Fluctuation suppression induced by gas puffing in HL-2A Tokamak


1Southwestern Institute of Physics, Chengdu, China
2Institute for Fusion Theory and Simulation, Zhejiang University, Hangzhou, China
3Department of Modern Physics, University of Science and Technology of China, Hefei

1. Introduction

Understanding the feature of electrostatic fluctuations is critical for suppressing the anomalous transport and obtaining high performance confinement in tokamak plasmas [1]. Recently, fluctuation suppression had been observed in scrape-off layer with gas puffing in ADITYA tokamak [2]. But, there is not report about turbulence spectra, nonlinear coupling and blob propagation characteristics in edge plasma with gas puffing, and it is not clear for the cause of fluctuation suppression induced by gas puffing. Thus, this experiment in HL-2A is extended for this goal and the measured position is inside the last closed flux surface (LCFS). During gas puffing, the flat radial profile of radial electric field, symmetric joint spectrum of poloidal-radial wave number, the disappearance of the geodesic acoustic mode (GAM) and the enhanced nonlinear coupling (NL) were simultaneously observed. Meanwhile, blob radial velocity has an apparent drop by 58 % from 1.2 km/s to 0.5 km/s. The increased NL and reduced electron temperature gradient are probably candidates for edge fluctuation suppression.

2. Experimental setup

Gas puffing experiments were performed in ohmically heated deuterium discharges on the HL-2A tokamak (major radius $R = 1.65$ m and minor radius $a = 0.4$ m), using the limiter configuration. Discharge parameters: $I_p \sim 180$ kA, line-averaged density $n_{el} \sim 1.8 \times 10^{19}$ m$^{-3}$, $B_t \sim 1.6$ T. Figure 1 elucidates the arrangement of a radial 12-tip array and a 4-tip array with tips 3 mm in length and 1.5 mm in diameter. There are adjacent separation of 4 mm for 12-tip array.
and the poloidal separation of 8 mm for the 4-tip array. The 1\textsuperscript{th} tip and the 15\textsuperscript{th} tip are poloidally separated $\sim 15^\circ$. The local electron temperature, electron density and particle flux can be simultaneously measured with negative biased voltage of $V_b \sim 160$ V between the tip 13 and the tip 14. Other tips are applied to measure floating potentials. The radial and poloidal electric fields can be inferred from $E_r = \Delta V_1/d_r$ and $E_\theta = \Delta V_2/d_\theta$, where $\Delta V_1$, $\Delta V_2$ denote the potential differences with radial separation $d_r$ and poloidal separation $d_\theta$, respectively. This kind of probe arrangement provides enough flexibility to study potential radial profile, fluctuation spectral characteristics, blob propagation velocity and particle flux during gas puffing. Data are acquired with frequency $f_s = 1$ MHz and the accuracy of 12 bits.

3 Experimental results

The potential radial profiles between without GP pulse and with GP pulse are contrasted in figure 2, which are denoted by circle and square markers, respectively. The $\Delta r = 0$ means the LCFS with error about 5 mm, the positive and negative values denote the outside and inside the LCFS, respectively. The sheared rate is estimated with $\tau_{sh} = \partial V_\theta/\partial r \sim E_r'/B_t$. Usually, the radial profile of potentials has a slope from $\Delta r = -16$ mm to $\Delta r = 0$ mm, see in figure 2(a). The different slope is indicated by $E_r$. In figure 2(b), $E_r$ has a potential well around $\Delta r = -10$ mm, suggesting the $E_r'$ close to zero. The most steep radial position of $E_r$ is at $\Delta r = -6$ mm, where the sheared rate has a peak. This observation is consistent with the characteristics of velocity shear stabilization mechanism. However, the dramatic difference is that the radial profile becomes flat when gas puffing switched, indicated by square markers. The positive potentials in edge region are probably caused by incomplete short-circuit of vertical charging by the Pfirsch-Schlüter current. At the $\Delta r = -10$ mm, the mean radial electric field reduce by $\sim 48\%$ and its gradient almost fully collapse, as shown in figure 2(b). This result highlights a collapse of $E \times B$ sheared flow layer, routinely used to interpret the fluctuation suppression, is not suitable to explain the present
fluctuation suppression.

The GAM is a dominant coherence mode in the edge plasma of HL-2A tokamak. Figure 3 shows the summed bicoherence at four different radial positions. Without GP, inside the LCFS (Δr = -8, -4 mm), there is a prominent peak with 9.8 kHz, see in figure 3(a) and figure 3(b), suggesting that the nonlinear coupling between the small-scale turbulence eddies is a plausible mechanism for the GAM generation. Outside the LCFS, the nonlinear coupling becomes very weak, indicated by dotted line in figure 3(c) and 3(d). However, gas puffing added, there is a great change. Firstly, the NL obviously increases from edge to SOL region. Secondly, the NL below 200 kHz has obviously increases, expected for the GAM frequency reducing. This observation indicates that the gas puffing can significantly enhance NL, especially inside the LCFS.

Blob radial velocity is critical to determine convective transport in SOL plasma, which is estimated with cross-conditional average [3]. The peak of cross conditional average at around Δτ = 0 is an indication of blob radial velocity. In figure 4, the curves from top to bottom show the time evolutions of four gas puffing pulses, edge electron temperature, neutral particle pressure measured by fast neutral pressure gauge installed in the main chamber and the contour plot of blob radial velocity measured at Δr = -5 mm. Without gas puffing, blob radial velocity is about 1.1-1.2 km/s, which is consistent with measurement at this position by reciprocating Langmuir 5-tip array in HL-2A [3]. However, when the gas puffing is added, edge electron
temperature obviously reduces by 55-78%. Meanwhile, the neural particle pressure increases by 40-50%. There is an important observation that the blob radial velocity distinctly decreases by 58% from 1.2 km/s to 0.5 km/s. As the theoretical prediction [4], plasma blobs are mainly driven by magnetic field curvature and damped by a variety of forces. The former is proportional to electron temperature and the latter is determined by electron-electron collision, neutral particle wind, et al. Thus, the electron temperature reduction and neutral particle rise may be responsible for blob deceleration.

4. Conclusion and discussion

The edge electrostatic fluctuation suppression has been observed using the probe combination of a radial 12-tip array and a 4-tip array during gas puffing, the corresponding suppression of potentials fluctuation clearly exists from plasma edge to SOL. The potential gradient collapses and the joint spectrum of radial and poloidal wave-number become symmetric. The GAM on potential fluctuation completely vanishes, but nonlinear coupling in the frequency range of 10-200 kHz increases. Meanwhile, blob radial velocity drops by 58% and such directly leads to radial particle flux reduction. The collapse of potential gradient points out that the E×B sheared flow is not suitable to interpreting the present experimental observation. The fluctuation suppression is not in a narrow gradient region but cross the LCFS from edge to SOL. Thus, other possible mechanism is needed for explaining present observation. At present, the nonlinear coupling rise and edge electron temperature drop induced by gas puffing are probably responsible for the fluctuation suppression. In future, we will focus on the causal link between particle flux reduction and nonlinear coupling or edge electron temperature gradient though the latter had been observed to significantly drop with pellet injection in DIII-D [5]. Therefore, a direct measurement of temperature gradient is urgent in the HL-2A experiment.

References