Evaluation of Electron Temperature Fluctuations Using a Conditional Technique*)

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Electron temperature fluctuation amplitude is evaluated with a single probe using conditional sampling technique on the PANTA (linear magnetic configuration device). Electron temperature fluctuations are extracted as a function of floating potential. Normalized temperature fluctuation amplitude of about 15% is observed in low neutral pressure discharge in PANTA.

Keywords: electron temperature fluctuation, conditional sampling, basic plasma device

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1. Introduction

Turbulent fluctuations are widely accepted as a major contributor to cross-field transport in magnetically confined plasmas. Correlated fluctuations of density, poloidal electric field and temperature result in time-average flux. Simultaneous measurement of these fluctuations and their correlations is required for experimental investigation of the fluctuation-driven transport.

The triple probe method is a powerful tool to measure electron temperature with high temporal resolution and is applied in many plasma devices [1, 2]. However, in the triple probe method, inhomogeneity of plasma along the three probe tips and/or subtle differences in form of probe tips can cause errors in the estimation of electron temperature. Thus careful experimental setup is required [1]. On the other hand, single probe method has no such restriction of applicable condition and thus easy to use. In the single probe method, electron temperature can be evaluated from the current-voltage (I-V) characteristic curve. However, it is difficult to obtain I-V curves with high temporal resolution. An additional technique to evaluate electron temperature fluctuation is required. One candidate is the conditional sampling technique [1–3]. The conditional sampling technique allows us to estimate the temperature fluctuation amplitude synchronized with potential fluctuations. Fluctuation amplitude is important information to identify instability and to evaluate fluctuation-driven flux.

In this paper, we first describe the experimental setup in the PANTA, then the method of the conditional technique is explained. Next, we give a result of the data analysis. Finally, we discuss results and summarize the paper.

2. Experimental Setup

Fluctuation measurements of electron temperature were carried out in the PANTA. The PANTA is a linear magnetic device and produces a cylindrical plasma (diameter 0.1 m, length 4 m) with a helicon wave (7 MHz, 3 kW) using a double-loop antenna around a quartz tube. The quarts tube is filled with argon gas. The neutral gas pressure is 0.4 Pa. The magnetic field is 0.09 T. Central density and temperature are $5 \times 10^{18}\,\mathrm{m}^{-3}$ and 3 eV, respectively. The Debye length is estimated to be about 6 μm. In this condition, fluctuations are strongly turbulent and fluctuation spectrum has a peak around 7 kHz with broad FWHM (~2 kHz) [4]. A 5-channel probe is used to measure single probe I-V curve, floating potential and ion saturation current, simultaneously. A schematic view of this probe is shown in Fig. 1 (a). The 5-channel probe consists of five tungsten pins (p1-p5 denote each pin) with a diameter of 0.7 mm and a length of 3 mm aligned on a line and separated by 3 mm. The probe is allowed to rotate and move

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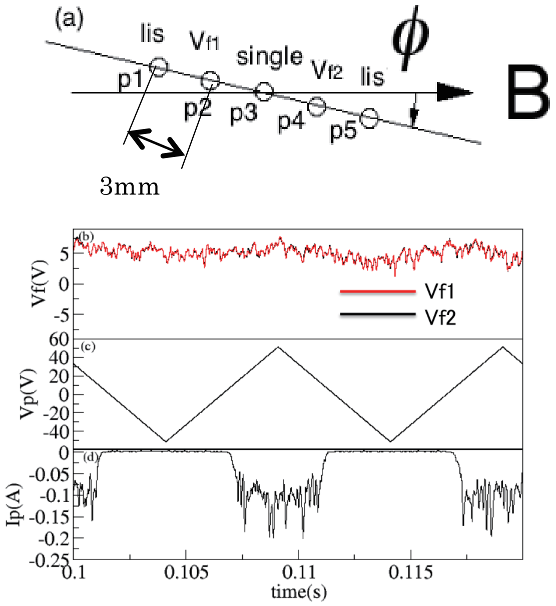

Fig. 1 (a) schematic view of 5-channel probe and typical time evolution of (b) floating potential measured with two probe pins, (c) bias voltage applied to pin3 and (d) probe current.

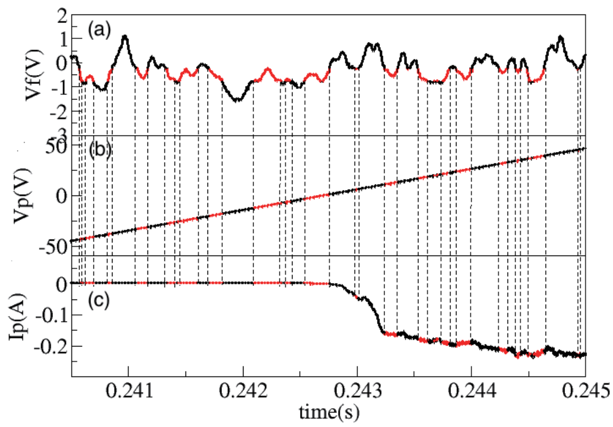

Fig. 2 Example of categorization of floating and resampling. Floating potential in the range of $-1.18 \sim -0.48$ V are highlighted in red (a), the highlighted V-I signals are extract and used to make V-I curve (b, c).

radially. This probe is installed at $z = 1.625$ m from the quartz tube. The center pin (p3) is working as a single probe. Low frequency (100 Hz) voltage was applied between the pin and vacuum vessel. The other pins measure floating potential (p2, p4) and ion saturation current (p1, p5). Fluctuations in PANTA usually propagate azimuthally with finite parallel wave number. The conditional sampling technique can extract the temperature fluctuation components synchronized with reference fluctuation. To avoid the mismatch of phase between the target fluctuation and reference one, the probe pins were aligned to the propagation direction as shown in Fig. 1 (a). In practice, phase delay between floating potentials measured at the different probe pins was minimized by adjusting the probe rotation angle ϕ.

Figures 1 (b)-(d) show a typical time evolution of floating potentials (V_f), probe current (I_p) and probe voltage (V_p) of central pin (p3). The phase delay between two floating potentials was almost zero as shown in Fig. 1 (b). The floating potential at the center probe tips, therefore, can be estimated as the average value at the neighboring probe pins.

3. Conditional Sampling Technique

We assume that for each value of the floating potential, a single consistent I-V curve of the probe can be determined. We therefore applied a conditional sampling technique to the single probe measurement. Figure 2 shows an example of categorization of floating potential and resampling of I-V data. First, we select the bin size for the floating potential and create categories. For example, the floating potential in the range of -1.18 V ~ -0.48 V is highlighted in red. Next, I-V data (both current and voltage data highlighted in red) are resampled into categories according to the instantaneous floating potential value. Then, the I-V curve in each category is obtained, and the electron temperature is determined for each category. Note that this conditional sampling can only be used when the fluctuation phase is random with respect to the probe bias voltage. In the conditional sampling technique, the data points for one category will be decreased, thus longer pulse discharges are required. The pulse length depends on the bin size [2].

4. Results

We categorize the floating potential into 10 bins. Figure 3 shows typical I-V curves before (Fig. 3 (a)) and after conditional sampling (Figs. 3 (b)-(f)) (the V-I curves for 5 categories are shown) at $r = 4$ cm. Here the ion saturation current was subtracted. The turbulence fluctuations are seen to affect the I-V curve as shown in Fig. 3 (a).

On the other hand, the effects of fluctuations on the I-V curve are dramatically reduced by conditional sampling. The logarithmic plots of the resampled I-V curves can be well fitted by a line. This means that there is no significant effect by high energy electrons. The temperature is obtained from linear fitting of each logarithmic plot of I-V curves. The voltage range for the fitting is 1-11 V and evaluation of electron temperature is not sensitive to the choice of the voltage range within these limits. The conditional sampling technique is validated in the high neutral density condition (0.4 Pa) in PANTA as demonstrated in ref. [1]. Here we presents the electron temperature fluctuation in the low neutral density condition (0.1 Pa) in which broader fluctuation spectrum are observed [3]. Figure 4 shows the electron temperature as a function of floating potential for each category. The electron temperature depends on the floating potential. This means that electron

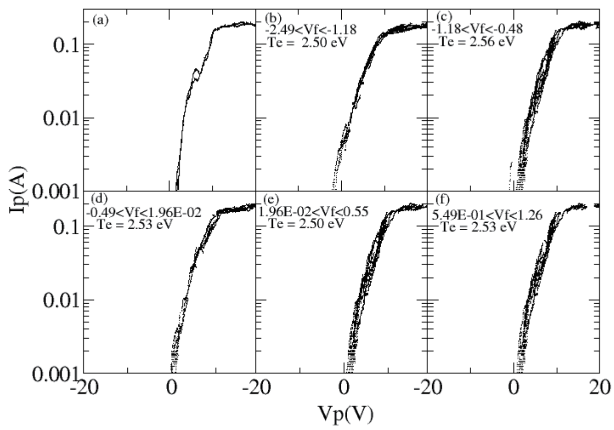

Fig. 3 I-V curve obtained before (a) and after conditional sampling for different bins (b)-(f).

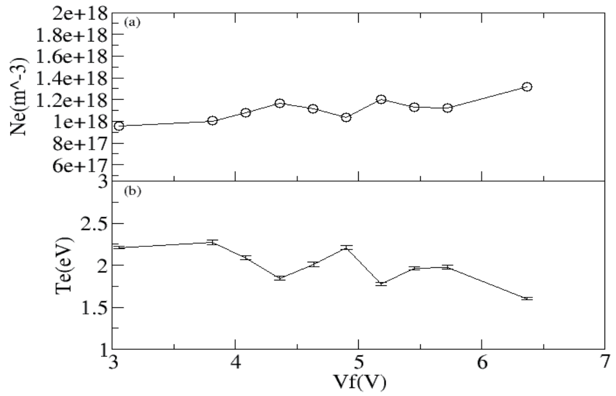

Fig. 4 (a) Electron density and (b) Electron temperature as a function of the floating potential amplitude.

temperature fluctuations exist and the amplitude of electron temperature fluctuations that are correlated with the floating potential is $\tilde{T}_e/\bar{T}_e \sim 15\%$ (here, $\tilde{T}_e$ is amplitude of T_e fluctuation and $\bar{T}_e$ is averaged value of T_e). The amplitude of density fluctuations can be also estimated to be $\tilde{N}_e/\bar{N}_e \sim 20\%$. These results are consistent with the observation with a triple probe.

5. Discussion and Summary

The conditional sampling method can estimate temperature flucutuation amplitude synchronized with potential fluctuation. In this method, temperature and floating potential fluctuations are considered to be in phase. A phase differences between floating potential and temperature fluctuation can lead to mixture of different temperature conditions, for each categories of the floating potential. Further categorization, for example, categorization of V_f not only their amplitude but also their time-derivation, may be required. The improvement of this method will allow us to evaluate phase relation between electron temperature fluctuation and floating potential fluctuation.

In summary, the electron temperature fluctuation amplitude was estimated by single probe method using a conditional sampling technique in PANTA. A finite level of temperature fluctuations is observed.

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