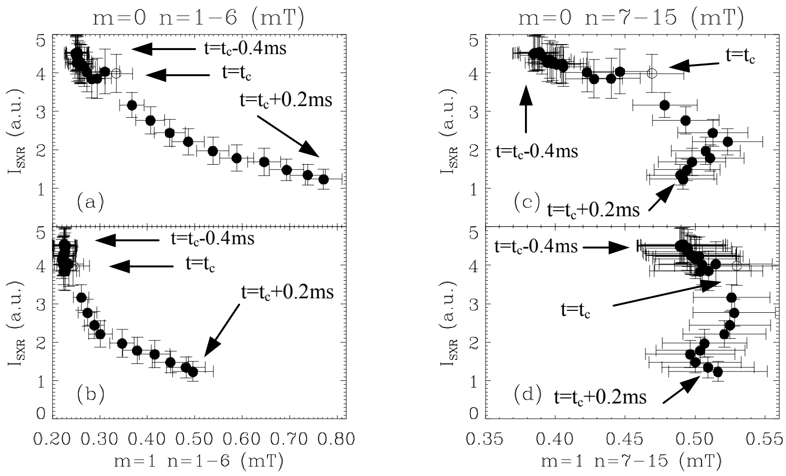

Figure 2: Correlation between I_{SXR} and magnetic modes in a time interval around the termination of ICR.

This behaviour is clear in Fig. 2, where the correlation between I_{SXR} and the magnetic modes is shown. The data of Fig. 2 are the result of the average over 10 PPCD shots. While m=0 modes increase before t_c, [Figs. 2(a) and 2(c)] the non-resonant m=1 modes grow only after t_c, Fig. 2(b), and the resonant modes are constant during all the time interval [Fig. 2(d)].

We can suppose that the perturbation of m=0 modes modifies the m=0 island generated at the reversal surface. The m=0 magnetic island can be reconstructed calculating the toroidal magnetic flux, see Ref. [4], using the radial profile of the eigenfunctions of the (m,n)=(0,n) modes obtained solving the Newcomb's equation. Examples of island reconstructions, for

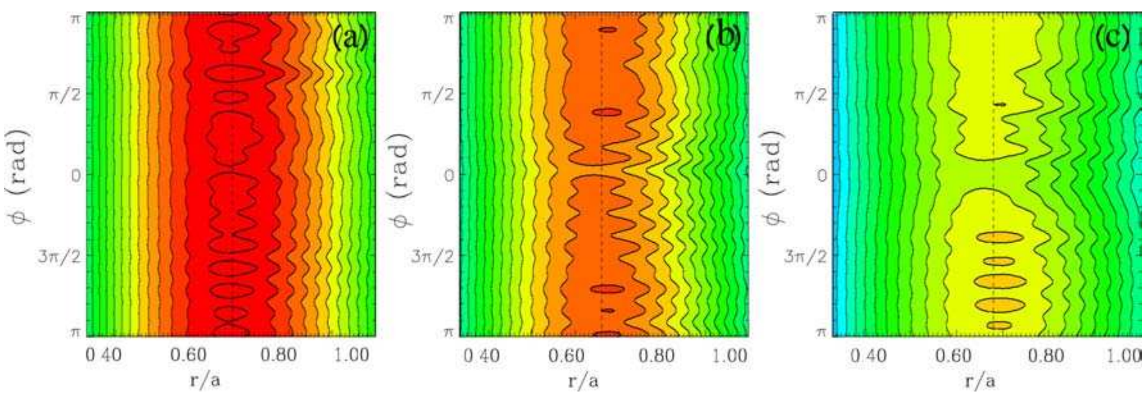

Figure 3: Reconstruction of the m=0 barrier at the reversal surface.

the same shot of Fig. 1, are shown in Fig. 3. Figures 3(a), 3(b) and 3(c) correspond respectively to the m=0 magnetic island at the time t_1, t_c and t_2 of Fig. 1(a). At t_1 the plasma is still in the ICR and at the reversal radius there are good flux surfaces that identify a m=0 island. At the crash time, t_c, the region of good flux surfaces is reduced and a *hole* is generated at the toroidal angle ϕ=0. After the crash time, at t_2, this region is further reduced and the hole is enlarged. The growth of the m=0 modes can increases the width of the corresponding magnetic islands and the superposition of larger island can create higher stochasticity, reducing the region with well-conserved flux surfaces. As far as the hole is concerned, its position corresponds to the position of the slinky structure. Note that during the PPCD the slinky is strongly suppressed but, before t_c, the slinky grows again.

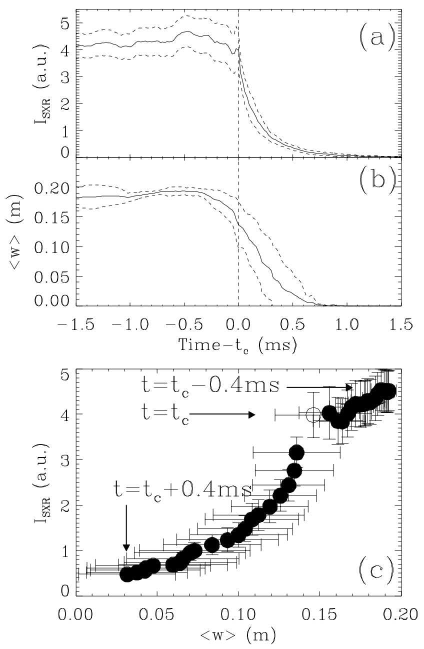

Figure 4: Time evolution of I_{SXR} (a) and of <w> (b). Correlation between I_{SXR} and <w> (c).

To quantify the modifications of the m=0 island, we have defined the variable <w>. To define <w>, we have considered the constant flux surface corresponding to the 75% of maximum flux; <w> is the toroidal average of the radial width of this surface. The decrease of <w> reflects both the reduction of the flux surface's width and the enlargement of the hole. Figures 4(a) and 4(b) show the shot-averaged time evolution of I_{SXR} and of <w> for the same set of shots of Fig. 2. The decrease of <w> starts before the I_{SXR} crash. This is evident in Fig. 4(c) where the correlation between I_{SXR} and <w> is shown.

Indeed the decrease of <w> is correlated with the increase of the magnetic modes, as shown in Fig. 5. Before the crash, <w> decreases with the increase of m=0 modes, both with low and high toroidal number n, Figs. 5(a) and 5(c). After the crash, the decrease of <w> is well correlated with low-n m=0 modes and low-n m=1 modes. Note that,

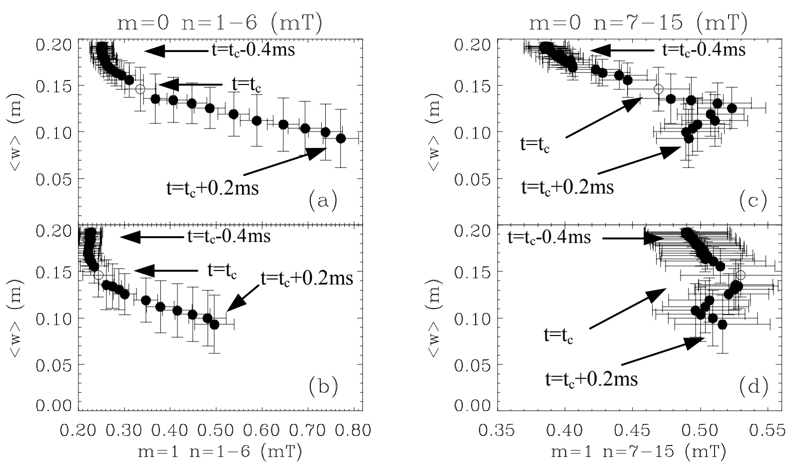

Figure 5: Correlation between <w> and magnetic modes.

within the standard deviation, the m=1 core resonant modes are not correlated with the decrease of <w>, Fig. 5(d).

The increase of m=0 modes seems to be a precursor of the crash phase at the end of the ICR, since these modes grow before t_c. m=0 modes could increase because of the decrease of $E_{\|}$, Fig. 1(b). During the PPCD, $E_{\|}$ increases from –3V/m to +1V/m [3]. When the effect of the PPCD is completely exhausted, $E_{\|}$ decreases, returning to its pre-PPCD value. In order to satisfy the Ohm's law, $E_{\|}+E_d=\eta J_{\|}$, the plasma could react to the marked decrease of $E_{\|}$ increasing the m=0 fluctuations and hence the dynamo term. Indeed, it was pointed out in Ref. [5] that at the RFP edge the dynamo is mainly generated by m=0 modes. The perturbation in m=0 modes modifies the m=0 magnetic island of the reversal surface. Before the crash, the flux surfaces' width decreases and a hole is generated.

We could speculate that the presence of the island's flux surfaces reduces the transport from the core to the edge. Recent numerical simulations [6] show that the m=0 modes produce a chain of m=0 islands which could create a transport barrier at the reversal surface. Therefore, the reduction of the width of the flux surfaces could enhance the transport, hence producing the I_{SXR} crash at the end of the ICR. Moreover, the hole generated by the slinky could be a preferential way for the losses of particles and energy, further increasing the transport. The cooperative effect of the flux surfaces reduction and of the generation of the hole could be the origin of the marked decrease of plasma performance, hence producing the end of the ICR. However, after the crash, the growth of m=1 low-n modes could further increase the magnetic stochasticity; even these modes could contribute to the transport enhancement.

References:

[1] J.S. Sarff et al., Phys. Rev. Lett. 72, 3670 (1994).

[2] P. Franz et al., Phys. Rev. Lett. 92, 125001 (2004).

[3] L. Frassinetti et al., Phys. Plasmas 11, 5229 (2004).

[4] P. Zanca and F. Sattin, Plasma Phys. Control. Fusion 45, 1 (2003).

[5] P.W. Fontana et al., Phys. Rev. Lett. 85, 566 (2000).

[6] A. Cravotta, *Proceedings of the 31st EPS conference on controlled fusion and plasma physics*, London, 2004.