Investigation of the high density discharges on the J-TEXT Tokamak

G. Zhuang[1], P. Shi[1], J. Chen[1], L. Gao[1], Y. Liu[1]

[1]Huazhong University of Science and Technology, Wuhan, China

Abstract

To satisfy increasing demands on high-quality measurement of interior magnetic field in tokamak plasma, a far-infrared laser-based polarimeter-interferometer system has been developed on J-TEXT. With this system, high density disruption experiments have been performed on the J-TEXT tokamak to investigate the mechanism behind the density limit. Some interesting features of disruptions in high-density discharges are identified by carefully interpreting the measured polarimeter-interferometer data. During the density ramp-up phase of a high density discharge, asymmetry would occur on both electron density and at the High-Field-Side (HFS) edge ($r < -0.8a$) and extend gradually toward the center. Besides, a low-frequency (< 1kHz) density perturbation suddenly occurs at the HFS edge and also gradually propagates towards the core region. The disruption takes place when the asymmetry on electron density reaches the $q = 2/1$ resonant surface. Asymmetrical behaviors presented on reconstructed electron density and current density profiles provide a possible explanation for the high density disruption.

1. Introduction

Tokamak is regarded as one of the most promising candidates for future magnetic confined fusion reactor. A tokamak plasma is confined by magnetic field supplied by external magnetic coils and its self-inducing plasma current. The topology of magnetic field is closely related to the equilibrium and stability of the plasma, which means that the measurement of internal magnetic structure of plasma is of importance to conduct the tokamak physics research [1].

The laser-based Faraday-effect polarimetry, originally proposed in 1972 [2], is now becoming one of the most promising diagnostics for equilibrium magnetic field structure and its perturbation measurements. Recently, a high resolution polarimeter-interferometer system (POLARIS) based on three-wave technique has been built on J-TEXT tokamak [3-5] to study time evolution of electron density and magnetic perturbations, with high phase resolution (<0.1° for Faraday angle and <1° for line-integrated density at 50 kHz bandwidth), high temporal resolution (<1 μs), and high spatial resolution (15 mm minimum).

Based on the J-TEXT POLARIS, high density disruption experiments have been performed on J-TEXT tokamak and some interesting features of disruptions in high-density discharges are identified. The details will be presented n in Sec. 3.

2. The J-TEXT POLARIS

J-TEXT POLARIS based on three-wave technique uses three laser beams for simultaneous polarimetric and interferometric measurement. Two laser beams, namely L-beam and R-beam with counter-rotating circular-polarization, are collinearly aligned and propagated through plasma, while the third laser beam with linear polarization serves as Local-oscillation (LO). Because of heterodyne measurement, frequencies of the three beams are slightly offset with no overlap among these three produced intermediate frequencies (IFs) (such as 1, 1.5, and 2.5 MHz). Each IF carries different plasma information, which can be isolated by band-pass filtering. Then the phase difference at each IF can be acquired by phase comparison with the signal provided by a reference mixer [6]. The laser frequency (694 GHz) is much larger than plasma frequency (~90 GHz) and electron cyclotron frequency (~56 GHz). Phase difference between L beam (or R beam) and LO beam is ϕ_L (or ϕ_R), while the Faraday effect depends on the phase difference between the L beam and R beam. Thus the Faraday angle α and line-integrated density ϕ can be described as $\alpha=(\phi_R-\phi_L)/2$ and $\phi=(\phi_R+\phi_L)/2$, respectively. At present, the J-TEXT POLARIS has a phase resolution less than 0.1° and temporal resolution less than 10 μs [7], so it is capable of both polarimetric and interferometric measurements with high spatial and temporal resolutions.

The optical layout of the J-TEXT POLARIS is shown in Fig. 1. To cover the whole plasma cross-section (a = 0.25-0.29 m), the probe beams and LO beam (both 60 mm in diameter) are expanded by 10 times along the major radius direction using two pairs of parabolic mirrors, so the final size of both beams is 600 mm × 60 mm. The expanded probe beams propagate through the plasma, and is focused onto the linear detector array, while the LO beam is also sent to the array without passing through the plasma. Part of the probe beam without passing through plasma, shown in Fig. 1, is used as a reference aiming to eliminate the mechanical vibration.

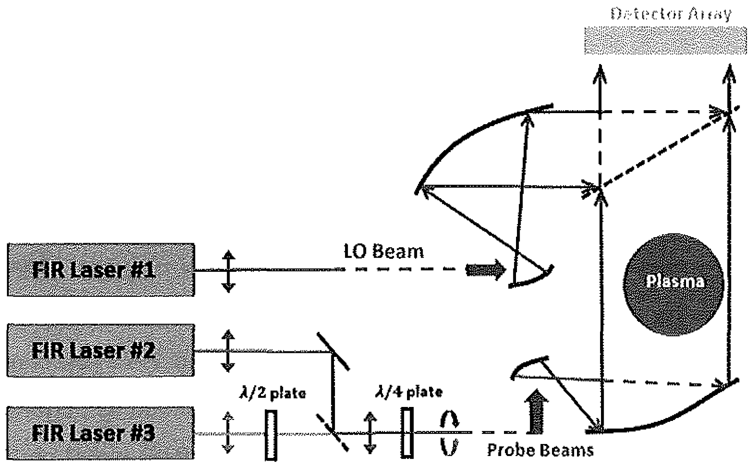

Fig. 1. Layout of J-TEXT POLARIS diagnostic.

3. High density experimental results

Recently, mechanisms of high-density disruption is under research on the J-TEXT. Up till now, some interesting features of high-density plasma disruptions are identified by the measured data supplied by POLARIS. In the density ramp-up phase, asymmetry phenomenon of electron density profiles would appear firstly at the outermost region x = -24 cm, be enhanced gradually and then spreads inward, as shown in Fig. 2(a). Asymmetry starts at the time when the ratio of line-averaged densities at -24 cm and 24 cm exceeds 1. Later on, it reaches x = -21 cm, as shown in Figs. 2(b) and 2(c). The maximum density at x = -24 cm can exceed twice of that at x = 24cm. Accompanying with the density asymmetry behavior, a low-frequency (<1 kHz) perturbation appears on electron density at the HFS edge and gradually propagates towards the core region, as presented in Fig. 3. The discharge ends with a disruption when the density perturbations reach $x = -18$ cm (where $q = 2$ rational surface locates at $x \sim -19$cm confirmed by ERP calculation). The estimated electron density and current density profiles calculated with slice-and-stack method before the disruption are shown in Fig. 4, and the asymmetry behavior is clearly seen which is excited at 0.28s and $x = -24$ cm. The current density bump at the HFS edge begins to move inward at 0.32s. Synchronously the electron density bump and low frequency density perturbation also move inward, without evident changes on the LFS edge density. The observations suggest that the density ramp-up would lead to the edge plasma cooling and the edge pressure gradient steeping. Consequently asymmetry happening on electron density and current density profiles, and the low frequency density perturbations as well, would spread inward. Once it reaches the q=2 rational surface, the 2/1 mode is triggered and then the discharge is terminated by a disruption.

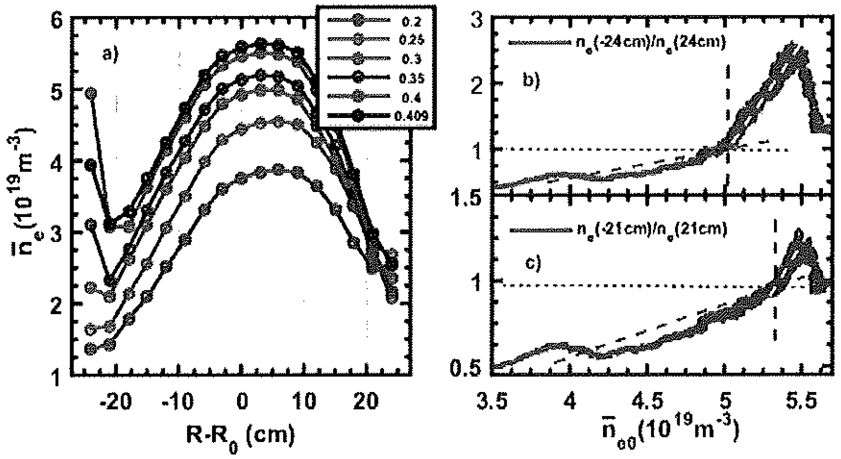

Fig. 2. (a) Profiles for line-averaged density measured by POLARIS; (b) and (c) the evolution of asymmetry at $x = \pm 24$cm and ± 21cm with the central line-averaged density, respectively.

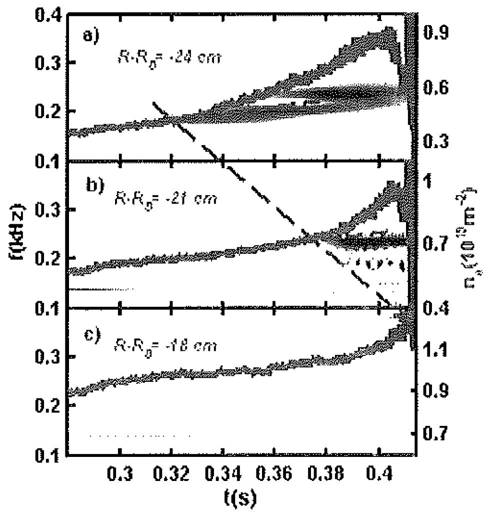

Fig. 3. (a),(b) and (c) Line-integral density and their spectra at -24cm, -21cm and -18 cm, respectively.

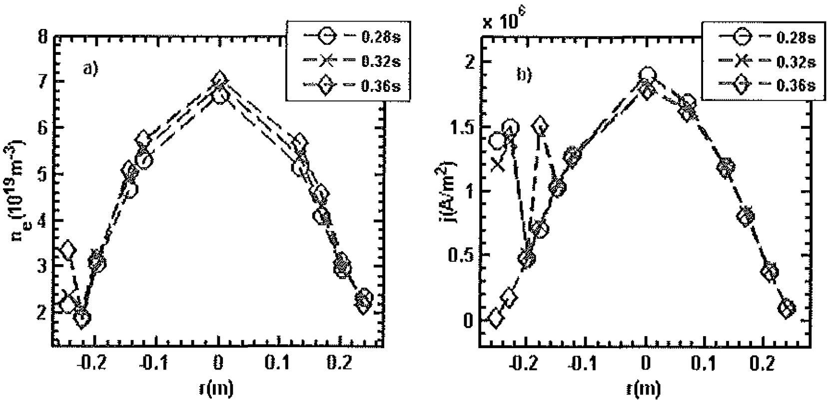

Fig. 4. (a) Estimated electron density profiles and (b) estimated electron current density profiles.

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