Study of core magnetic and electron density perturbation associated with magnetic island on J-TEXT tokamak

J. Chen[1], G. Zhuang[1] and Q. Hu[1]

[1]*State Key Laboratory of Advanced Electromagnetic Engineering and Technology, Huazhong University of Science and Technology, Wuhan 430074, China*

1. Introduction

Experimental study of magnetic island structure is helpful to understand the mechanism of Magnetic-Hydro-Dynamic (MHD) instability and associated phenomena, such as disruption. The magnetic island, though it is observable via many channels e.g. electron density, electron temperature and lots of optical emissions, is firstly characterized by magnetic /current density perturbation around the rational surface. However, as lacking of effective diagnostic tool, direct experimental study of core magnetic perturbation associated with magnetic island is rare.

Recently, a high resolution polarimetric-interferometric diagnostic has been developed on J-TEXT, which enables the study of magnetic and electron density perturbation associated with magnetic island [1, 2]. Magnetic and density perturbation during tearing activity have been directly observed. Comparing to the simulation results based on cylindrical geometry, experiment results show large asymmetry at high field side (HFS) and low field side (LFS), indicating asymmetric island structure probably due to toroidal effect. Except the asymmetry, experiment and simulation results are highly similar with each other, suggesting magnetic island in experiment has similar mode structure to the simulation. Taking the asymmetry into account, structure of electron density perturbation has been preliminarily obtained.

2. Experiment results

The polarimetric-interferometric diagnostic launches laser probe beams into the plasma to simultaneously measure Faraday angle α and integrated density φ along the beam path:

$$\alpha \sim \int n_e B_l dl\,,\ \ \varphi \sim \int n_e dl \quad (1)$$

n_e is electron density, B_l is magnetic field along the path of probe beam and l is the path of probe beam. The perturbation of α and φ are then:

$$\delta\alpha \sim \int (\delta n_e B_l + n_e \delta B_l + \delta n_e \delta B_l) dl\,,\ \ \delta\varphi \sim \int \delta n_e dl \quad (2)$$

The third term of δα is usually very small comparing to the first two terms and is ignorable. Though δα is line-integrated and associated with electron density perturbation, the magnetic perturbation can still be directly distinguished when pattern of δα and δφ is different. The J-TEXT polarimetric-interferometric diagnostic is capable to catch small perturbation of α and φ up to hundreds of kHz, enough for tearing activity study; and multi-chord measurement covering the whole plasma cross section provides good spatial resolution of the perturbation structure.

Typical experimental results of δα and δφ during m=2/n=1 tearing activity are shown in figure 1. 17 chords δα and δφ are plotted in figure 1(a) and 1(b) respectively, in which case the measurement covers ~95% of the plasma column (a=0.255 m). As magnetic island rotates, δα and δφ show periodic oscillations with the same frequency associated with mode number and rotation speed. According to the variation of island location, δα and δφ at different chords exhibit different amplitude and phase, providing spatial information of the island structure. For J-TEXT normally the amplitude is ~50 degree for δφ while ~0.5 degree for δα, corresponded to integrated density perturbation ~$5x10^{17}m^{-2}$ and averaged magnetic perturbation tens of gauss. Contour plots of these time-space data provide a better view of the perturbation structure, as shown in figure 1(c) and 1(d). As can be seen, δα and δφ exhibit different patterns along the direction of major radius, which manifests the existence of magnetic perturbation.

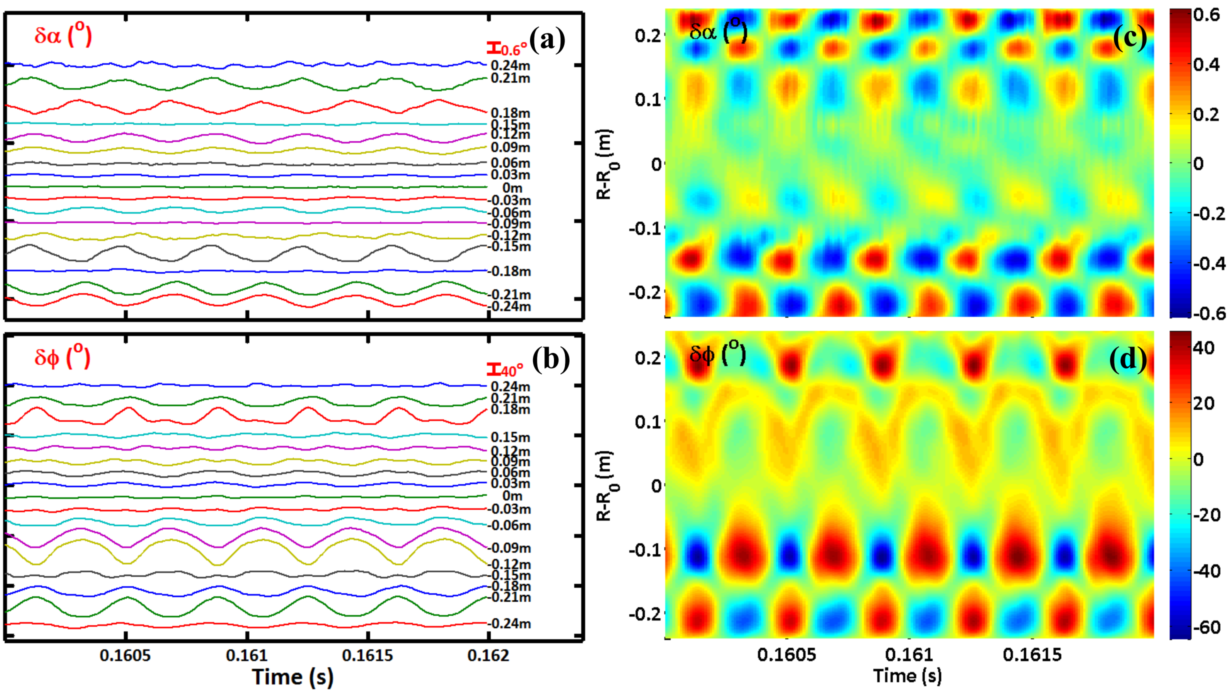

Figure 1 Experimental results of δα: (a) multi-chord time-sequence data and (c) profile evolution, and δφ: (b) multi-chord time-sequence data and (d) profile evolution during m=2/n=1 tearing activity.

As the perturbation is coherent and sine-shaped for most chords, δα and δφ can be simply characterized by the amplitude and phase. Figure 2 shows their perturbation amplitude (solid line) and phase (dashed line) profile. It should be noted that π equals to –π for the phase. For this mode (m=2/n=1), there are 4 phase reversal points across the profile for δφ and 5 phase reversal points for δα. These reversal points divide the profiles of δα and δφ into several regions, and each of these regions has the same phase. In general there are two phases for all these regions: 0 and π (-π).

3. Simulation results

Based on nonlinear two-fluid model [3, 4] and J-TEXT parameters, the spatial structures of local current density and electron density perturbation for m=2/n=1 islands are numerically simulated under cylindrical geometry. The simulated electric current density and electron density perturbation equal to zero at the position of rational surface q=2 and have bipolar feature inside and outside the rational surface.

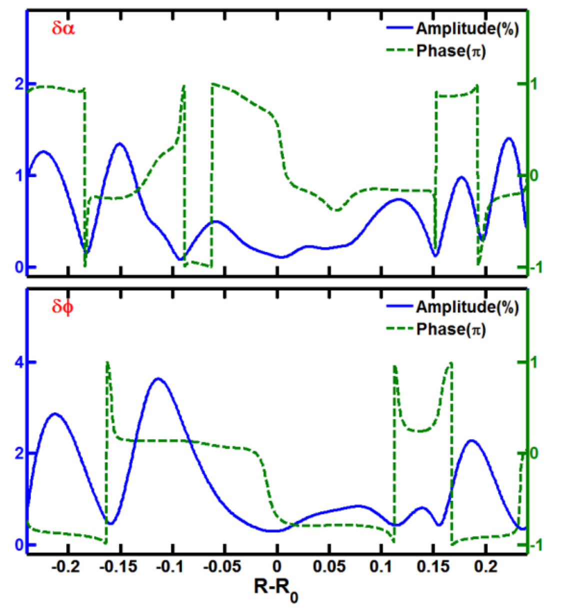

Figure 2 Amplitude (solid) and phase (dashed) of δα and δφ

Using these simulated structures and diagnostic synthesizer, simulated δα and δφ are obtained and their amplitude and phase are shown in figure 3. In the first place, a large difference between simulation and experiment results is: the simulation result is symmetric at HFS and LFS, while experiment result is obviously asymmetric, both the amplitude and the phase. The apparent asymmetry suggests the island structure at HFS and LFS is largely different. Because the simulation is based on cylindrical geometry, the asymmetry of experiment results is probably due to toroidal effect. On the other hand, except the asymmetry, it is found that the simulation results show high similarity to the experimental results. They have the same number of phase reversal points for δα and δφ, furthermore the phase of each region is also the same. The similarity indicates the real island structure is similar to the simulation.

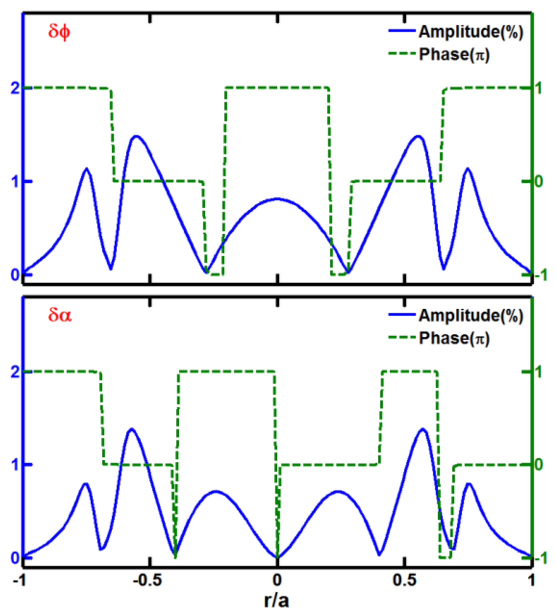

Figure 3 Synthesized δα and δφ using simulated profiles

4. Preliminary inversion result

To resolve the local perturbation from the line-integrated experimental data, the asymmetry of LFS and HFS must be taken into account. Figure 4 gives the asymmetric inversion result of electron density perturbation for the case shown in figure 1. Equilibrium flux geometry including Shafranov shift is used. Density perturbation on each flux surface is considered as sinusoidal form consistent to the mode number and rotation speed, while poloidal-dependent amplitude is used to characterize the asymmetry. According to the inversion, the density perturbation at HFS is larger than that at LFS by a factor ~2. Further work is underway to improve the model and resolve the local electric current density perturbation.

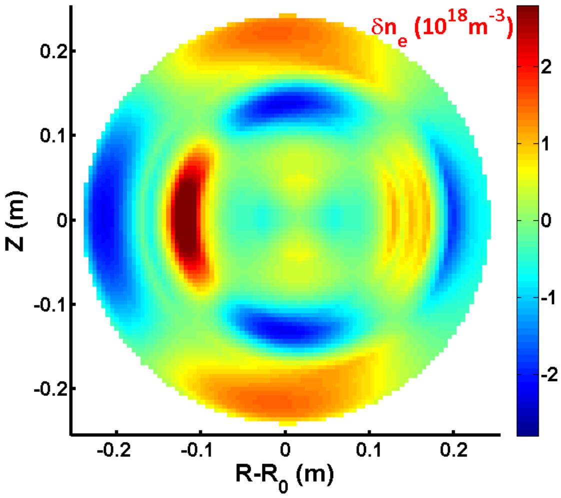

Figure 4 Asymmetric inversion result of electron density perturbation for m=2/n=1 tearing mode

The authors appreciate Prof. K. Gentle, Dr. D. Brower, Dr. W. X. Ding and Dr. L. Lin for their help and discussion. This work is supported by the ITER Project Funds of People's Republic of China: Contract No. 2011GB109001 and 2014GB118001.

References

[1] G. Zhuang et al., Nucl. Fusion 53, 104014 (2013)
[2] J. Chen et al., Rev. Sci. Instrum. 83, 10E306 (2012)
[3] Q. Yu et al., Nucl. Fusion 49, 062001 (2009)
[4] Q. Hu et al., Nucl. Fusion 54, 064013 (2014)