Investigation of statistical characterization of radial turbulence in the edge of HuanLiuqi-2A plasma with visible spectroscopy diagnostic

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The radial motion and structure of edge turbulence in the HuanLiuqi-2A tokamak [Y. Liu et al., Nucl. Fusion 45, S239 (2005)] was measured with visible spectroscopy diagnostic system; the radial turbulence propagation velocity and correlation length were evaluated by time-delay correlation technique and there were typically $V_{r} = 0.4–1$ km/s and $L_{r} = 2–6$ cm, respectively. The edge intermittent events accompanied with turbulence have been observed in plasma edge and propagated outward radially; especially through the scrape-off layer, the fluctuation signals of $D_{\alpha}$ exhibit strong asymmetric probability distribution functions (PDFs). Their propagation trajectories and radial velocity PDFs were inferred from a special correlation technique and the results indicated the radial velocity of intermittent event depends on its amplitude. Some comparisons with previous measurements and models were also presented. © 2010 American Institute of Physics. [doi:10.1063/1.3512938]

I. INTRODUCTION

Transport processes are believed to be driven by plasma turbulence which behaves the plasma parameters (density, temperature, potential, and magnetic field) with fluctuations and determines or affects the confinement properties of tokamak or other toroidal devices. In order to optimize fusion-energy systems and attain high performance of fusion plasma, it is important to investigate and understand the turbulence dynamics, especially the edge turbulence, since it dominates radial cross-field transport in the scrape-off layer (SOL) and determines the interaction between the plasma and the first-wall and/or divertor structures, and it also probably affects the global plasma confinement.

Edge turbulence whose structure is perpendicular to the magnetic field is in the “drift wave” range of size scales ($\sim 0.1–10$ cm) and dominantly consists of broadband plasma density fluctuations with typical fluctuation amplitude $\delta n/n \sim 5\%–100\%$ at the outward midplane and observed frequency range $f \sim 10$ kHz–1 MHz. The spatial structure of edge turbulence is generally described by the spectrum-averaged poloidal and radial correlation length ($L_{p}$ and $L_{r}$). There is a relationship $L_{r} \sim (0.5–1)L_{p}$ and $L_{p} \sim 0.5–5$ cm in most tokamaks and stellarators, but along the magnetic field direction, the turbulence has a large scale parallel structure ($L_{\parallel} \sim 10$ m). Radial propagation velocity of edge turbulence relates to the cross-field transport in the SOL, typically $\sim 1$ km/s (or $\sim$ a few percent of the local sound speed). Convective transport was experimentally observed and proved to universally exist in magnetically confined plasmas; the edge particle transport is mainly caused by burst events, and statistic analyses indicate the fluctuations exhibit deviating Gaussian distributions from the plasma edge to the SOL. The radial $E \times B$ drift of edge turbulence was also simulated by the “blob model.” Some results reveal the blobs have a dipole structure perpendicular to the magnetic field and large radial drift velocities ($\sim 1$ km/s). In this paper, we attempt to characterize turbulence by the visible spectroscopy measurements and emphasize on its statistical characterizations in the HuanLiuqi-2A (HL-2A) edge plasma. In the first part, the wave-number spectrum is used to characterize the statistical properties of the radial turbulence. Then, the scales of radial turbulent motion and structure are estimated by time-delay correlation analysis both in the L-mode and H-mode. In the next part, the probability distribution functions (PDFs) calculations indicate that large amplitude events dominate the plasma edge especially the SOL region. The propagation trajectories of the intermittent events are then derived by a specific correlation technique and the PDFs of its radial velocities are also obtained under the different thresholds of the correlation function.

II. EXPERIMENTAL SETUP

The HL-2A device is a medium-size tokamak with a double null closed divertor configuration. Its major and minor radius are $R = 1.65$ m and $a = 0.4$ m, respectively, toroidal magnetic field $B_{t} = 2.8$ T, plasma current $I_{p} = 480$ kA, line averaged electron density $(1–8) \times 10^{19}$ m$^{-3}$, edge safety factor $q_{a} = 3–5$, and a discharge duration of $\sim 30$ s. The visible optical diagnostic system for edge turbulence measurement mainly consists of three lenses which are designed to reduce spherical aberration and coma, an interference filter for $D_{\alpha}$ line emission, and a photodiodes detector array which has 46 available channels. The distance between the detectors and the object plane is 110 cm. The $D_{\alpha}$ line emission is located in the region where the neutral deuterium particles are significantly excited but not yet ionized, which corresponds roughly to the electron temperature range $T_{e} = 5–100$ eV; this region is about $\pm 4$ cm around the HL-2A separatrix, this line emission intensity is a nonlinear function of the local plasma electron density $n_{e}$ and electron temperature $T_{e}$ at a given neutral density, but it has a monotonically...