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Direct experimental evidence of coupling between sheared flows development and increased turbulence levels in the TJ-II stellarator

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I.- Introduction

One of the important achievements of the fusion community has been the development of techniques to control plasma fluctuations based in the shear stabilizing mechanism[1]. When the shearing rate approaches the characteristic frequency of the turbulence, a reduction in the turbulence amplitude is predicted[2]. A large increase in ExB sheared flows play a key role both in edge and core transport barriers[1]. Results emphasize the importance of clarifying the driving mechanisms of sheared flows in fusion plasmas.

A reversal in the poloidal phase velocity of fluctuations (v_θ) has been observed in the proximity of the last closed flux surface (LCFS) in all magnetic fusion devices. Experiments show that the resulting radial gradient dv_θ/dr is comparable to the inverse of the correlation time of fluctuations, suggesting that the naturally occurring shear layer and fluctuations organize themselves to be close to marginal stability[3]. The similarity in the structure of the velocity shear layer in different devices points out to the possible role of turbulence driven mechanisms as a universal ingredient to explain the driving mechanisms of sheared flows in the plasma boundary region[4]. This paper shows that the generation of spontaneous sheared flows is coupled to the increase in the level of edge turbulence.

II.- Experimental set-up

Experiments were carried out in Electron Cyclotron Heated plasmas (P_{ECRH}= 200 kW, B_T = 1 T, R = 1.5 m, $\langle a \rangle \leq 0.22$ m, $\iota(a)/2\pi \approx 1.7 - 1.8$) created in the TJ-II stellarator. Plasma density was systematically modified (on a shot to shot basis) in the range (0.35 – 0.80) x 10^{19} m^{-3}. Radial profiles and fluctuations were simultaneously measured at the plasma edge region using Langmuir probes[5]. With this probe array, it is possible to measure edge plasma profiles in a single shot. The probe signals were digitised at a sampling rate of 500 kHz. Shearing rates of spontaneous sheared flows have been compared with those needed to reduce turbulent transport in biasing induced improved confinement regimes[6]. For the biasing experiments, one limiter was radially localized up to 2 cm inside the LCFS and was biased ($\Delta V_{limiter}$ =160 – 250, $I_{limiter} \approx 30 – 50$ A) with respect to the second mobile outer limiter located in the scrape-off layer region (0.5 cm beyond the LCFS).

III.- Critical density and sheared flows

The influence of plasma density on different plasma parameters has been investigated near the LCFS ($\rho \approx 0.85 – 1.15$). The effect of the iota ($\iota(a)/2\pi$) on the value of the critical density is under study. Preliminary results point to an increase in the critical density as iota increases. Results obtained in plasma configurations with $\iota(a)/2\pi \approx 1.7$ are shown in figure 1. The poloidal phase velocity of fluctuations (perpendicular to the magnetic field and to the radial direction) is computed using the two points correlation technique[7] from two floating potential signals poloidally separated about 0.3 cm.

As plasma density increases, edge ion saturation current and its radial gradient increases, and the floating potential becomes more negative in the plasma edge. Because edge temperature profile (in the range of 20 – 30 eV) is rather flat in the TJ-II plasma periphery[8], the radial variation in the floating potential signals directly reflects changes in the radial electric field (E_r), which turns out to be radially inwards in the plasma edge as density increases above 0.5 x 10^{19} m^{-3}. As shown in figure 1, the resulting radial profile of v_θ is radially flat for plasma density below 0.5 x 10^{19} m^{-3}, whereas above this critical density the poloidal phase velocity reverses and the naturally occurring velocity shear layer appears in the proximity of the LCFS. This phase velocity reversal can be explained, or at least is consistent, in terms of E_rxB drifts (figure 1.c) in agreement with previous results obtained in other devices[9,10]. The link

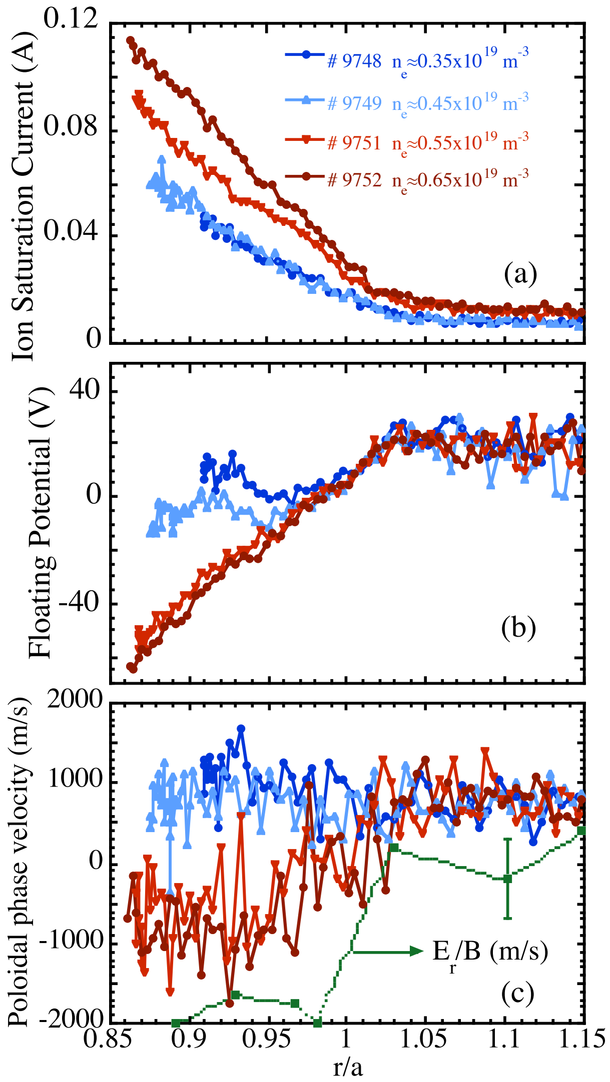

Figure 1

between the development of sheared flows and plasma density in TJ-II has also been observed in other plasma magnetic configurations.

Electrostatic fluctuations produce a fluctuating radial velocity given by $\tilde{v}_r = \tilde{E}_\theta / B$, $\tilde{E}_\theta$ being the fluctuating poloidal electric field and B the toroidal magnetic field. The electrostatic fluctuation driven radial particle flux is given by $\Gamma_{ExB} = < \tilde{n}(t)\, \tilde{E}_\theta(t) > / B$.

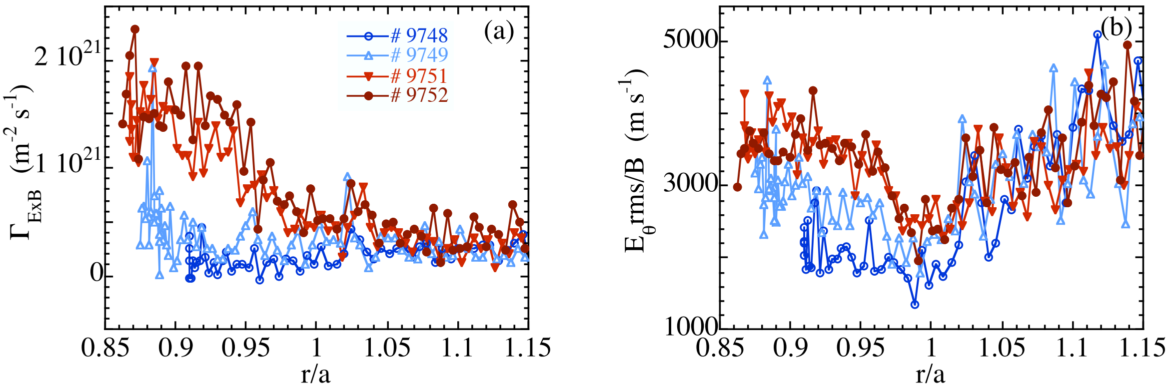

Figure 2

The local ExB turbulent transport (Γ_{ExB}) has been obtained neglecting the influence of electron temperature fluctuations. Radial profiles of turbulent ExB induced transport and root mean squared values of radial velocity fluctuations (i.e. $E_\theta$rms/B) for the same shots as in figure 1 are shown in figure 2. The level of local turbulent transport remains radially rather constant and small in low density regimes. During the development of the shear layer (i.e. above the critical plasma density) Γ_{ExB} increases about a factor of ten in the plasma edge ($\rho \approx 0.9 - 0.95$) whereas Γ_{ExB} decreases when moving radially outwards (Fig. 2.a). Turbulent radial velocity of fluctuations ($E_\theta$rms/B) increases in the plasma edge as plasma density increases (Fig. 2.b).

The magnitude of the spontaneous developed shearing rates have been compared with those measured during biasing induced improved confinement regimes in TJ-II. During the transition to improved confinement regimes induced by limiter biasing a clear reduction in the ExB turbulent flux has been observed in the TJ-II stellarator[6]. The evolution of shearing rates and turbulent velocities with plasma density measured at the plasma edge ($\rho \approx 0.9$) are shown in figure 3. For comparison values measured in biasing induced improved confinement regimes are included (b and d). It is remarkable that the observed shearing rates during improved confinement regimes are (at most) a factor of two larger than those

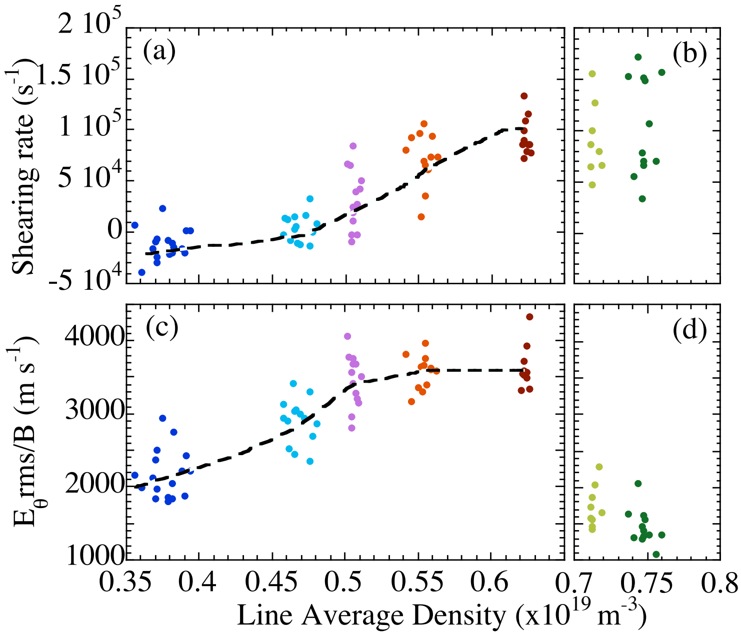

Figure 3

observed associated to the naturally occurring shear layer. This result clearly shows that spontaneous sheared flows and fluctuations are indeed near marginal stability. Simulations have shown that no poloidal flow is generated for a flow damping above a critical value and a minimum value of pressure gradient is needed for a sheared flow to be generated.

IV.- Conclusions

The investigation of the coupling between the generation of sheared flows and turbulence in the plasma boundary region of the TJ-II stellarator has shown that the development of the naturally occurring velocity shear layer requires a minimum plasma density that depends on the iota value. Near the critical density, where the sheared flow is developed, the level of edge turbulent transport and the turbulent kinetic energy significantly increases. The resulting sheared flow is close to the one required to reduce turbulent transport (as measured during biasing experiments), proving that spontaneous sheared flows and fluctuations are near marginal stability. Consistency between experimental findings and transition models based on turbulence driven sheared flows has been found. Present results have a direct impact in our understanding of the physics mechanisms underlying the generation of critical sheared flows pointing out to the important role of turbulent driven flows.

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