29th EPS Conference on Plasma Phys. and Contr. Fusion Montreux, 17-21 June 2002 ECA Vol. ***26B****, P-4.126 (2002)*

First results of SXR profile measurements in the MST reversed field pinch

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A miniaturised diagnostic for multichord measurements of soft x-ray (SXR) has been designed and installed in the MST [1] reversed field pinch. The line integrated emissivity (brightness) is measured, along several lines of sight, in a poloidal section of the machine, using an array of 20 silicon photodiodes. The array is inserted in one of the 1.5 inch porthole of the vacuum vessel. The poloidal coverage of the fan of chords is about 70% of the MST cross section. This allows the measurement of SXR profiles in MST. In fact, the spatial coverage and time resolution is sufficient to detect localised, rotating structures in the plasma core of MST, corresponding to Quasi-single helicity (QSH) states [2], i.e. when a single m=1 tearing instability dominates the magnetic fluctuation spectrum.

Signatures of these structures are seen as oscillations in the SXR signal: Figure 1,(a) displays a contour plot of SXR brightness measurements, where the horizontal axis is the impact parameter of each line of sight, and the vertical axis is the time. The SXR emission follows a snake-like pattern : on the chords looking at the periphery of the plasma core, the emission is dominated by a ν_p~ 20 kHz oscillation, which is in counter-phase in the inner and outer section of the plasma. This is evident in the expanded insets (b) and (d) of Figure 1, where the time signals of two chords, opposite one to each other with respect to the geometrical centre of

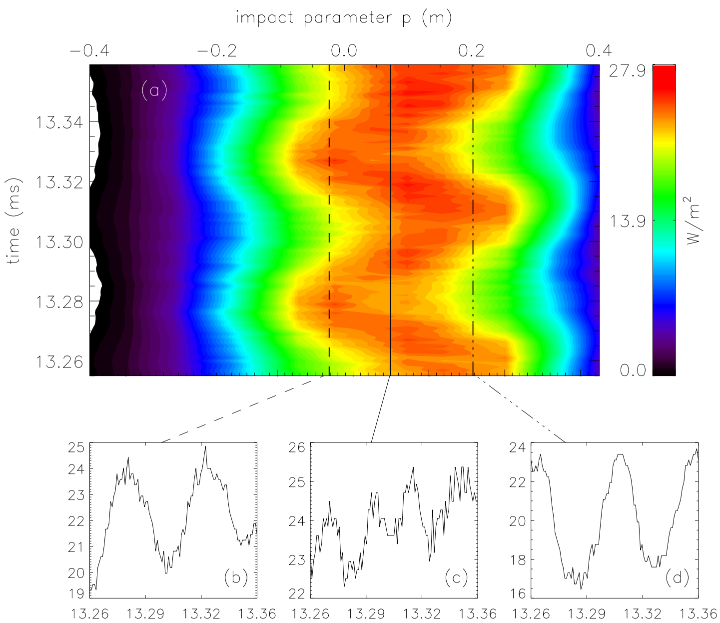

Figure 1:(a) contour plot showing the time evolution of the SXR emission, over the time, and as a function of the impact parameter p; (b-d) expanded insets showing the time signals for three diodes, marked as vertical lines in (a).

the machine, is shown. The insets correspond to the two dashed lines in Figure 1(a). A oscillating behaviour is evident also in the central chord, displayed in frame (c); the time trace corresponds to the solid line in the centre of Figure 1(a). Nevertheless, the oscillation frequency in the central chord is around ~ 40 kHz, which is approximately twice as the frequency ν_p seen in the adjacent chords (frames (b) and (d)). There are two facts that connect these fluctuations with a rotating, localised structure caused by a QSH state: the oscillation frequency of the periphery chords ν_p corresponds to the rotation frequency $\nu_{1,6}$ of the dominating m=1, n=6 mode; moreover, these fluctuation show an m=1 nature, since they are in counterphase in the inner and outer chords.

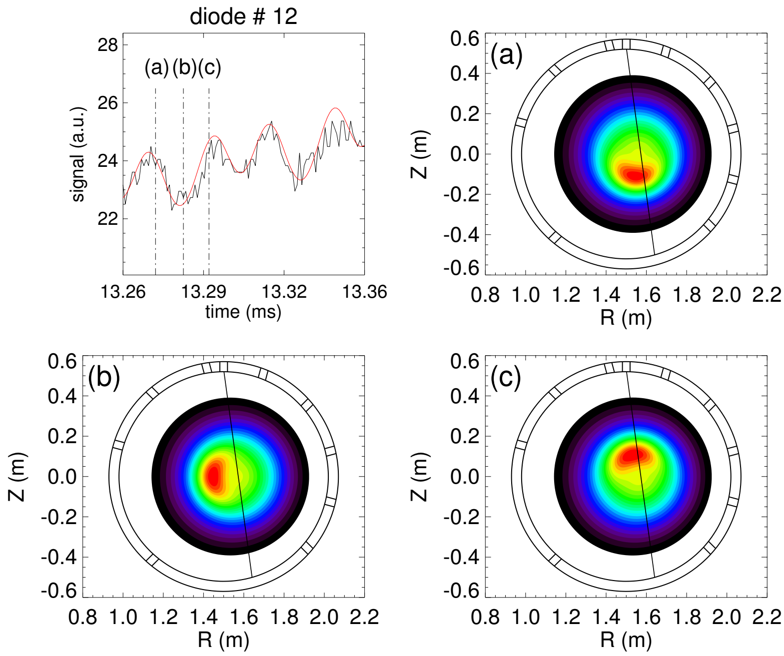

Figure 2: (black) Time evolution of the SXR brightness along a central chord (diode #12); (red) simulated data, assuming an emissivity pattern with a localised structure at r*= 13 cm; the three vertical dashed lines correspond to the three snapshots in frames (a-c), where the simulated emission is shown as a contour plot.

The origin of the higher 2 ν_p harmonic in the central chord is more difficult to explain, but it can be accounted for by a simple model of SXR emission. Let us assume that the SXR emission is a 2D pattern, described by a gaussian function centred at r = 0, symmetric in the poloidal angle θ, plus a perturbation centred at $r = r^*$ and $\theta = \theta^*$, modelled as the product of two gaussian functions in the r and θ co-ordinates, with certain radial and poloidal widths σ_θ and σ_r . The Shafranov shift can be accounted for using flux coordinates ti describe the final emissivity distribution.

If the impact parameter of the line of sight is greater than r^* , the localised structure intercepts the outer chords only once in a rotation period, and therefore the fluctuation seen in the SXR signal is approximately equal to the rotation frequency of the 1,6 mode. In the case of a central chord (at least with impact parameter $p < r^*$) the same structure intercepts the chord twice. The result is summarised in Figure 2, where the emission model is shown in 3 snapshots (a-c) during a single rotation period, along with the measured (black) and simulated (red) brightness, integrated along the central chord. When the structure intercepts the chord on the bottom side (time (a)), there is a local maximum; when it intercepts the chord on top (time (c)), there is another local maximum, during the same rotation period. The minimum is achieved when the structure is approximately parallel to the viewing chord (time (b)). This behaviour is not possible if the impact parameter of the chord is greater than r^*; the limiting situation is when the chord is tangent to the rotating structure, and $p = r^*$. Within the simple model proposed, the SXR localised structure should be centred at $r^* = 13$ cm, with radial and poloidal widths $\sigma_r = 6$ cm and $\sigma_\theta \sim 50°$, and with a Shafranov shift $\Delta_h = 6$ cm. The presence of a higher harmonic $2\nu_p$ in the central chord of the SXR camera, which we think is due to the rotation of a localised structure on the poloidal plane of MST, is otherwise difficult to explain. In the case of a periodic change of the plasma shift, or the rigid displacement of the SXR gradient in presence of a rotating m=1 structure, the oscillation frequency should be the same over all the chords, and equal to the tearing mode frequency, $\nu_{1,6}$.

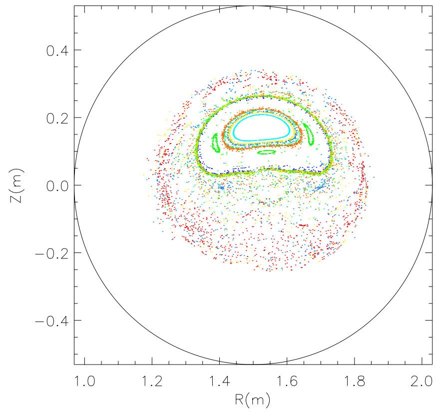

Figure 3: Poincaré map of the magnetic field lines on a poloidal plane of MST.

The presence of a localised structure in the core of MST is confirmed by results of the simulations performed with the code ORBIT. This is a hamiltonian guiding centre Monte Carlo code with numerical or analytic equilibria [3]. The equilibrium magnetic fields in this case are numerically computed through the $\mu\&p$ [4] equations, using the experimental values of the reversal parameter F ($F = B_t(a)/<B_t>$) and pinch parameter Θ ($\Theta = B_\theta(a)/<B_t>$). The eigenfunctions of the magnetic field perturbations are calculated solving the Newcomb's equation: their amplitudes are obtained from the experimental m=1, $n \geq 6$ tearing mode spectrum. On the basis of the equilibrium fields, and computed eigenfunctions, ORBIT calculates the particle trajectories, starting from a uniform particle distribution. Starting from a peaked, QSH spectrum of m=1 fluctuations, the poloidal Poincaré section shows a clear localised structure (see Figure 3), which qualitatively agrees with the SXR model sketched in Figure 2.

The newly realised SXR camera is capable of revealing other tiny details in the plasma emission: evidences of beating of two frequencies are seen in the signals of chords viewing the core of the plasma. In fact, in some cases, instead of the usual $\nu_p = 20$ kHz oscillation, the beating of two frequencies with $\Delta\nu = 1$ kHz is seen: this is shown in Figure 4,(c), where the signal coming from a single chord is filtered over 4 kHz to show the fluctuating behaviour. The beat phenomenon is seen only when the *m*=1 mode amplitudes are rather low, as it is evident in Figure 4,(a): in fact, the example shown refers to a PPCD experiment [5], when usually the tearing mode amplitudes are greatly reduced. Moreover, in the example shown, almost all *m*=1 modes are locked, except for the two innermost resonant *m*=1, *n*=6 and 7, which rotate at two frequencies that are almost identical ($\Delta\nu \sim 1$ kHz, see Figure 4,(b)). This correspondence between magnetic data and SXR behaviour suggests that in this case we are observing the slinky pattern of two modes, locked one to the other, as reported in a previous work in MST [6]. Anyway, since the mode amplitude is quite low, and the PPCD usually induces modifications of the *q* profile, in the direction of separating the magnetic islands associated to the inner resonating modes, it could also be the case that the SXR beating is the signature of the presence of two individual islands that rotate at two near frequencies. The validation of this assumption, with emission models and the code ORBIT, is ongoing work.

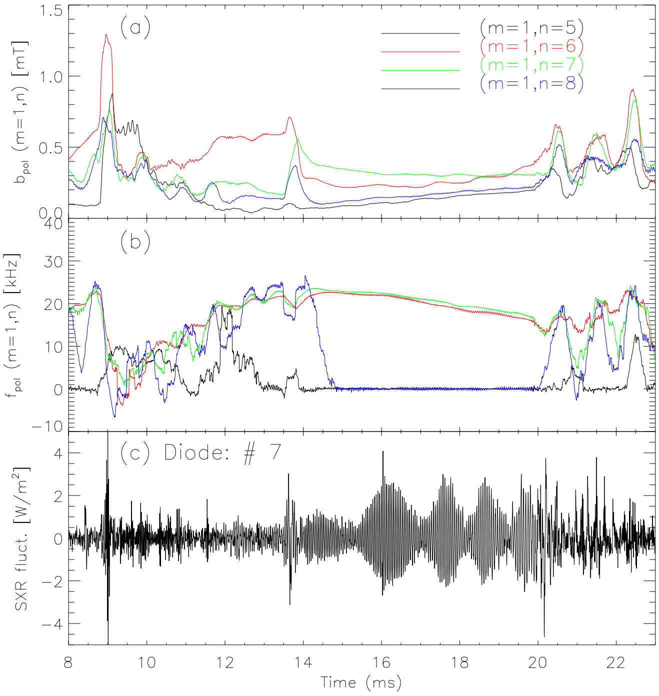

Figure 4: (a) fluctuation amplitudes of the m=1, n=5-8 modes; (b) their frequencies, (c) SXR signal, filtered over 4 kHz, showing the beat of two near frequencies. These SXR frequencies coincide with the rotation frequencies of the m=1, n=6 and 7 modes.

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