Spatiotemporal Behavior of Drift Waves in LMD-U

Takuma YAMADA$^{1)}$, Sanae -I. ITOH$^{1)}$, Kenichiro TERASAKA$^{2)}$, Naohiro KASUYA$^{3)}$, Yoshihiko NAGASHIMA$^{1)}$, Shunjiro SHINOHARA$^{2)}$, Takashi MARUTA$^{2)}$, Masatoshi YAGI$^{1)}$, Shigeru INAGAKI$^{1)}$, Yoshinobu KAWAI$^{1)}$, Akihide FUJISAWA$^{3)}$ and Kimitaka ITOH$^{3)}$

$^{1)}$Research Institute for Applied Mechanics, Kyushu University, Kasuga 816-8580, Japan
$^{2)}$Interdisciplinary Graduate School of Engineering Sciences, Kyushu University, Kasuga 816-8580, Japan
$^{3)}$National Institute for Fusion Science, Toki 509-5292, Japan

In the LMD-U linear magnetized plasma, fluctuation measurements with multi-channel poloidal Langmuir probe arrays have been performed. The mean poloidal mode number of the fluctuation and its spread suggest the existence of broadband fluctuation, which is considered to be produced by nonlinear couplings. The broadband fluctuation develops into high poloidal mode number and high frequency region, which do not satisfy the linear dispersion relation of drift wave modes. The broadband fluctuation revealed small correlation time and poloidal length than the fluctuation peaks. Poloidal mode decomposed axial coherence was measured with two poloidal probe arrays. The axial coherence was strong both for the broadband fluctuation and fluctuation peaks.

Keywords: linear plasma, multi-probe, drift wave, turbulence, nonlinear coupling

1 Introduction

Recently, there has been an advance in the study of nonlinear interaction between drift wave turbulence and meso-scale structures such as zonal flows and streamers [1, 2]), and experiments in linear plasma devices have been in progress [3–10]. In these studies, complex wave patterns in poloidal direction have been observed (see also reports from toroidal plasma experiments, e.g., [11–14]). These advancements highlight the need to measure fluctuations at multiple spatial positions simultaneously. Fluctuation measurements using poloidal multi-probe arrays have been performed in linear plasmas and torus plasmas [3, 4, 6, 15].

In the LMD-U linear magnetized plasma [16], multi-point measurements of the ion saturation current and floating potential fluctuations using poloidal Langmuir probe arrays have been in progress. Drift wave modes driven by steep radial density gradient were identified, and a drift wave turbulence regime was achieved [17]. The poloidal mode numbers and frequencies of the drift wave modes were compared with the calculated linear dispersion relation of drift wave [18], and they were in a good agreement. Moreover, in a drift wave turbulence regime, quasi-modes and broadband components that do not satisfy the dispersion relation were found and suggested that they were produced by nonlinear couplings of parent modes [19]. In this article, we report the details about the broadband components found in the drift wave turbulence regime.

2 Poloidal Probe Arrays

We have performed a quasi-two-dimensional measurement of the ion saturation current fluctuation of the LMD-U linear plasma [16]. The schematic view of the LMD-U device is shown in Fig. 1. A linear magnetized plasma is created by an rf (the frequency of 7 MHz and the power of 3 kW) antenna in a quartz tube (the axial length of 0.4 m and the inner diameter of 0.095 m) with argon gas filled in. The plasma is guided along straight magnetic field created by magnetic coils surrounding the vacuum vessel to form a column shape. The axial length and inner diameter of the vacuum vessel are 3.74 m and 0.445 m, respectively.

There are two poloidal Langmuir probe arrays installed on LMD-U. A 64-channel poloidal probe array is installed at the axial position of 1.885 m and a 48-channel poloidal probe array is installed at 1.625 m. The tungsten probe tips of the 64-channel probe array are fixed at the measuring radius of 40 mm (the probe tips are 3.9 mm apart), and the position of the whole probe array is adjustable two-dimensionally in the plasma cross section. Therefore, the precise poloidal mode number of the fluctuation is available by this probe array [20]. The 48-channel probe array consists of 16 probe units, which are mov-
The spatiotemporal behavior of the ion saturation current $I(\theta, t)$ varies by changing parameters from periodic coherent wave structure to turbulence regime, which consists of many fluctuation components with different poloidal mode numbers and frequencies [4]. In LMD-U, increasing the magnetic field (over 0.04 T) and decreasing the filled argon pressure (under 0.4 Pa) make the plasma turbulence regime measured with the 64-channel poloidal probe array. The magnetic field was 0.09 T and the argon pressure was 0.27 Pa. The increasing direction of the poloidal angle $\theta$ corresponds to the electron diamagnetic direction. The spatiotemporal waveform consists of a number of fluctuation components. The main fluctuation is the flow in the electron diamagnetic direction. The magnetic field and its spread, respectively. They are defined by

$$\langle m(f) \rangle = \frac{\sum_m mS(m, f)}{\sum_m S(m, f)}, \quad (1)$$

$$\Delta m(f)^2 = \frac{\sum_m [m - \langle m(f) \rangle]^2 S(m, f)}{\sum_m S(m, f)}. \quad (2)$$

The mean poloidal mode number traces the strong fluctuation peaks, and the spread decreases in the existence of the strong peaks. In the high frequency region with no remarkable fluctuation peaks ($f > 10$ kHz), the mean poloidal
mode number increases with the relationship \( \langle m \rangle \propto f \) and the spread is an increasing function of \( f \). These facts imply the existence of broadband components. The quasi-mode peaks and broadband components appear nearly on the line \( \langle m \rangle \propto f \), and they are away from the linear dispersion relation curve of the drift wave. This is because nonlinear couplings between the parent modes force to excite quasi-mode peaks and broadband components in the position away from the dispersion relation. Thus, energy cascade to high \( m \) and high \( f \) region is expected [19].

Figure 4 shows the logarithmic plots of power spectra \( S(f) \) and \( S(m) \) calculated by integrating \( S(m, f) \) with \( m \) and \( f \), respectively. Both spectra have relations \( S(f) \propto f^{-7.0} \) and \( S(m) \propto m^{-7.0} \) in broadband regions \((f > 10 \text{ kHz} \text{ or } m > 5)\). It is interesting that the decay laws are the same in the frequency and poloidal mode number spaces. It is also interesting that the power law of \( S(m) \) is nearly equal to that led from the previous work \((i.e., S(m)^{0.5} \propto m^{-3.6} [3])\). Although different experimental conditions induce individual eigen functions, the power laws in broadband regions become almost the same.

![Figure 4](image-url)  
**Fig. 4** One-dimensional power spectra (a) \( S(f) \), (b) \( S(m) \) (squares) and \( S(-m) \) (triangles) (arb. unit). Dashed lines show the relationship \( S \propto f^{-7.0} \) and \( S \propto m^{-7.0} \).

### 4 Broadband Fluctuation

Figure 5 shows the auto-correlation functions of the ion saturation current fluctuation in the frequency ranges of full-range and \( f > 10 \text{ kHz} \). Owing to the main fluctuation peaks, the auto-correlation time of the frequency of full-range is long (about the order of 10 ms). On the other hand, the auto-correlation time of the frequency of \( f > 10 \text{ kHz} \), which is in the broadband fluctuation region, is short (about the order of 1 ms). It means that the broadband fluctuation has a short time life than the main fluctuation peaks. Many short time fluctuations with various frequencies accumulate to form a broadband fluctuation.

Correlation length (poloidal angle) was calculated from the 64-channel data. Coherence \( coh \) of two time data

\[
coh^2(f) = \frac{|S_{xy}(f)|^2}{S_{xx}(f)S_{yy}(f)},
\]

where \( S_{xy} = \langle \hat{I}_x \hat{I}_y^* \rangle / df \). Correlation length is the distance where the coherences become \( e^{-1} \). Figure 6 shows the frequency dependence of the coherence in the poloidal angle space. The coherence between different poloidal channels of the 64-channel probe array was calculated to produce Fig. 6. The correlation length in the poloidal direction is long for fluctuation peaks such as 0.9 kHz and 2.8 kHz, and is small (under \( \pi/4 \)) for broadband fluctuation. The correlation length gradually decreases as the frequency becomes high. From this result, strong fluctuation peaks are produced globally in the poloidal direction, while broadband fluctuation is produced locally in the poloidal direction.

One of the features of our experiment is that two poloidal probe arrays are used for fluctuation measure-
Fig. 7 Poloidal mode number decomposed axial coherence between the two poloidal probe arrays. The coherence is strong not only for fluctuation peaks but also for broadband fluctuation. The solid white line shows the mean poloidal mode number, and the broken white lines show its spread.