

Investigation of the sawtooth behaviors by using the J-TEXT three-wave polarimeter-interferometer

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Introduction

Sawtooth oscillations associated with $q = 1$ surface in a tokamak plasma were first observed on soft X-ray emission [1]. Such phenomena were thought to be the result of periodically peaking and rapid drop of central electron density and temperature. Nevertheless, variations of current density profile relevant to magnetic reconnection may also take an important role during such periodic oscillations. The J-TEXT tokamak now has equipped with a high-resolution three-wave far infrared laser polarimeter-interferometer system (POLARIS) for simultaneous line-integrated electron density and Faraday rotation angle measurements. The J-TEXT POLARIS would have the capability to provide the detailed temporal-spatial evolution of electron density and current density (and/or internal magnetic field) profiles. Thus investigation of the role current density variation playing during the sawtooth cycles by POLARIS would be possible.

Experimental observations by POLARIS

J-TEXT is a medium-sized tokamak with a circular cross-section ($R=1.05\text{m}$, $a=0.27\text{m}$) [2]. POLARIS is a laser-aided diagnostics which adopts three-wave polarimetry technique to measure line-integrated electron density and Faraday rotation angle simultaneously. The measurements can be depicted by

$$\phi_{ne} = 2.82 \times 10^{-15} \lambda \int n_e(z) dz, \quad (1)$$

$$\psi_F = 2.62 \times 10^{-13} \lambda^2 \int n_e(z) \vec{B}_p(z) dz, \quad (2)$$

where λ is the wavelength of the laser beam, ϕ_{ne} is the line-integrated electron density (n_e) phase, and ψ_F is the Faraday rotation angle involving internal magnetic field (\vec{B}_p)

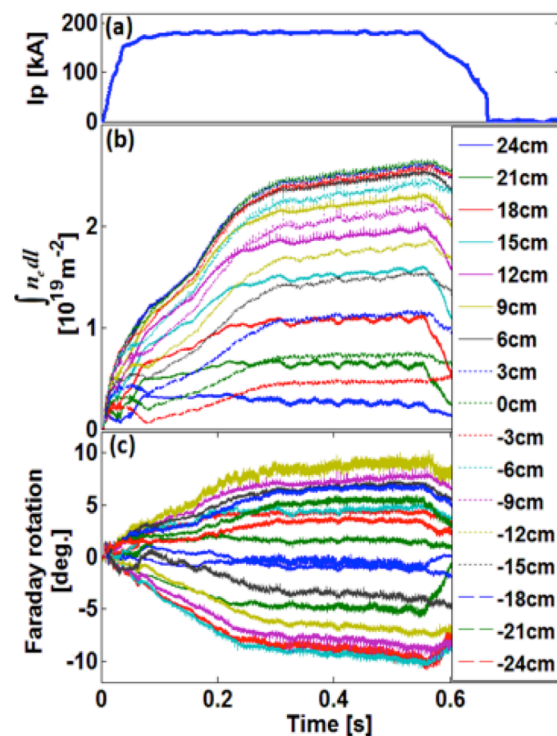


Figure 1. 17 chords' signals of POLARIS. (a) Plasma current; (b) Line-integrated electron density; (c) Faraday rotation angle.

[3-4]. Three HCOOH lasers are chosen as the beam source ($\lambda=432.5\mu\text{m}$). High intermediate frequency (> 1 MHz) provided by three-wave technique enables the system to have a higher temporal resolution, up to $1\mu\text{s}$. The phase resolutions of the POLARIS is $\sim 0.1^\circ$ [5].

POLARIS now has as many as 17 viewing chords on J-TEXT tokamak. They share the same vertical view and distribute symmetrical from -24 cm to 24 cm with the same spacing of 3 cm. Figure 1 shows 17 chords' signals of line-integrated electron density (Fig. 1b) and Faraday rotation angle (Fig. 1c), respectively. The POLARIS signals presented here are obtained in a typical J-TEXT discharge with plasma current of 180 kA at a center-line toroidal field of 2.0 T ($q_a=3.4$). As shown in Fig. 1c, Faraday rotation angle is negative on the low field side (LFS), but positive on the high field side (HFS), due to the projection of \vec{B}_p vector on the viewing chord, either along the beam direction or in its opposite.

Investigations of sawtooth behaviors

Benefiting from its high sensitivity to line-integrated density (e.g., $\sim 1.5 \times 10^{16} \text{ m}^{-2}$) and Faraday rotation angle (e.g., 0.1°), POLARIS can carry out some fine measurements of the perturbations in a tokamak plasma. For example, sawtooth, one of the most important MHD instabilities, can be scrutinized by the J-TEXT POLARIS, both on line-integrated density and Faraday rotation angles. Fig. 2 gives an example of 8 line-integrated electron density signals (from -9 cm to 12 cm). In the figure, it is obvious that the amplitudes of sawtooth oscillations do not exceed $5 \times 10^{17} \text{ m}^{-2}$, only $\sim 2\%$ of the equilibrium value. And the locations of sawtooth inversion are around -6 cm on the HFS and 9 cm on the LFS, indicating that the mixing radius over which $q=1$ surface is around -6 cm and 9 cm, which agree with the observations of soft X-ray emission array.

Furthermore, it is found that ~ 6 kHz $m=1$

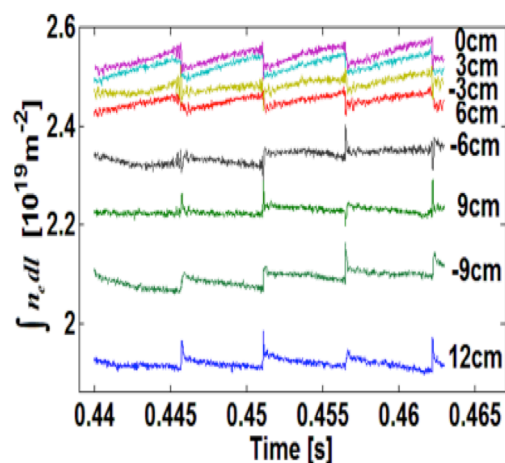


Figure 2. Sawtooth oscillations on line-integrated electron density signals

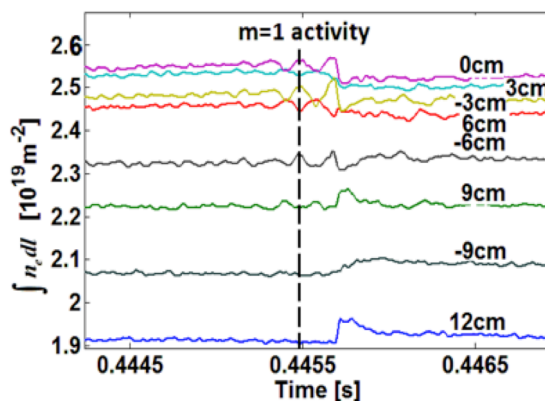


Figure 3. $m=1$ activity in a sawtooth cycle

(where m is poloidal mode number) oscillations are embedded in the sawtooth cycle, as traced by line-integrated density signals in Fig. 3. In the figure, once there is positive phase on the HFS for coherent oscillation, its counter-part on the LFS would have negative phase. There is a π -phase difference between each other, as marked by the black dotted line in the figure.

Apart from the line-integrated density, Faraday rotation angles also bring forth some interesting results. Figure 4 shows an example of sawtooth oscillations on Faraday rotation angle signals. In the figure, it is obvious that sawtooth amplitude can be $\sim 0.5^\circ$ at some chords, which is about 10% of the equilibrium value (As to the line-integrated density phase, this value is only 2%). It is worth notice that the locations of sawtooth inversion appear twice on the LFS ($3 \leftrightarrow 6\text{cm}$, $9 \leftrightarrow 12\text{cm}$), similarly twice on the HFS ($-3 \leftrightarrow -6\text{cm}$, $-6 \leftrightarrow -9\text{cm}$).

Obviously, the observations manifest that the perturbations on Faraday rotation angles due to the sawteeth are different from those on line-integrated electron density phases.

Figure 5 plots the perturbation parts of POLARIS signals in three different J-TEXT discharges having sawteeth. It's indicated that the sawtooth behaviors are much the same on line-integrated electron density but quite different on Faraday rotation angle.

Here the perturbation part of Faraday rotation angles can be obtain by rewriting the equation in terms of the equilibrium and perturbed quantities for each variable (e.g., $\psi_F = \psi_0 + \tilde{\psi}$, $n_e(z) = n_{0z} + \tilde{n}$, $\vec{B}_p(z) = B_{0z} + \vec{\tilde{B}}$). Hereafter the perturbation part can be approximated by $\tilde{\psi} \propto c(\int B_{0z} \tilde{n} dz + \int n_{0z} \vec{\tilde{B}} dz)$, which is the sum of the perturbed electron density weighted by equilibrium magnetic field and perturbed magnetic field weighted by equilibrium density [6-8]. Since the observations of sawteeth events on Faraday rotation angles are extremely different from shot to shot, it implies that internal magnetic field fluctuations (and/or current density fluctuations) should take an importance role in determining the perturbation pattern of sawtooth oscillations.

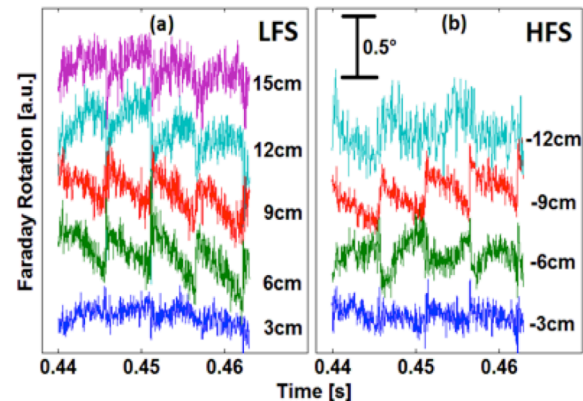


Figure 4. Sawtooth oscillations on Faraday rotation angle signal, all of the chords have been offset to provide a better display and match the same scaling

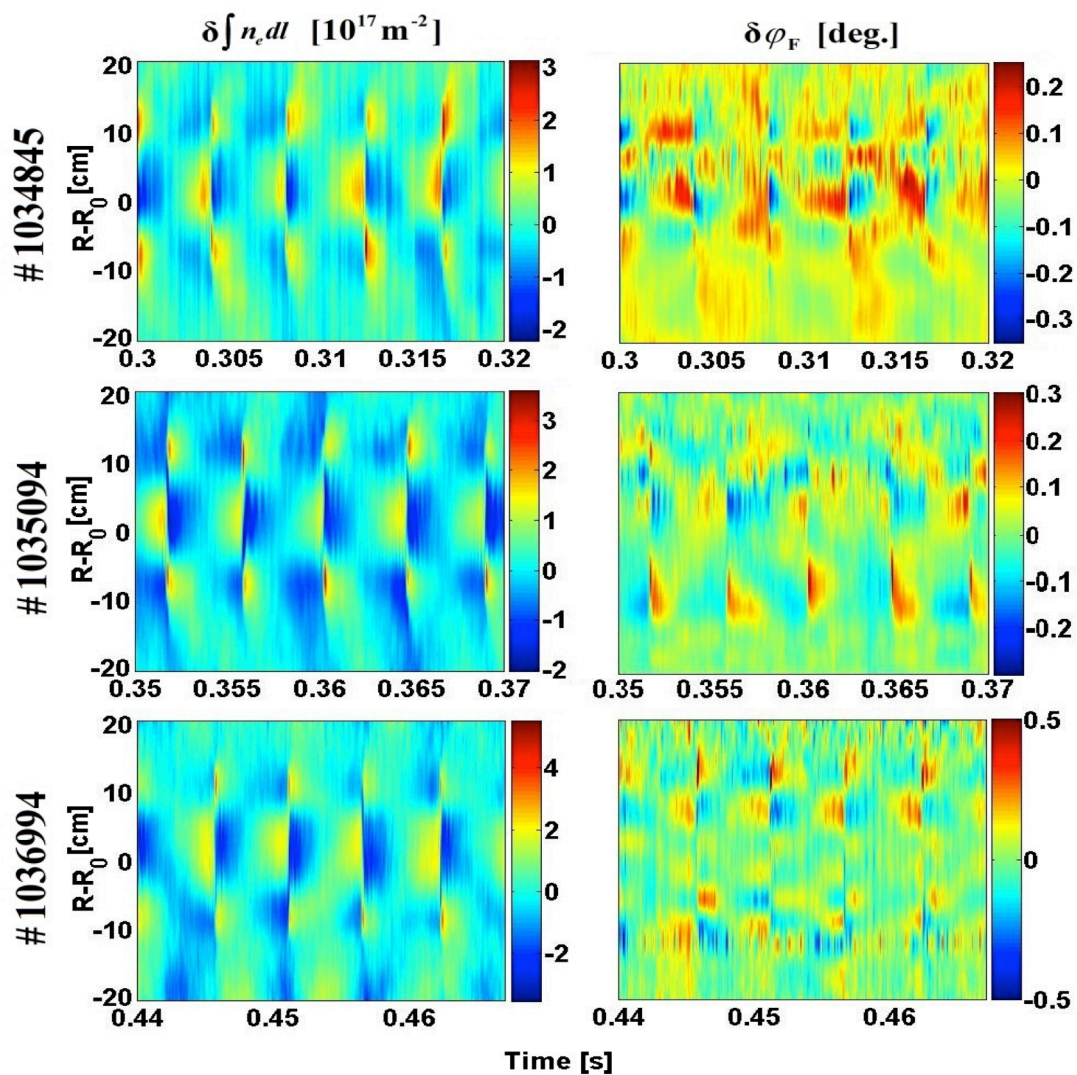


Figure 5. Sawtooth behaviors on the perturbation parts of POLARIS signals in three different J-TEXT discharges.

Acknowledgement

This work was supported by the ITER Project Funds of People's Republic of China (Contract No.2009GB107003).

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