

RADIAL STRUCTURE OF REYNOLDS STRESS IN THE PLASMA BOUNDARY OF STELLARATOR AND TOKAMAK PLASMAS

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1. Introduction

Poloidal flows have been found to play an important role in the transition to improved confinement regimes in fusion plasmas [1]. Sheared poloidal flows can influence the turbulence by shear decorrelation mechanisms and, as a consequence, they can modify transport. Several mechanisms have been proposed to explain the generation of sheared poloidal rotation in the plasma boundary region including ion orbit losses [2] and Reynolds stress [3].

In the present paper we have studied the link between poloidal flows and fluctuations via the Reynolds stress in plasmas. This comparison is particularly relevant in understanding the effect of turbulence via Reynolds stress in the generation (or damping) of poloidal flows, and its relation to the L to H transition.

2. Experimental set-up

The radial profile of the fluctuation driven flows via Reynolds stress has been investigated in the plasma boundary region of the TJ-IU torsatron ($l=1$, $m=6$, $P_{\text{ECRH}} = 200$ kW, $f_{\text{ECRH}} = 37.5$ GHz, $iota(0) = 0.23$, $R = 0.6$ m, $a = 0.1$ m, $B_t = 0.67$ T, $n_{\text{line}} \approx 0.5 \times 10^{13}$ cm⁻³) and ISTTOK tokamak ($R = 0.46$ m, $B \approx 0.5$ T, $I_p \approx 6$ kA) using multi-arrays of Langmuir probes. Signals are conditioned and digitized at (0.5 - 1) MHz.

The experimental set-up consists of two arrays of three Langmuir probes, radially separated by $\Delta_r \approx 6 - 8$ mm. Two tips of each set of probes, aligned perpendicular to the magnetic field and poloidally separated by $\Delta_\theta \approx 3$ mm, were used to measure the poloidal electric field. This experimental set-up provides a measurement of radial and poloidal electric

field fluctuations in a plasma volume smaller than the typical correlation volume of fluctuations (figure 1). The $\langle \tilde{v}_r \tilde{v}_\theta \rangle$ term of the electrostatic Reynolds stress has been related to the ExB velocities, and experimentally computed as [3]

$$R = \langle \tilde{v}_r \tilde{v}_\theta \rangle = \langle \tilde{E}_r \tilde{E}_\theta \rangle / B^2$$

\tilde{E}_r and \tilde{E}_θ being the radial and poloidal components of the fluctuating electric field and B is the toroidal magnetic field. The electrostatic component of the Reynolds stress has been computed neglecting the influence of electron temperature fluctuations.

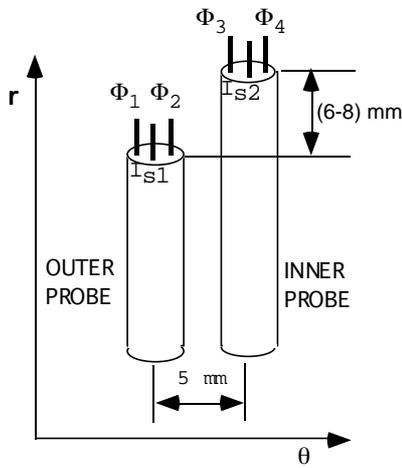


Fig. 1.- Experimental set-up. Probes are radially separated 0.8 cm in the TJ-IU experiment and 0.6 cm in ISTTOK experiments. The probe length is 0.3 cm.

3. Experimental results

In both devices the floating potential becomes more negative and the ion saturation current increases as the probe is inserted into the plasma edge. The level of rms fluctuations in the floating potential fluctuations is rather similar in both devices and is in the range (4-12) V (figure 2). Fluctuations are dominated by frequencies below 200 kHz. As observed in other devices, the radial electric field is sheared in the proximity of the velocity shear layer. From the $S(k, \omega)$ function, computed from the two-point correlation technique using two floating potential signals, the average poloidal phase velocity of fluctuations is defined as, $v_\theta = \Sigma_{\omega, k}(\omega/k)S(\omega, k) / \Sigma_{\omega, k}S(\omega, k)$. In both devices, the poloidal phase velocity of fluctuations reverses from the ion drift direction in the SOL region to the electron drift direction in the plasma edge region (see figure 2). In the proximity of the velocity shear layer ($r = a_{\text{shear}}$) the electron density is about $(0.5 - 1) \times 10^{18} \text{ m}^{-3}$ and the electron temperature is $T_e \approx 20 \text{ eV}$ in

both devices. In the plasma edge region ($r - a_{\text{shear}} \approx 1$ cm) the electron temperature increases up to 50 eV in ISTTOK and up to 30 eV in TJ-IU.

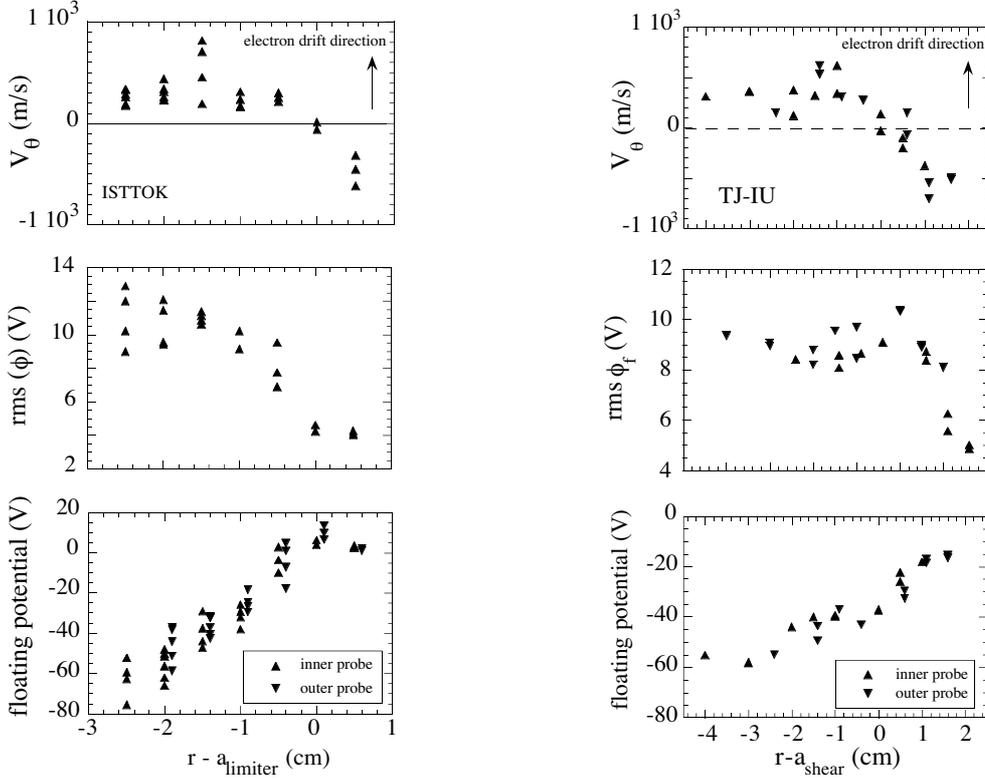


Fig. 2.- Radial profile of phase velocity of fluctuations (v_θ), root mean squared (rms) value of floating potential fluctuations and floating potential in the plasma boundary region of TJ-IU torsatron and in the ISTTOK tokamak.

Figure 3 shows the radial profile of the Reynolds stress in the boundary of the TJ-IU torsatron and ISTTOK tokamak. The Reynolds stress shows a radial gradient in the proximity of the naturally occurring velocity shear layer [4]. The radial gradient in the Reynolds stress is in the range $dR/dr \approx 10^8 \text{ m s}^{-2}$ in both devices. Interestingly, the sign of the Reynolds stress is opposite in TJ-IU torsatron as compared with results in ISTTOK tokamak.

The importance of fluctuation induced flows in the evolution of the poloidal flow requires a comparison with the magnitude of the flows driven or damped by other mechanisms. The damping term due to magnetic pumping in the plasma edge region is $\gamma_{\text{MP}} v_{i\theta}$, where $v_{i\theta}$ is

the ion poloidal velocity. For ISTTOK edge plasma parameters, γ_{MP} is expected to be of the order $v_{ij} \approx 10^4 \text{ s}^{-1}$. Assuming that $v_{i\theta}$ is of the order of the ExB poloidal velocity ($v_\theta \approx 10^3 \text{ m s}^{-1}$), the contribution of magnetic pumping to the time evolution of the poloidal flow is comparable to the contribution of fluctuations via Reynolds stress. The damping of the poloidal rotation due to atomic physics (charge exchange) can be expressed as $v_{iCX} v_{i\theta}$, where v_{iCX} is the momentum loss rate due to charge exchange mechanisms. For typical edge plasma conditions it follows that the contribution of atomic physics to the time evolution of the poloidal flow is in the range of 10^7 m s^{-2} . These results illustrate the importance of fluctuation induced flows in the plasma boundary region of fusion plasmas.

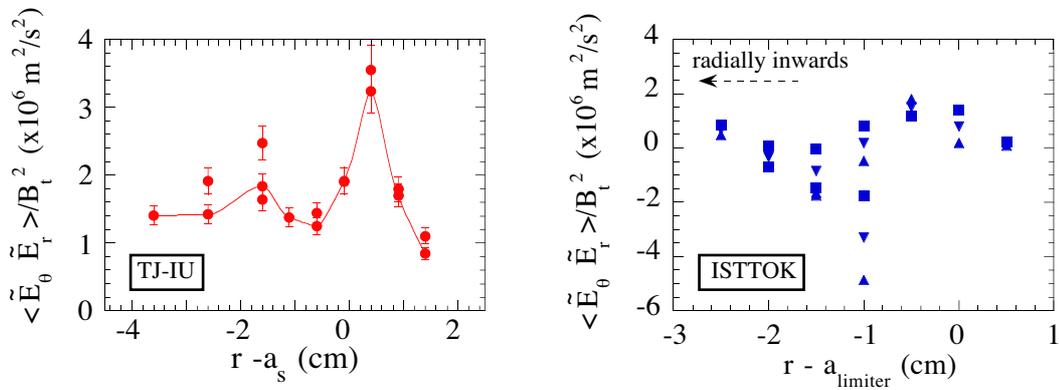


Fig. 3.- Cross-correlation between poloidal and electric field fluctuations in the TJ-IU torsatron and in the ISTTOK tokamak.

4. Conclusions

The experiments carried out in the plasma boundary region of tokamak and stellarator plasmas point out that the electrostatic Reynolds stress shows a radial gradient in the proximity of the velocity shear layer location. These results indicate that this mechanism can generate significant flows in the plasma boundary region of tokamak and stellarator plasmas.

References

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