Evaluation of Edge Electron Temperature Fluctuations Using a Conditional Technique on TST-2

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(Received 25 February 2010 / Accepted 1 May 2010)

The amplitudes of electron temperature fluctuations are evaluated in the edge plasma of TST-2 using a new technique. Langmuir probe current-voltage characteristic curves are conditionally reconstituted in terms of the magnitude of the floating potential. High/low electron temperatures are obtained in low/high floating-potential phases. The relationship between the electron temperature fluctuations and the time-averaged electron temperature gradient is discussed.

Keywords: electron temperature fluctuation, edge plasma, spherical tokamak, Langmuir probe

DOI: 10.1585/pfr.5.023

The development of a fast, precise, and high-resolution measurement of the electron temperature in edge plasmas is important in fusion plasma research [1, 2]. Recent studies on momentum transport by edge turbulence were performed with Langmuir probe (LP) floating-potential data under the assumption that the electron temperature fluctuation is negligible [3]. However, in high-beta toroidal plasmas (e.g., spherical tori), this assumption may not be valid, and may lead to an incorrect estimation of turbulence transport. In this study, we propose a new approach [4] to estimate the time-averaged and fluctuating components of the electron temperature in turbulent plasmas. This approach focuses on the use of a single-LP measurement to obtain high spatial resolution, instead of the commonly used triple probe technique. First, we describe the experimental setup on TST-2 [5] and the method of conditional classification. Second, we provide an example of data analysis, and estimate the time-averaged and the fluctuating components of the electron temperature. Third, to check the validity of this analysis technique, we form a relationship between the fluctuation amplitude and the time-averaged gradient. Finally, we discuss the results and summarize the study.

Experiments were conducted on the TST-2, which is a spherical tokamak device with major radius $R_0 \sim 0.38$ m, minor radius $a \sim 0.25$ m (aspect ratio $A \geq 1.5$), toroidal magnetic field $B_t \leq 0.3$ T, and typical plasma current $I_p \leq 200$ kA. A multichannel LP was used to measure the floating potential V_f, probe voltage V_{probe}, and probe current I_{probe} simultaneously at a specific point in the edge plasma. The LP is radially movable, and measurements were performed at radial locations of $x = -30, -25, -15$, 0, and 15 mm, where x is the radial position relative to the low-field side limiter, located at $R = 630$ mm (R is the major radius). The positive x direction is taken outward, away from the plasma center. A slowly varying (1 kHz) bias voltage V_{probe}, from −250 to 50 V, was applied to one electrode of the LP and I_{probe} was measured on the same electrode. Two other electrodes were used to measure V_f. We selected data within the range 22.5-25.5 ms out of the plasma duration of 16-33 ms, because the plasma is nearly stationary during this interval. Figure 1 (a) shows the waveforms of V_f and I_{probe} during a single voltage sweep.

We introduce a new conditional classification method. We assume a one-to-one correspondence between V_f and the electron temperature T_e. The validity of this assumption is discussed later. This assumption enables us to calculate T_e as a function of V_f, and helps estimate the fluctuation of T_e from the fluctuation of V_f. Firstly, we categorize the data by V_f at any fixed x. Secondly, we estimate T_e and its temporal fluctuation, and derive the dependence of T_e on V_f. Thirdly, we calculate the average T_e, and the fluctuation of T_e from the fluctuation of V_f at fixed x. Finally,

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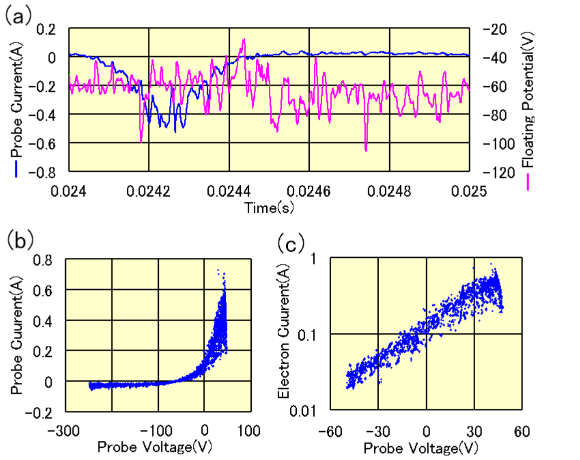

Fig. 1 (a) Waveforms of V_f and I_{probe} during a single voltage sweep, (b) V_{probe} and I_{probe} at $x = -25$ mm and $-76.3\,V < V_f < -74.9\,V$, and (c) V_{probe} and electron current $I_{probe} - I_{i,sat}$ under the same condition.

at any x, we estimate the position fluctuations about V_f and T_e from the plot of the average V_f and T_e, and from the fluctuations versus x (the average and fluctuation of V_f is directly calculated from the original data).

We categorize the data according to the value of V_f, and estimate T_e in each range of V_f. Figures 1 (b) and (c) show the relationship between V_{probe} and I_{probe} in the range $-76.3\,V < V_f < -74.9\,V$ measured at $x = -25$ mm. In Fig. 1 (b), I_{probe} becomes nearly constant for $V_{probe} < -150\,V$, corresponding to the ion saturation current $I_{i,sat}$. The curve is nearly exponential for $V_{probe} > 0\,V$. We calculate T_e from the semi-log plot of V_{probe} and electron current $I_{probe} - I_{i,sat}$, such as that shown in Fig. 1 (c).

Now, we illustrate the relationship between T_e and V_f. Figure 2 (a) is a plot of average T_e at each V_f, taken at $x = -25$ mm. Here, we can estimate δT_e, the fluctuation of T_e caused by δV_f (the fluctuation of V_f). We also evaluate the T_e fluctuation at fixed V_f, assuming that the fluctuation of I_{probe} at fixed V_f originates from the temporal fluctuation of T_e. It is of the order 1-2 eV, and this is discussed later.

Next, we calculate the fluctuation in position from V_f and T_e data at any x. Figure 2 (b) shows the average V_f and average T_e, as well as δV_f and δT_e. It is natural that the position fluctuation of T_e at x, $\delta x_{T_e}(x)$, is defined as the distance between x and x_f, where $T_e(x_f)$ is equal to $T_e(x) \pm \delta T_e(x)$ (when there are two x_f 's, we take their average). We define $\delta x_{V_f}(x)$ in the same manner. Figure 2 (c) plots $\delta x_{T_e}(x)$ and $\delta x_{V_f}(x)$.

There are two types of fluctuations for T_e: the fluctuation when V_f is fixed and the fluctuation caused by δV_f. If the ratio of the former to the latter were small, the assumption of one-to-one correspondence between V_f and T_e is valid, because if this ratio is nearly zero, T_e can be expressed as a function of V_f. Thus, this ratio represents the validity of the assumption. In fact, the ratio is about 0.5. This small ratio indicates that T_e mainly depends on simultaneous V_f, and supports our assumption.

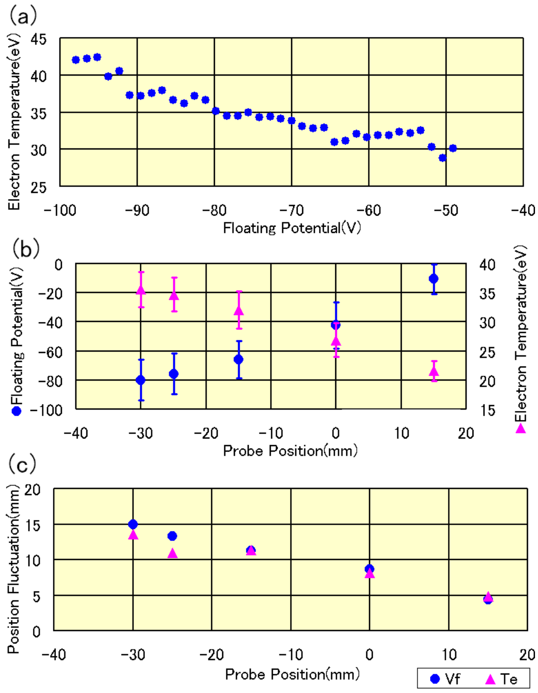

Fig. 2 (a) T_e versus V_f at $x = -25$ mm. It is estimated in the range $V_{probe} > -50\,V$, (b) average V_f and T_e versus x, and δV_f and δT_e (shown by error bars), and (c) spatial fluctuations of V_f and T_e versus x.

Now, we assume a radial fluctuation of velocity from a magnetohydrodynamics-type oscillation, and that the fluctuations of parameters are caused entirely by the oscillation of the plasma with the spatial gradients. Under this assumption, we compare the spatial fluctuations of two scalar parameters, V_f and T_e. Figure 2 (c) shows $\delta x_{V_f} \sim \delta x_{T_e}$, which implies V_f and T_e have similar types of fluctuations; both fluctuations have the same origin, the spatial oscillation of the plasma.

In summary, using the new conditional classification technique, we have evaluated the variance of the electron temperature in the edge plasma of the TST-2. The normalized fluctuation level of the electron temperature is around 18% or higher for the case studied. We compared the relationships between fluctuations and time-averaged gradients in two parameters, and the validity of the analysis was discussed. This study was supported by Japan Society for the Promotion of Science (JSPS) Grants-in-Aid for Scientific Research (S) No. 21226021 and for Scientific Research (A) No. 21246137, and partially by JSPS Grant-in-Aid for Scientific Research (S) No. 21224014.

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