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Measurement of temperature fluctuations and anomalous transport in the SINP tokamak

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Abstract. Temperature fluctuations have been measured in the edge region of the SINP tokamak. We find that these fluctuations have a comparatively high level (30–40%) and a broad spectrum. The temperature fluctuations show a quite high coherence with density and potential fluctuations and contribute considerably to the anomalous particle flux.

Keywords. Temperature fluctuations; anomalous transport; plasma rotation.

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1. Introduction

Coulomb collisions in a magnetised plasma give rise to electrical resistivity and particle diffusion across the magnetic field. This diffusion process is known as classical transport and can be calculated exactly. For the curved magnetic geometry of a tokamak, the collisional transport is termed as neoclassical transport. However, the observed particle and energy transport in the tokamaks exceeds the neoclassical value by about two orders of magnitude. This transport, which cannot be attributed to known classical processes, is termed as anomalous transport and is believed to be driven by microscopic fluctuations (turbulence) [1–3].

Usually the fluctuation induced particle flux is calculated using the density and potential fluctuations and the temperature fluctuations are neglected. We have carried out the measurement of temperature fluctuations in the edge region of the SINP tokamak and found that these fluctuations are not negligible and contribute considerably to the particle flux. The preliminary results are presented here.

2. Experiment

The SINP-tokamak is a small tokamak with an iron core transformer, a poloidal limiter located 1 cm from the wall and having the following parameters:

Major radius = 30 cm	Minor radius = 7.5 cm
Maximum B_T = 2 T	Maximum I_P = 75 kA.

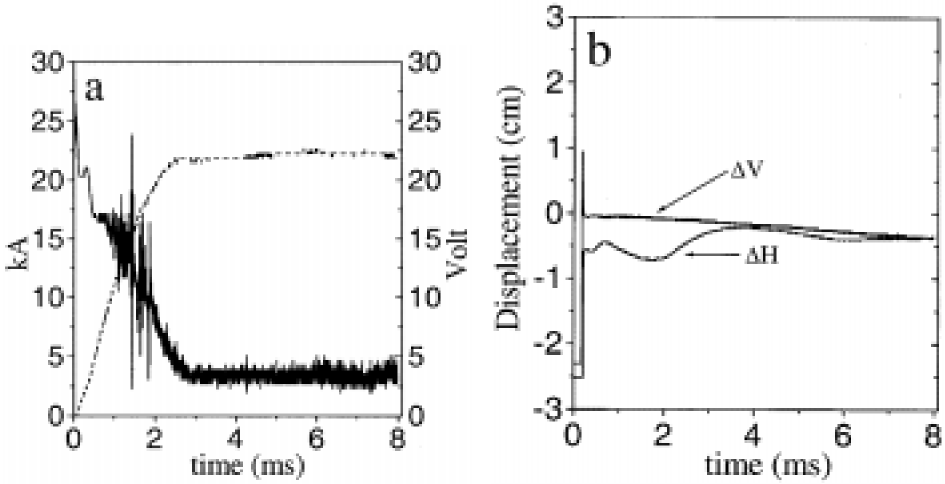

Figure 1. A typical discharge: (**a**) plasma current (dashed line) and loop voltage (solid line). (**b**) Displacement of plasma from the centre of the vacuum vessel; horizontal displacement ΔH ($-$ve means inward shift) and vertical displacement ΔV ($-$ve means downward shift).

The typical plasma parameters for this experiment are:

B_T = 1.1 T, $I_P \approx 22$ kA, $q_a \approx$ 4–5 and gas pressure $\approx 4 \times 10^{-4}$ torr.

The measurements have been carried out in the edge region and the scrape off layer (SOL) region ($0.8 < r/a < 1.1$). Fluctuation data is recorded at 1 MHz sampling rate for about 4 ms during the flat top phase of plasma current where the plasma is in equilibrium and the fluctuation parameters are stationary (figure 1). The plasma current is obtained from the output of a rogowski coil and the plasma position is obtained in real time from the outputs of cosθ and sinθ coils using a hardware unit fabricated for this purpose [4]. We have used Langmuir probes for the measurement of the fluctuations. The arrangement consists of an array of 4 probes of identical dimensions separated along the toroidal and poloidal directions as shown in figure 2. The probes are cylindrical probes made of tungsten having 0.16 cm length, 0.05 cm diameter and a separation of 0.5 cm between the diagonally opposite probes. Probes are mounted on a linearly moveable drive and the radial position of the probe can be changed from shot to shot. The toroidally separated probe pair is biased using an isolated DC power supply (having negligible capacitance with respect to ground or the vacuum vessel) and the ion saturation current I_s drawn by the pair is obtained by measuring the voltage drop across a $10\ \Omega$ resistance using a battery operated isolation amplifier. The potential of the positively biased probe ϕ_+ is also recorded. The instantaneous value of electron temperature T_e is calculated by numerically solving the following equation for the triple probe [5]

$$\frac{1-\exp(-eV_d/kT_e)}{1-\exp(-eV_b/kT_e)} = \frac{1}{2},$$

where V_b is the bias voltage and $V_d = \phi_+ - 0.5\,(\phi_1 + \phi_2)$. The poloidally separated probes measure the floating potentials ϕ_1 and ϕ_2. The propagation velocity of the fluctuations

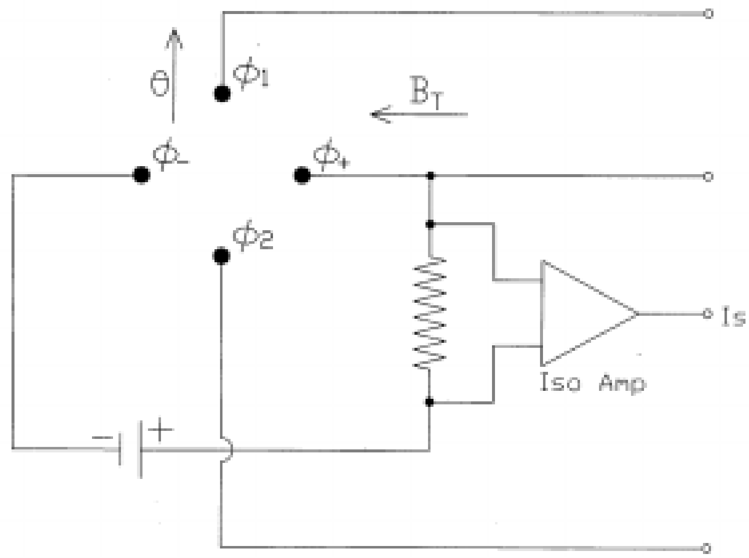

Figure 2. Schematic diagram of the probes and the biasing arrangement.

and the poloidal wave number, $k_\theta(\omega)$, are calculated from the phase difference between these floating potential fluctuations. The plasma potential ϕ_s and the floating potential ϕ_f are related as $\phi_s = \phi_f + \alpha T_e$, where α is a constant. The value of α is obtained from the Langmuir probe characteristic curve data and is found to be 3.2.

The fluctuation induced particle flux is given by

$$\Gamma_r = \frac{\langle \tilde{n}\ \tilde{E}_\theta \rangle}{B_T} + \frac{\langle \tilde{j}\ \tilde{B}_r \rangle}{eB_T},$$

where $n = I_s/\beta T_e^{1/2}$; β being a constant depending on probe area, j is the toroidal current density and B_r is the radial magnetic field. As the magnetic fluctuations are negligible in the edge region, we consider only the electrostatic fluctuations and the transport can be written as [6,7]

$$\Gamma_r = \frac{n}{B_T}\,\mathrm{Im}\left[\frac{\langle \delta I_s^* k_\theta(\omega)\delta\phi_f \rangle}{I_s} - \frac{\langle \delta T_e^* k_\theta(\omega)\delta\phi_f \rangle}{2T_e} + \frac{\alpha\langle \delta I_s^* k_T(\omega)\delta T_e \rangle}{I_s}\right],$$

where the first term is the usual term neglecting temperature fluctuations and second and third terms are the contributions from the temperature fluctuations. The δ's denote the fluctuating quantities in the frequency domain, * denotes the complex conjugate and the k_θ and k_T are the poloidal wave numbers of potential and temperature fluctuations, respectively.

The standard spectral analysis techniques are used for calculating the particle flux. The data is divided in blocks of 128 points each for computing the FFT and other required

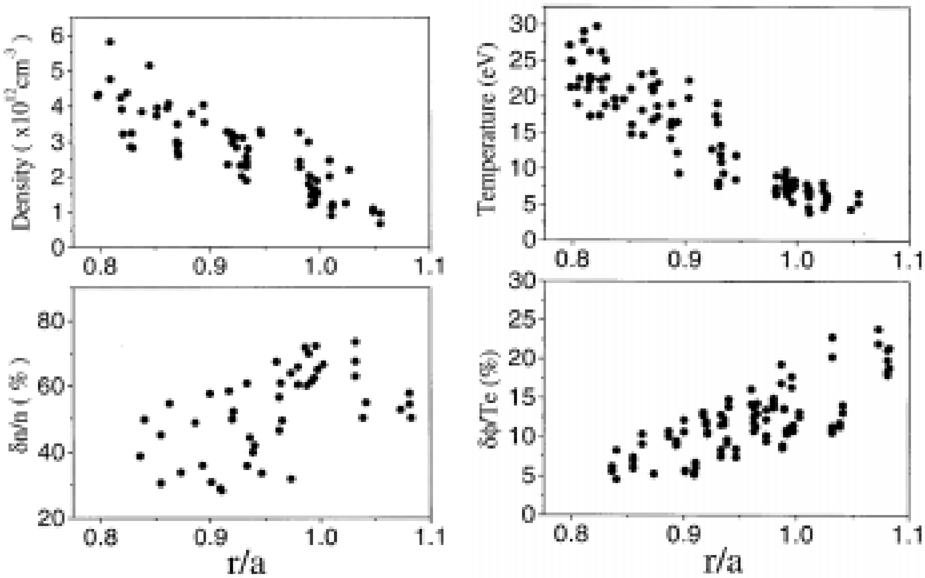

Figure 3. Radial profiles of various quantities, constructed from data collected on shot to shot basis.

quantities and then ensemble average is taken over the blocks. The radial profiles are constructed from the data collected on shot to shot basis.

3. Results and discussion

The radial profiles of plasma density, electron temperature, relative density fluctuation level $\delta n/n$ and $\delta\phi/T_e$ are shown in figure 3. The edge plasma has sharp density and temperature gradients and large fluctuation levels. The $\delta n/n$ and $\delta\phi/T_e$ profiles are similar indicating that there is no measurable departure from Boltzmann like behaviour. The relative temperature fluctuation level is about 30–40%.

The power spectra of potential and density fluctuations show that most of the power lies in low frequencies (<200 kHz) whereas the temperature fluctuation spectrum is found to be somewhat broadband (figure 4a). The potential spectra show a $\omega^{-2.5}$ dependence. The spectra show a peak at around 50 kHz and the coherence between the fluctuation signals, figures 5a and 5b, also has a peak at the same frequency suggesting the presence of some coherent mode. The spectrally resolved particle flux is also maximum at this frequency. The phase difference between the potential fluctuations is almost linear upto 200 kHz (figure 5c), which means that fluctuation propagation velocity is independent of frequency. However, it has been observed that this velocity changes from electron diamagnetic direction to ion diamagnetic direction as we move radially outward showing the presence of a sheared $\mathbf{E_r} \times \mathbf{B}$ rotation (plasma rotation) as observed in other machines [8].

The fluctuation induced particle flux is shown in figure 4b. The flux lies mainly in low frequencies if the temperature fluctuations are neglected whereas considering the

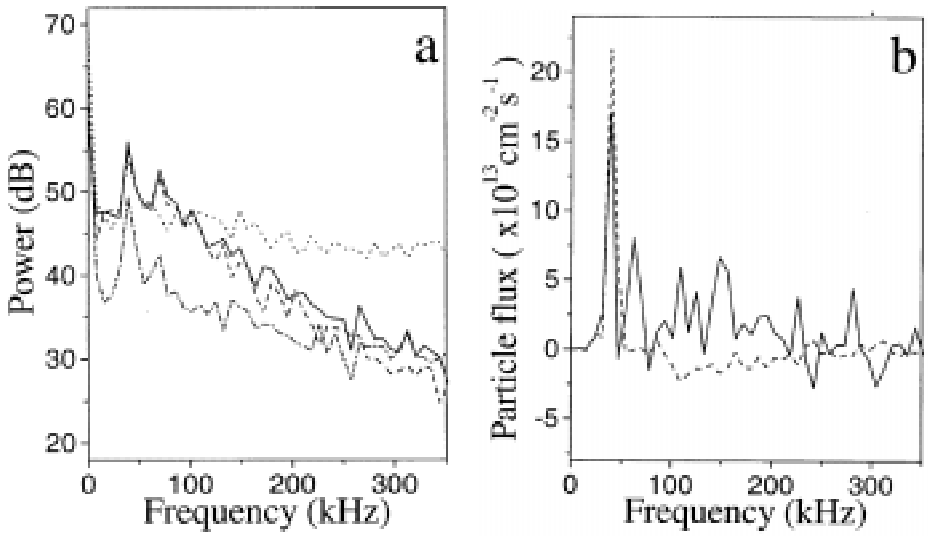

Figure 4. (**a**) Power spectra of floating potential fluctuations $\tilde{\phi}_1$ (solid line), $\tilde{\phi}_2$ (dashed line), density fluctuations (dash-dot line) and temperature fluctuations (dotted line). (**b**) Particle flux neglecting the temperature fluctuations (dashed line) and considering the temperature fluctuations (solid line).

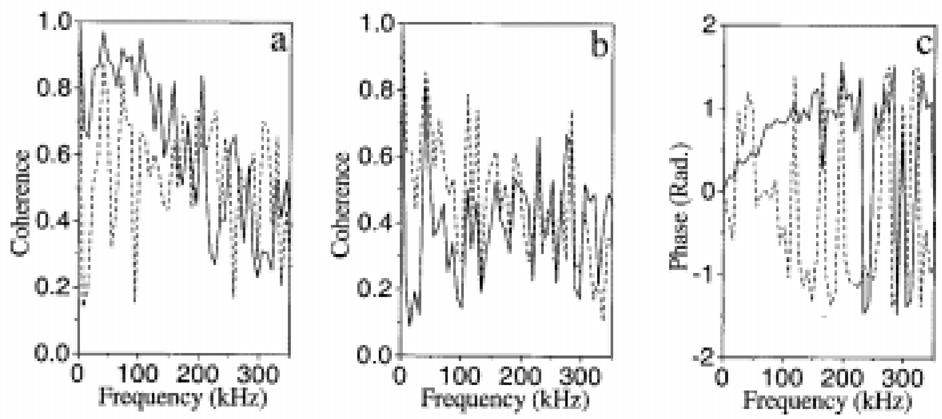

Figure 5. (**a**) Coherence between $\tilde{\phi}_1$ and $\tilde{\phi}_2$ (solid line) and between $\tilde{n}$ and $\tilde{\phi}_1$ (dotted line). (**b**) Coherence between $\tilde{\phi}_1$ and $\tilde{T}_e$ (solid line) and between $\tilde{n}$ and $\tilde{T}_e$ (dotted line). (**c**) Phase difference between $\tilde{\phi}_1$ and $\tilde{\phi}_2$ (solid line) and between $\tilde{n}$ and $\tilde{\phi}_1$ (dotted line).

temperature fluctuations gives a contribution from the higher frequencies also. This contribution is considerable (about 50% in the frequency integrated flux) and therefore it appears that the temperature fluctuations are very important and cannot be neglected while computing the anomalous transport.

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