Spatial and spectral characteristics of large scale coherent structures in edge turbulent plasmas of HL-2A tokamak

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1. Introduction

- Formation of large scale coherent structures (LSCS) such as zonal flows (ZFs, including LFZF and GAM) and blobs/filaments is universal in turbulent plasmas.
- ZFs are defined as azimuthally symmetric radial electric field fluctuations with radial meso-scale.
- Blobs (filaments) are identified as asymmetric LSCS stretching along magnetic field lines
- Experimental identification of the LSCS is important to understand transport and confinement in fusion plasmas.
- Formation mechanism of the LSCS is of fundamental scientific interest and under intensive investigation.
- Spatial and spectral characteristics and generation mechanism of the LSCS are studied in the edge of HL-2A tokamak plasmas.
2. Discharge parameters and probe setup

HL-2A

• \( R: \) 1.65 m
• \( a: \) 0.40 m
• \( B_t: \) 1.9/2.7T
• Configuration:
  - Limiter, LSN divertor
• \( I_p: \) 168/450 kA
• \( n_e: \) 1.9/8 \times 10^{19} m^{-3}
• Edge safety factor \( q_{95}=4.7 \)

**Auxiliary heating:**

- ECRH/ECCD: 3 MW
  - (4/68 GHz/500 kW/1 s)
  - modulation: 10~30 Hz; 10~100 %
- NBI (tangential): 1.0 MW
- LHCD: 1 MW
  - (2/2.45 GHz/500 kW/1 s)

**Fueling system \((H_2/D_2)\):**

- Gas puffing (LFS, HFS, divertor)
- Pellet injection (LFS, HFS)
- SMBI (LFS, HFS)
  - LFS: \( f = 1\sim60 \) Hz, pulse duration > 0.5 ms, gas pressure < 3 MPa
3D Langmuir probe arrays

- Sampling rate = 1 MHz
- Spatial resolution = 4 mm
- Diameter of tips is 1.5 mm.
- Height of tips is 3 mm.
3. Experimental results for zonal flows

Coexistence of intensive LFZFs and GAMs

The poloidal and toroidal symmetries, i.e, $m=0, n=0$ were measured, simultaneously, for LFZF and GAM.
(a) Radial wave vector-frequency spectrum of potential fluctuations,

(b) radial wave vector spectra for the LFZF and GAM,

c) Radial coherency spectrum.

- $K_r = 0.6 \text{cm}^{-1}$, $\Delta k_r = 3.7 \text{cm}^{-1}$ for the LFZF
- $K_r = 3.8 \text{cm}^{-1}$, $\Delta k_r = 3.8 \text{cm}^{-1}$ for the GAM
Radial variation of ZF power spectra

- Moving from the last close flux surface inwards, the intensity of GAM first goes up, then decreases.
- The intensity of LFZF increases inwards
- The intensities of LFZF and GAM both increase with ECRH power
The LFZF (a), and GAM (b) power partition as a function of radial position in OH, ECRH discharges.

- LFZF+GAM (c), AT (d) power partition as a function of radial position in OH and ECRH plasmas.
- GAM dominating near LCFS, but LFZF & GAM are nearly equal in the inner region.
- LFZF+GAM power partition has a maximum at r~1.2 cm and is lower in ECRH plasmas.
Radial profiles of edge plasma shear flows, Reynolds stress shearing rate and fluctuations

- $R_{est} = \langle V_r V_\theta \rangle$
- $R_s' = (V_r V_\theta)'$

- Multiple shear flows are driven by nonlinear coupling of turbulence via Reynolds stresses.
Turbulence modulation by shear flows

(a) The shearing rate of LFZF and
\[ |\phi|^2 - \langle\phi\rangle^2 \] in LFZF frequency band,

(b) the shearing rate of GAM and
\[ |\phi|^2 - \langle\phi\rangle^2 \] in GAM frequency band.

The waveforms of the radial electric field fluctuation of GAM, Reynolds stress and its gradient in GAM frequency band.
The contour of maximum coherence, the maximum coherence and average wave vector measured in SOL (a)-(c) and edge plasmas (d)-(f).

\[ \gamma_{xy}(\tau) = \frac{E\{[x(t + \tau) - \bar{x}][y(t) - \bar{y}]\}}{\sqrt{E\{[x(t) - \bar{x}]^2\}E\{[y(t) - \bar{y}]^2\}}} \]
Two-dimensional images of conditional average of the floating potentials across the LCFS at six times of 2 µs interval.

\[ \tau_{sh} = \left( \frac{k_\theta L_r \partial V_\theta}{2\pi \partial r} \right)^{-1} \]

In the shearing region, \( L_r \sim 1.5 \text{ cm}, \)
\( k_\theta \sim 2.0 \text{ cm}^{-1}, \)
\( \partial V_\theta / \partial r = \gamma_E = 2.8 \times 10^5 \text{s}^{-1}, \)
\( \tau_{sh} \sim 5 \mu \text{s}. \)
Two-dimensional images of conditional average of the floating potentials in the SOL at six times of 5 μs interval.
5. Summary

- The spatial structure of multiple shear flow populations, the shear flow-turbulence dynamics are investigated at the edge plasmas of HL-2A tokamak with OH and ECRH.
- The LFZF and GAM power tends to coexist in the inner region and GAM dominates near the LCFS.
- The Reynolds stress of the ambient turbulence is found to be well correlated with the mean flow, LFZF and GAM, suggesting that multiple shear flows are driven by nonlinear interaction with turbulence via the stress.
- The analysis of shear flow-turbulence interaction demonstrates that the edge turbulence is modulated by all the multiple shear flows.
The characteristics, generation mechanism and propagation of blobs are investigated in the edge and scrape-off layer plasma of HL-2A tokamak for the first time.

The spontaneous $E \times B$ sheared flows are identified responsible for the generation of the blobs.
Thank you for your attention!