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Two-Dimensional Measurements of Edge Density Fluctuations in LHD Heliotron and CPD Spherical Tokamak

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1. Introduction

It is widely believed that the stability of the edge plasma and transport properties there affect the core plasma confinement in toroidal systems, e.g. tokamaks and stellarators. The fluctuations observed in the edge region are usually “turbulent” and the transport characteristic is “anomalous”. In addition to this classical picture for the edge plasma properties, recently, there has been a growing consensus that the intermittent bursts which exhaust particles as “blobs” account for the considerable amount of overall particle flux to the plasma facing components including the vacuum vessel wall [1,2]. Experimental observations of blobs have been reported in various devices, i.e. tokamaks, helical devices and linear machines, although the magnetic configurations and the plasma parameters are different from each other. This means, in other words, the blobs are the universal phenomena for the confined plasma.

In this paper the fluctuation measurements in the Large Helical Device (LHD) and the Compact PWI Experimental Device (CPD), by using a newly developed two-dimensional lithium beam probe (2D-LiBP) [3-5], are described. Since the edge magnetic field structures in two devices are quite different, the comparison of the experimental results between them is worthwhile to understand the underlying physics of the blob phenomena.

2. Experimental apparatus and conditions

The LHD is the super conducting heliotron device with major and minor plasma radius of 3.9 m and 0.6 m, respectively. Experiments were carried out with electron cyclotron resonance heated (ECH, 77 GHz, P_{rf} ~ 500 kW) plasma in relatively low averaged density range below 0.3×10^{19} m^{-3}. The toroidal magnetic field B_t was 2.7 T. On the other hand, the CPD is a small spherical tokamak with major and minor plasma radius of 0.3 m and 0.2 m, respectively. The plasma was initiated and sustained with ECH (8.2 GHz, P_{rf} ~ 1 kW) in the typical density range of ~ 10^{18} m^{-3} at B_t of 0.3 T. Some magnetic configurations were chosen for the experiments, i.e. simple torus, weak mirror and ST with rf-driven plasma current.

The edge electron density and its fluctuation were two-dimensionally measured with the 2D-LiBP which utilizes the sheet-shaped thermal lithium beam widely spread on the poloidal cross section of the plasma. The Li I emission (2s - 2p, 670.8 nm) from the plasma were detected with a CCD camera for 2D density profiles and photomultiplier tubes (PMTs) coupled with a 50-channel (5 × 10) fiber bundle for fluctuation measurements. Signals from PMTs were digitized at 1 MHz for LHD and 300 kHz for CPD. Schematics of the diagnostics for each device are depicted in Fig. 1 (a) and (b). Spatial resolutions of the optical system for fluctuation measurement are 50 mm for LHD and 5 mm for CPD.

3. Experimental results

In order to get general information about the fluctuations, the conventional analyses by using the Fast Fourier Transformation (FFT) were performed for time series data from both devices. In LHD, no characteristic coherent mode was seen in the ergodic region outside the

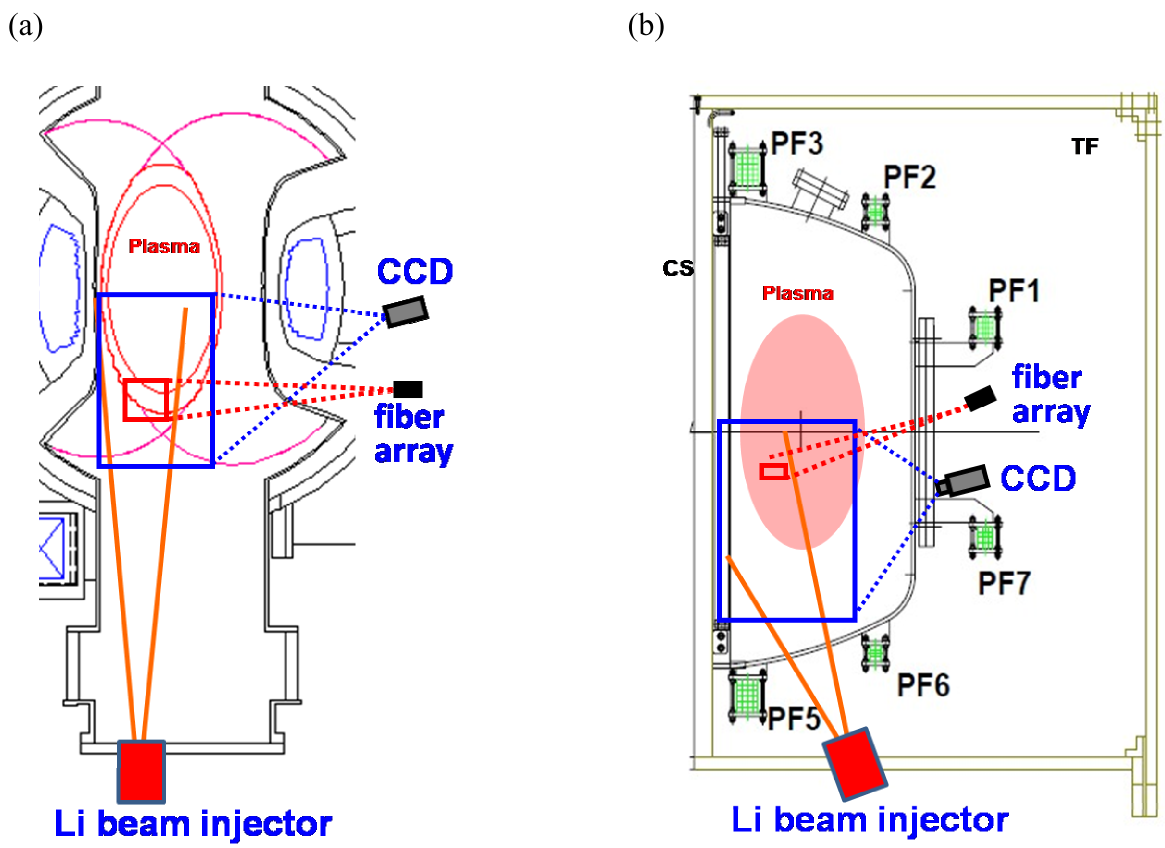

Fig. 1. Schematics of 2D-LiBP for (a) LHD and (b) CPD.

last closed flux surface (LCFS). The spectra show the turbulent structure. On the other hand, some coherent peaks associated with drift mode instabilities were sometimes observed in the low frequency region in CPD. Nevertheless, in the high frequency region, spectra are broad and monotonically decrease with increase in frequency.

Although no coherent modes are presented in the spectra, intermittent fluctuations like bursts or "blobs" may exist and be active, which are often hidden in the spectra derived with FFT. In order to see the blob activity, the "skewness" calculated from the probability density function (PDF) were estimated for the time series data. If the skewness is positive, it means that the positive spikes are dominant in the fluctuation. On the contrary, negative skewness means negative spike fluctuations. The zero skewness is realized if the density oscillates both in positive and negative directions isotropically, i.e. the PDF presents almost Gaussian shape. Figure 2 shows the radial profiles of skewness of electron density fluctuations for LHD (a) and CPD (b). Since the skewness is always positive for both devices, it can be said that blob-like oscillation which exhausts particles from the inner region exists outside the LCFS. In LHD, the skewness near the LCFS is small, although it increases with the increase of the radius, as shown in Fig. 2 (a). On the other hand, in CPD, skewness is almost constant in whole region, as seen from Fig. 2 (b). For LHD, it may be interpreted that the blobs are created just outside the LCFS, then transported to the outer region, although the birth region for large tokamaks is thought to be just inside the LCFS. This is not so peculiar speculation, since LHD has the thick ergodic layer outside the LCFS, where the connection length (L_c) of the magnetic field lines is long enough to confine the plasma. In CPD, experimental result suggests that blobs are not so active in this region, because the plasma pressure is very low

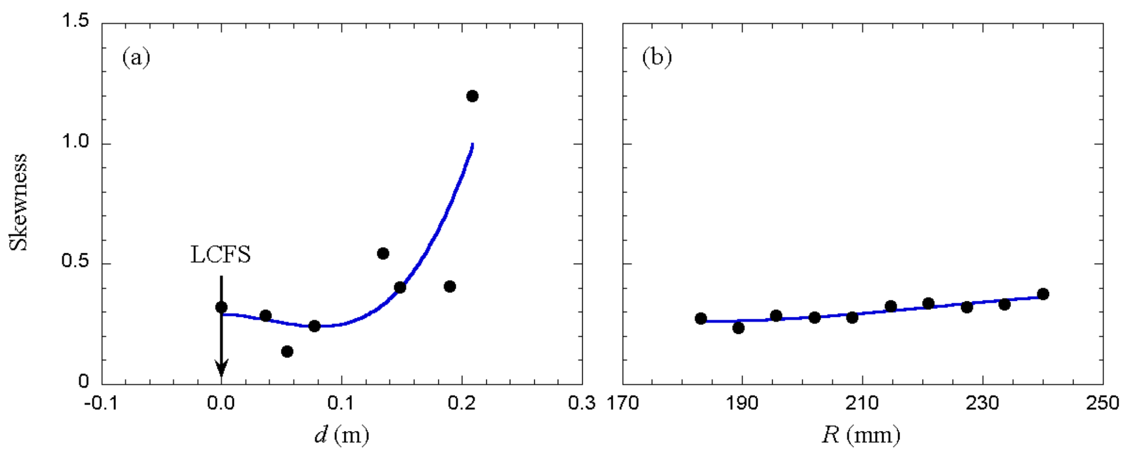

Fig. 2. Radial profiles of skewness for (a) LHD and (b) CPD. In (a), horizontal axis d is the distance from the LCFS.

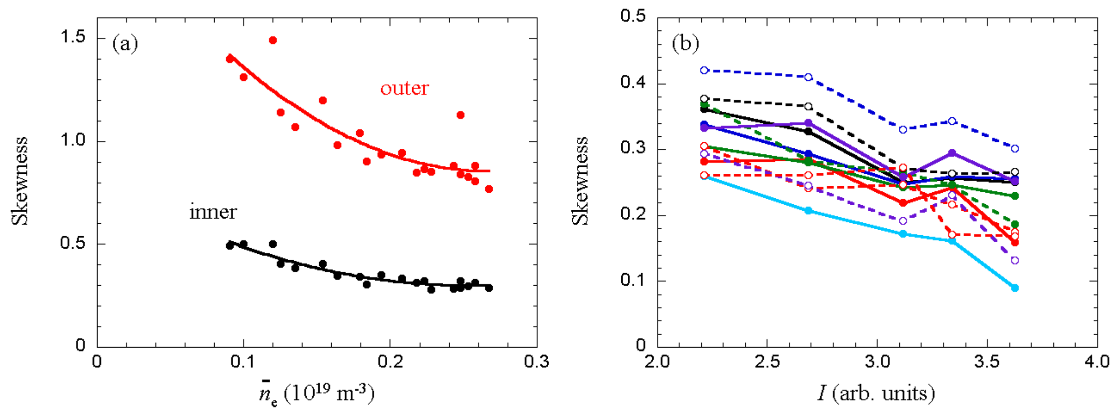

Fig. 3. Dependence of skewness on density in (a) LHD and (b) CPD.

especially in the edge region. If the plasma parameters are increased by the improvement of the confinement performance and/or the increase of the heating power, blobs may become active, as is seen in LHD.

It is though that mechanism of the creation and the transport of the blobs is strongly affected by the plasma parameters. Figure 3 shows the dependence of skewness on density in (a) LHD and (b) CPD. For CPD, it is depicted in the function of Li I emission intensity which has the similar trend to density in this region. It can be seen that the skewness is the decreasing function of density in both devices. This means that the skewness becomes small with the increase of the collisionality, if the temperature is assumed to be constant. There may be an effect for collisions to reduce the life time of the blobs.

Further inter-machine experiments are necessary to clarify the underlying physics for blobs.

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