Fluctuation Measurement in the Edge Plasma on TST-2

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A new technique is used to estimate the amplitude of temperature fluctuation in the edge plasma on TST-2. Langmuir probe current-voltage characteristic curves are conditionally reconstituted in terms of the intensity of the floating potential. High/low electron temperatures are obtained in low/high floating potential phases. As a result, normalized temperature fluctuation levels are found to be about 19 % or larger.

Keywords: plasma turbulence, temperature fluctuation, edge plasma, conditional technique

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1. Introduction

The development of fast, fine and precise measurement of electron temperature in edge plasmas is important for fusion plasma research. In particular, turbulence transport caused by temperature fluctuations (i.e., ion temperature gradient turbulence) is believed to be significant in high performance fusion plasmas. In TEXTOR, highly sophisticated harmonic techniques are presented for turbulent temperature fluctuation measurement [1]. Recent studies on edge turbulence momentum transport have been performed with Langmuir probe (LP) floating potential data, assuming the temperature fluctuation is negligible [2]. However, in high-beta toroidal plasmas (i.e., spherical tori), this assumption is not guaranteed, and may lead to a misunderstanding of turbulence transport. Meanwhile, turbulence fluctuation may affect the evaluation of stationary electron temperature calculated by Langmuir current-voltage characteristic curves (I-V curves) [3]. Therefore, easy evaluation of electron temperature fluctuation is urgently required. In this paper, we propose a new approach to estimate the stationary and fluctuating electron temperature in turbulent plasmas in the TST-2 spherical tokamak [4]. The approach focuses on a single Langmuir probe measurement to maintain fine spatial resolution; a triple probe technique was not used. The method is based on conditional techniques provided by Inagaki, et al. [5]. First, we describe the experimental setup in TST-2 and method for the conditional technique. Second, we give an example of the data analysis, and estimate the stationary temperature and fluctuating components. Finally, we discuss the results and summarize the paper.

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2. Experimental Setup

TST-2 is a small spherical tokamak device with major radius $R_0 \sim 0.38$ m, minor radius $a \sim 0.25$ m (aspect ratio $A \geq 1.5$), elongation $\kappa \leq 1.2$-1.8, and toroidal magnetic field $B_t \leq 0.3$ T. Typical plasma parameters are: plasma current $I_p \leq 200$ kA, line-averaged electron density $\overline{n}_e \leq 2 \times 10^{19}$ m^{-3}, electron temperature at plasma center $T_{e,0}$ = 100-300 eV, and discharge duration ≤ 20 ms. There are two kinds of operation in TST-2: One is ohmically heated discharge with/without auxiliary rf (ion cyclotron range of frequency) heating. In the ohmic plasmas, research on parametric decay instability during high harmonic fast magnetosonic wave heating has progressed in recent years [6–8]. The other is electron cyclotron heating (ECH) discharge. In the ECH plasmas, spherical tokamak start-up experiments have been conducted [9]. Plasmas in these experiments are produced by ohmic heating without RF power. The low-field side boundary of the plasmas is determined by the limiter ($R = 0.63$ m) attached to the RF antenna.

Experimental data were obtained by a multi-channel LP [8]. The LP is located at a toroidal angle of $\phi = -165°$ relative to the toroidal location of the rf antenna, and is radially movable. Figure 1 shows the experimental setup for LP measurement. We use three electrodes. A slowly varying bias voltage (1 kHz) is applied to one of them to obtain I-V curves, from which the local electron temperature T_e can be derived. In this experiment, rf power is not injected into the plasmas, and we used the LP to which rf compensation was not applied. The other two electrodes measure the floating potential fluctuation. We set the radial location of the LP at $r = -15$ mm, where r repre-

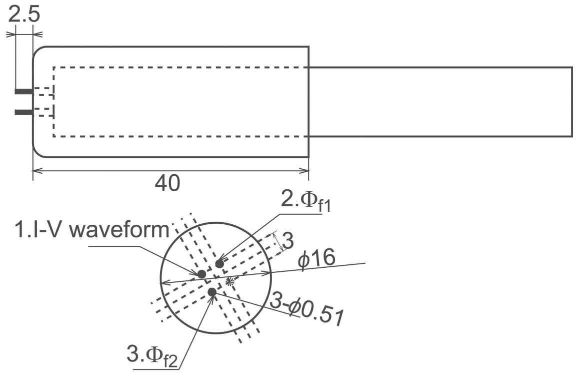

Fig. 1 Enlarged view of Langmuir probe and experimental setup of electrodes.

sents the radial location relative to the low field side limiter, and positive or negative r indicates a location inside or outside the limiter position, respectively. TST-2 plasmas in this experiment have a duration of about 20 ms, and we selected data for analysis when the low-field side of the plasma was bound by the limiter (25-30 ms). Figure 2 shows examples of the discharge waveforms obtained in this experiment.

3. Data Analysis Procedure

We assume that a one-to-one correspondence is maintained among the floating potential and I-V characteristic. In other words, plasma has a unique floating potential and I-V characteristic curve. The validity of this assumption is discussed in section 5. The floating potential and I-V data should be obtained by the same digitizer to maintain simultaneous data sampling. In TST-2, the floating potential fluctuation in the edge plasma reveals a broadband spectrum with a spectral peak around 20 kHz. Figure 3 shows waveforms of an I-V curve and floating potential. The correlation between the two is significant, and the phase delay between them appears to be almost zero. This supports conditional classification of I-V data in terms of the value of the floating potential. First, we select the bin size for the floating potential, and create categories. The floating potential data have array indices, and the indices are also classified. Next, I-V data (both current and voltage data) are classified into the categories by the array indices; then, the I-V curve in each category is reconstituted, and the electron temperature is obtained. Note that this conditional technique can be used when the fluctuation phase is random and the fluctuation is turbulent. In this analysis, we need many current data points at different bias voltages to obtain the I-V curve in each category, also large variation in the bias voltage data is required. In turbulent fluctuation, the phase of the top and bottom amplitudes in the horizontal direction (time axis) fluctuates significantly, and variation in the bias voltage is obtained.

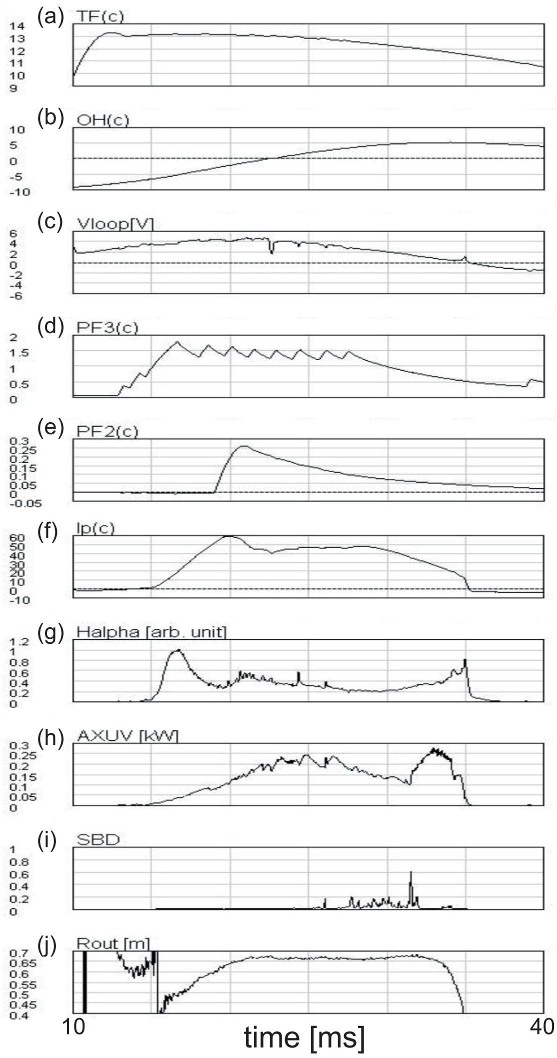

Fig. 2 Discharge waveforms in this experiment. (a) Toroidal coil current, (b) ohmic coil current, (c) loop voltage, (d, e) vertical field coil currents, (f) plasma current, (g) H_α emissivity, (h) radiation power, (i) surface barrier diode detector signal, and (j) approximate indicator for plasma boundary on the low-field side.

4. Experimental Results

In this section, we present the results of data analysis. First, we show an example of the results of I-V curve fitting. Figure 4 shows a typical I-V curve after conditional classification. In Fig. 4 (b), current fluctuation caused by turbulence fluctuation is dramatically reduced, and the electron temperature is obtained by linear fitting of the logarithmic plot of the I-V curve from which the ion saturation current is subtracted. The voltage range for the fitting is chosen beginning at −50 V because of data instability in the highly negative voltage range (note that the ion saturation current is subtracted from the I-V curves.)

Next, we calculated the electron temperature in each category of floating potential and obtained the dependence of the electron temperature on the floating potential. Figure 5 shows the relationship between the floating potential

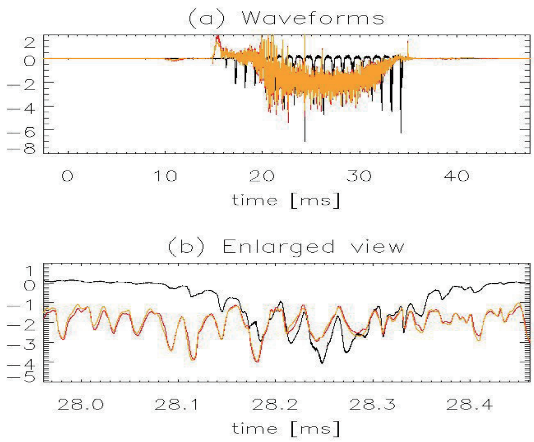

Fig. 3 (Color online) Time trace of I-V curves and floating potential in arbitrary units. Negative or positive current indicates electron or ion current direction. (a) Full trace during a single discharge, and (b) enlarged view of the traces around 28 ms. Red, orange, and black plots indicate floating potential 1, floating potential 2, and the I-V curve, respectively.

and the electron temperature. The average floating potential is around −66 V. The relationship between the floating potential and the electron temperature is not linear. That is, $\frac{d\Phi_f}{dT_e}$ is not stationary. In addition, positive and negative variations in amplitude relative to the mean value are not symmetrical. The validity of detailed properties of Fig. 5 is discussed later. However, the electron temperature fluctuation is significant. The average electron temperature is around 32 eV, and the lowest electron temperature is about 26 eV. Thus, the normalized amplitude of the electron temperature fluctuation is about 19 % or larger without considering fluctuation weighting.

5. Summary and Discussion

We observed significant electron temperature fluctuation corresponding to floating potential fluctuation under the assumption that the relationship among the floating potential, I-V curve, and plasma is a one-to-one correspondence. This assumption breaks when a phase difference exists between the floating potential fluctuation and the I-V data fluctuation. Conditional analysis under a finite phase difference leads to a mixture of different plasma conditions. For instance, consider a sinusoidal waveform. If a finite phase difference exists between the current data of the I-V curves and the floating potential, one floating potential data point corresponds to two different current data points. In a sinusoidal waveform, there are two different current data points with the same amplitude and the opposite sign. Thus, two different current data points would be placed in the same category in terms of floating potential fluctuation. In this experiment, the phase difference between the I-V curves and floating potentials are negligible, and the mixture is possibly insignificant.

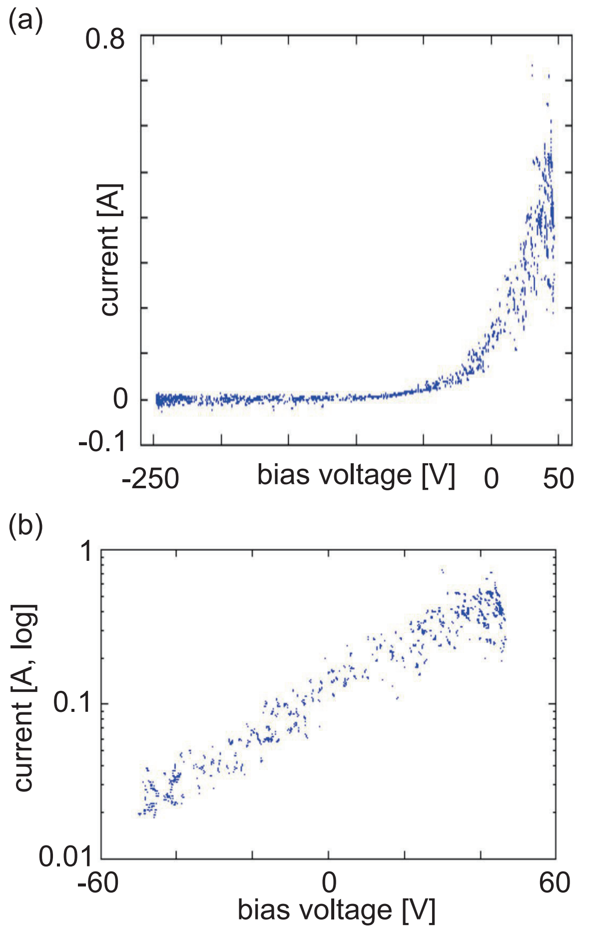

Fig. 4 Example of conditionally reconstituted I-V curve. (a) Linear plot of the I-V curve, and (b) logarithmic plot of the I-V curve. In (b), the ion saturation current is subtracted. I-V data were measured in $r = -1.5$ cm and about 24.5-25.5 ms.

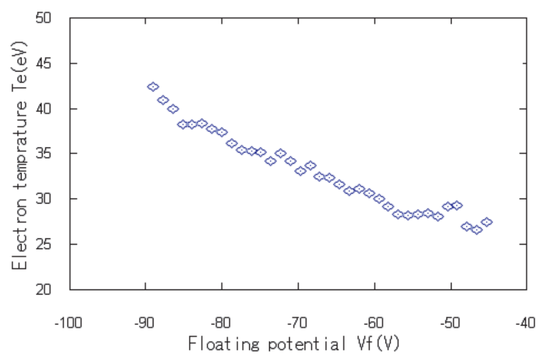

Fig. 5 Floating potential vs electron temperature. Stationary floating potential is about −66 V. I-V data were measured at $r = -1.5$ cm and about 24.5-25.5 ms.

Another difficulty arises in the conditional classification. I-V curves are classified in terms of floating potential bin size without weighting the distribution function. In this case, the high electron temperature bin (low floating potential) is derived from a smaller number of data points than that around the mean electron temperature bin. This leads to over-emphasis of the highest or lowest electron temperatures even though the exact data for the “real” high or low electron temperature are few. In contrast, when we increase the bin size, the problem returns to the starting point and conditional classification is less effective. In any case, further study is necessary to improve the conditional classification techniques.

In summary, by use of new conditional classification techniques, we have evaluated the peak variance in electron temperature fluctuation in the edge plasma of the TST-2 spherical tokamak. The normalized levels of electron temperature fluctuation are around 19 % or larger in TST-2. We discuss the validity of the analysis.

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