First results of J-TEXT high resolution polarimeter-interferometer

G. Zhuang1,2, J. Chen1,2, Z. J. Wang1,2, L. Gao1,2, Q. Li1,2,W. Chen1,2

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

[2]*College of Electrical and Electronic Engineering, Huazhong University of Science and Technology, Wuhan Hubei, 430074, China*

1. Introduction

The radial profiles of plasma current density and pressure in a tokamak are considered as the underlying dominant driven sources responsible for most of magnetohydrodynamics (MHD) instabilities. By careful tailoring those profiles, the inherent MHD stability limits can be extended for some advanced operation scenarios. Indeed, precise measurements of the current density profiles are definitely needed for the understanding and possibly controlling of the MHD behaviours. Due to the inaccessibility of high temperature plasma interior, current density profile measurements are only available either by a far-infrared (FIR) laser polarimetry based on the Faraday effect or by a diagnostic of motional stark effect.

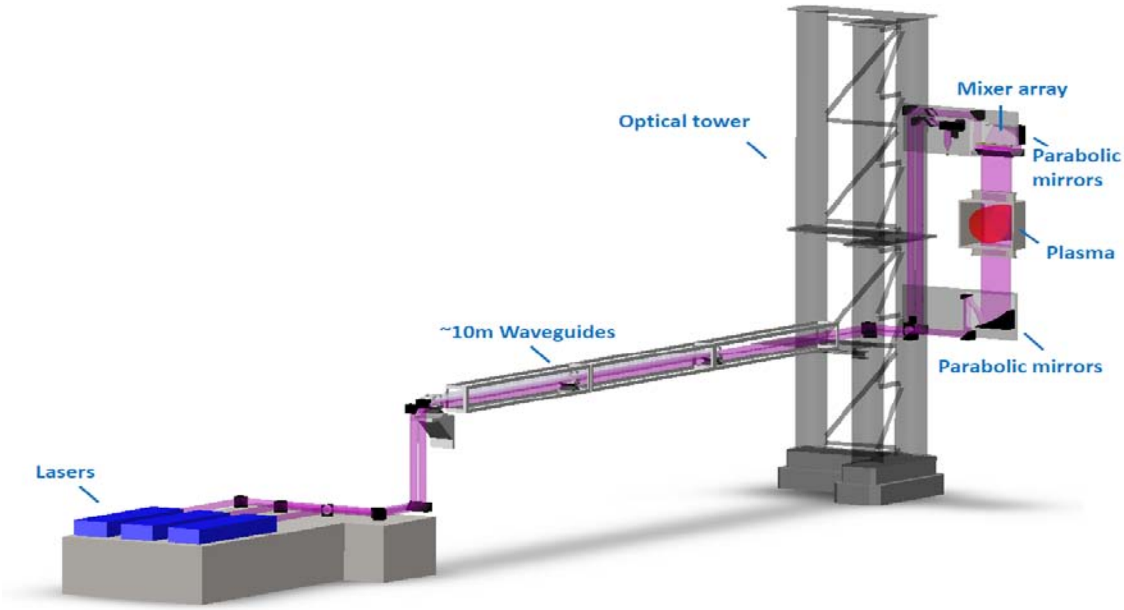

Fig. 1 3D structure of the J-TEXT three-wave polarimeter-interferometer

The FIR laser polarimetry based on three-wave technique, proposed by Dodel and Kunz [1], uses two collinear counter-rotating circularly-polarized beams for extraction of the Faraday rotation angle, while introduces the third beam for simultaneously interferometric measurement of plasma density. The technique accomplishes the measurements by phase comparing between the three electromagnetic waves, aiming to achieve higher resolutions in both phase and time. Recently, a three-wave polarimeter-interferometer was implemented in J-TEXT tokamak [2] and preliminary results were obtained in 2011 Fall campaign [3, 4]. The radial profiles of the equilibrium line-integrated plasma density and Faraday rotation angle, which can deduce the current density, are routinely obtained. Benefiting from the high resolutions possessed by this system, localized perturbations on the Faraday rotation angle (current density) and electron density are obviously observed.

2. Descriptions of the J-TEXT three-wave polarimeter-interferometer

The J-TEXT polarimeter-interferometer equips three FIR lasers operated at 432.5μm, each pumped by one 50W CO_2 laser individually. The total output power of the three FIR cavities is >100 mW, large enough to promise a high S/N measurement. The two probe beams from the FIR lasers aiming to measure the Faraday rotation angle are combined in the laser room, and then transmitted through ~10 m waveguide tube to target the J-TEXT diagnostics port together with the local-oscillator (LO) beam, as illustrated in figure 1. An optical tower isolated from the J-TEXT tokamak is used to position and mount the relevant optics components and detectors. By a set of parabolic mirrors, the combined probe beam is expanded into a ~45cm wide slab beam, which can cover ~80% of the plasma cross-section. The slab probe beam propagates through the plasma, then mixes with similarly expanded LO beam and focuses into the detectors (mixer array). It is worth mentioning here that polarization and collinearity are necessary to calibrate carefully for promising a precise measurement [4].

During the system commissioning phase, only three mixers with the impact parameters as 15 cm, -2 cm, and -9 cm (sign '+' denotes the radius on the low field side) are installed. The detectors will be upgraded to 30 mixers which can provide 1.5cm spatial resolution in 2013. The intermediate frequencies (IFs) among the lasers are chosen as 1 MHz, 1.5 MHz and 2.5 MHz, correspondingly, the temporal resolution is about 1 μs. Phase resolutions are ~0.05^o achieved for the Faraday rotation angle and ~0.4^o for the line-integrated electron density fringe-phase, corresponding to 4.3×10^{-4} T × 10^{19} m^{-2} and 5×10^{15} m^{-2}, respectively. The typical experimental measurements are presented in figure 2, where the traces of (a) the Faraday rotation angles and (b) line-integrated plasma densities at three different radii are given.

3. Observations of the MHD activities

Profiting from the merits of high resolutions, perturbations on plasma density and current density profiles essentially relevant for the MHD activities can be detected by the J-TEXT polarimeter-interferometer. The experimental observations, catalogued as sawteeth, classical tearing modes and their mode-locking, are presented below.

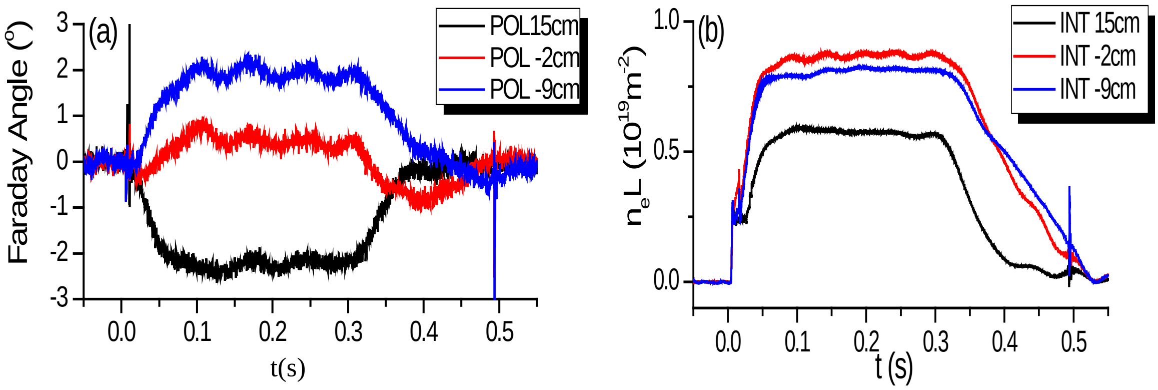

Fig. 2 Typical measured traces done by the J-TEXT three-wave polarimeter-interferometer: (a) polarimetry and (b) interferometry.

3.1. Sawteeth

As indicated in figure 3, both signals from interferometry and polarimetry modulated by the intrinsic sawteeth are acquired and verified by those appeared on the soft X-ray emission signal. In the figure, traces from three viewing chords of line-integrated plasma density fringe-phase, one polarimetric chord (of the Faraday rotation angle), and one reference chord of the soft X-ray emission, record the time evolution of sawteeth activities during the current ramp-up phase. The sawtooth cycles on all the traces have the synchronous triggering, and the period of one sawtooth cycle is about 2 ms. The measured sawtooth amplitudes on the density traces are ~10^o, about 1% of the equilibrium values. Meanwhile, the measured sawtooth amplitudes on the polarimetric trace are ~0.1^o, near ~4% of the equilibrium value. The measured results confirm that perturbations on both current density and plasma density profiles due to the sawtooth oscillations are clearly visible, further analysis to sort out which profile acts as the dominant role on sawtooth behaviors needs to be done.

3.2. Tearing mode and its mode-locking

Another remarkable phenomenon, involving the mode oscillations and their mode-locking and disruption events, is demonstrated in figure 4. In the figure, traces from three viewing chords of line-integrated plasma density fringe-phase, and one reference Mirnov coil signal, character the time evolution of the MHD activities. The SVD analysis on Mirnov coils' signals concludes that such oscillations are m/n=2/1 classical tearing modes. Perturbations on the interferometry data due to the tearing mode can be easily distinguished, and also matches the reference Mirnov signal. Different chords of interferometry would provide a different phase, which is accounted for the magnetic island structure and its rotation speed. In most cases, the oscillated amplitudes on the interferometry data are about 10^o, near 1% of the equilibrium value. Nevertheless, when the tearing mode starts to be locking, the oscillated amplitudes tend to reach much higher values. As an example shown in Fig. 4, when Mirnov signal shows the 2/1 tearing mode growing gradually and the mode frequency slowing down, the oscillated amplitudes on the interferometry data increase from ~10^o to ~70^o, nearly 10% of the equilibrium value. At t=1.903s, the 2/1 tearing mode is locked (the mode frequency drops to zero), the oscillations on the interferometry data disappear and the equilibrium density starts to decrease. About 6 ms later the plasma is ended with a disruption. Unfortunately, there is no obvious perturbation due to the tearing modes grasped by the polarimetry, further noise reduction of the system is absolutely needed for such delicate measurements.

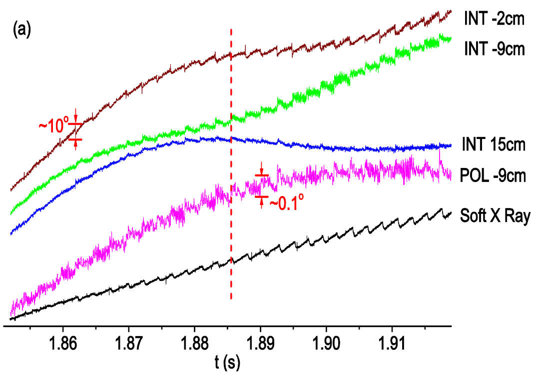

Fig. 3 Sawteeth on the traces from interferomtry and polarimetry, where a reference soft X-ray emission signal is given for verification.

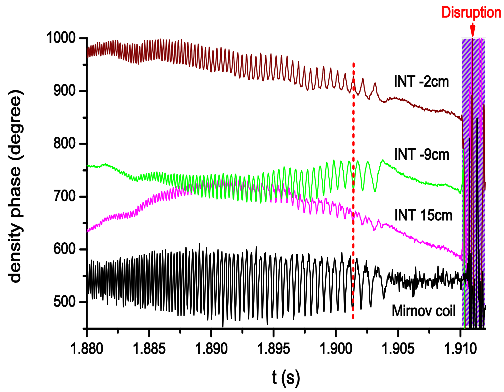

Fig. 4 Typical MHD activities on the traces from interferometry, where a reference Mirnov coil signal is given for comparison.

Acknowledgement

This work is partly supported by the ITER Project Funds of People Republic of China: No. 2009GB107003.

References

[1] G. Dodel and W. Kunz, Infrared Phys. 18, 773(1978)
[2] G. Zhuang, et al., Nucl. Fusion 51, 094020 (2011)
[3] J. Chen, L. Gao, et al., Rev. Sci. Instrum. 81, 10D502(2010)
[4] J. Chen, G. Zhuang, et al., Rev. Sci. Instrum. 83, 10E306 (2012)