Control of the edge turbulent transport by emissive electrode biasing on the tokamak ISTTOK

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Abstract

In this paper results are presented on the changes induced by emissive electrode biasing in the ISTTOK edge transport. The boundary plasma is characterized with focus on the relation between ExB sheared flows and particle transport. We suggest that the distinct behaviour of the particle confinement for positive and negative bias observed in ISTTOK is related with the low ExB shear induced by positive bias in the core periphery region associated with the appearance of large amplitude fluctuations. In addition, the effect of electrode bias on the edge turbulent transport has been investigated identifying the changes induced on the fluctuations frequency spectrum and PDF. We have shown that negative electrode bias reduces the propagation of large-scale events, making the fluctuations distribution more Gaussian and resulting in low amplitude fluctuations across most of the edge plasma region. For positive bias, large amplitude, broad spectrum fluctuations appear in the core periphery, which increase the cross-field diffusion and contribute to the observed asymmetry in particle transport with the bias polarity.

1. Introduction

Emissive electrode biasing experiments have been previously investigated on ISTTOK [1]. Experiments revealed that although a large radial electric field is induced by emissive electrode bias for both polarities (up to ±15 kV/m), a significant improvement in particle confinement is only observed for negative bias. A substantial increase in the plasma density is observed for both polarities; however, positive bias tends to increase recycling. The main motivation for this work is therefore to contribute to the better understanding of the distinct plasma behaviour with positive and negative bias. The boundary plasma was further characterized with focus on the relation between ExB sheared flows and particle transport. The use of emissive electrodes allowed, for the first time, the extension of this investigation to negative bias.

2. Experimental Setup

Two different probe systems are routinely used on ISTTOK for edge plasma investigations: a radial array of probes (rake probe) and a turbulent transport probe. The rake probe consists of a boron-nitride head carrying seven tungsten tips with a spatial resolution down to 4 mm. A second radially movable array of Langmuir probes (turbulent transport probe), consisting of three tungsten pins poloidally separated, measuring the floating potential, V_f, and the ion saturation current, I_{sat}, allows the determination of the cross-field fluctuations induced particle flux, Γ_{ExB}.

A movable emissive electrode has been developed for the biasing experiments in ISTTOK, which consists of a LaB_6 (Lanthanum Hexaboride) disk with a diameter of 16 mm and

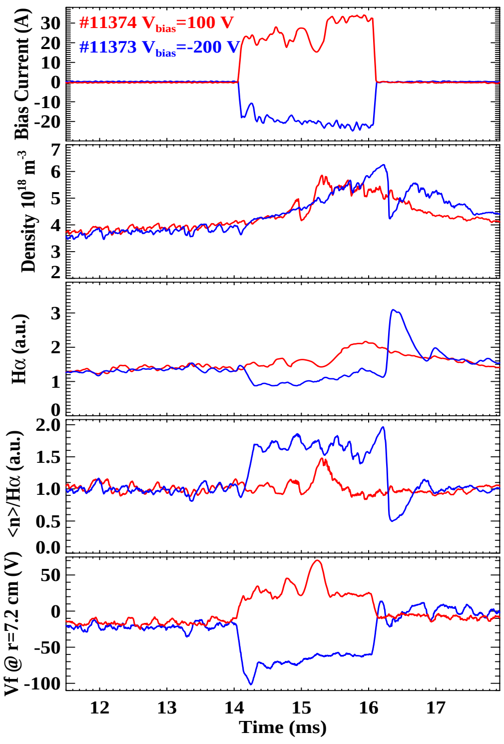

Figure 1: Time evolution the main plasma parameters for positive and negative emissive electrode bias. Bias has been applied at t=14.1 ms during 2 ms.

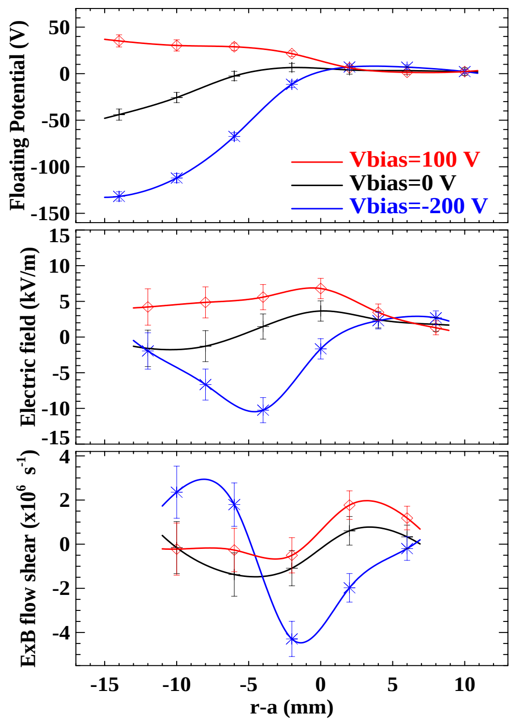

Figure 2: Radial profiles of the floating potential, radial electric field and ExB flow shear for positive, negative and without bias.

covered by a Tantalum cylinder, which is protected by Boron Nitride cup as insulating material to be exposed to the plasma. When heated the electrode emits up to 30 A of steady state current. The bias voltage is applied between the electrode and the vacuum vessel.

3. Influence of emissive electrode bias on the ExB flow profile

3.1 Comparison between positive and negative bias

Emissive electrode biasing experiments have been described in detail before [1]. In this section the plasma behaviour for positive and negative bias is briefly compared for two discharges with similar bias current. The time evolution of the main plasma parameters for a discharge with negative (V_{bias}=-200 V) and another with positive (V_{bias}=100 V) emissive electrode bias is presented in figure 1. The bias voltage is applied at t ≈ 14 ms for 2 ms and the axis of the electrode is located 12 mm inside the LCFS. As the bias is applied, the bias current amplitude increases rapidly to a value around 20 A for both polarities, leading to a strong modification in the radial electric field in the region just inside the limiter.

For negative bias, the line-averaged density increases substantially, $\Delta\bar{n}/\bar{n} \approx 40\%$ and the H_α radiation intensity decreases, $\Delta I_{H\alpha}/I_{H\alpha} \approx -30\%$, leading to an increase of the gross particle confinement time (estimated from the $\bar{n}/H_\alpha$ ratio) by a factor of almost two. As can be seen in figure 1, for positive bias the floating potential is also modified and the plasma density increases in this case too. However, contrary to the results obtained for negative bias, the H_α

radiation also increases during biasing, causing a rather modest increase in particle confinement.

To better characterize the modifications introduced by the electrostatic polarization at the plasma periphery, we have measured the radial electric field, E_r, and the ExB flow shear, γ_{ExB}=dv_{ExB}/dr, radial profiles using the rake probe, figure 2. A detailed description of the E_r determination using probe data may be found elsewhere [1]. As the bias is applied, a large electric field is observed for both polarities, associated with a strong E_r shear. As illustrated in figure 2, the maximum E_r magnitude for positive bias is typically 2-5 kV/m smaller than that observed for negative bias and it is located radially ~4 mm further out. In the region just inside the limiter position the E_r magnitude and more importantly, the magnitude of the ExB flow shear are larger for negative bias. For positive bias, a significant γ_{ExB} is only observed near the LCFS.

The ExB flow shear necessary to suppress turbulence, γ_{ExB}^{crit}, is given by the inverse of the fluctuations autocorrelation time in a region where the ExB shear is near zero [2]. We find that autocorrelation time for both I_{sat} and V_f in the SOL (r-a=6 mm) is typically 3-4 μs and therefore $\gamma_{ExB}^{crit} \approx 3\text{x}10^5$ s^{-1}. For negative bias the ExB flow shear exceeds largely the necessary value for turbulence suppression across the whole region sampled by the probes, while for positive bias this is only clearly true for r-a>-2 mm. This difference may explain the distinct behaviour of the particle confinement for positive and negative bias.

3.2 Dependence of the particle confinement on γ_{ExB}

In this section we will discuss further experiments dedicated to clarify the importance of the ExB flow shear. Different flow shears have been induced in the edge plasma by varying the bias voltage, allowing therefore the study of its importance on particle transport. Figure 3 illustrates the biased induced variation of the gross particle confinement (estimated from the $\bar{n}/H_\alpha$ ratio) as a function of the average ExB flow shear in the region just inside the LCFS. The experimental points presented have been obtained in a wide range of discharges conditions, where the bias voltage has been varied between -200 and + 150 V. It is important to note that using data from a single discharge, E_r is derived with a significant error bar (typically 2-3 kV/m, see figure 2) and therefore the error in the estimation of the ExB flow shear is large. However, the scatter in the data presented in figure 3 is not substantial, allowing the identification of a clear trend. We find that above a certain threshold value of γ_{ExB} (~$1\text{x}10^6$ s^{-1}) an improvement in particle confinement is observed for both polarities, being that value a factor of three larger than the turbulence de-correlation time. Above the threshold value the particle confinement increases roughly linearly with the ExB flow shear, illustrating the close link between these two quantities.

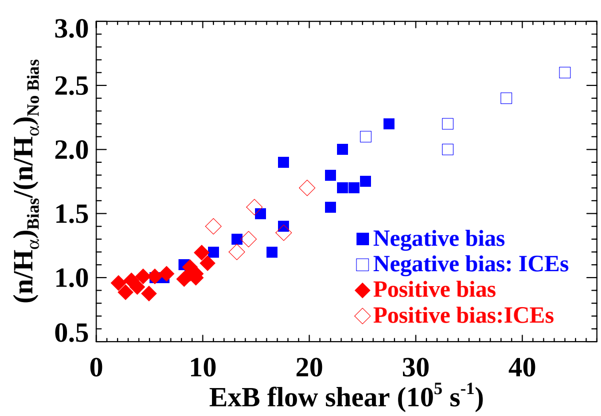

Figure 3: Dependence of the modification in particle confinement induced by electrode biasing with the ExB flow shear in the region just inside the LCFS.

The behaviour at low applied voltages is distinct for the two polarities. While for negative bias a degradation in confinement has never been observed, for low positive bias ($50<V_{bias}<80$ V) the magnitude of the ExB flow shear in the core periphery is often reduced in relation to the case without bias leading to a small degradation in particle confinement.

It is routinely observed in the ISTTOK emissive electrode biasing experiments that above a certain threshold bias current (~20 A) improvement confinement events (ICEs) are observed where a further increase in E_r is seen during a short period (~0.1-0.3 ms) [1]. During the ICEs both the particle confinement and the ExB flow shear increase significantly, highlighting again the correlation between these two quantities. Data obtained during ICEs are also shown in figure 3 as open symbols. These experimental points fit well into the steady-state data, expanding the operational space. For positive bias, a significant improvement in particle confinement is only observed during ICEs and therefore no steady state confinement enhancement has been obtained.

4. Emissive electrode bias effect on the edge plasma fluctuations

Edge plasma biasing strongly modifies the fluctuations in the boundary plasma, being the changes distinct in the SOL and in the core periphery. In order to better understand the modification in transport induced by biasing, the statistical properties (RMS, skewness and kurtosis) of the particle flux fluctuations, $\tilde{\Gamma}_{ExB}$, have been investigated across the ISTTOK boundary plasma and are summarized in figure 4. Also shown is the radial profile of the average turbulent particle flux, $\langle \Gamma_{ExB} \rangle$. A strong reduction in the average radial transport is observed across the SOL and in the region just inside the limiter as commonly observed in electrode biasing experiments [e.g. 3]. As we move towards the centre we observed that the reduction in transport is larger for negative bias, being an increase even seen for positive bias at the inner most position. It is important to note that the biased induced variation in the $<\Gamma_{ExB}>$ radial profile is broadly consistent with that of the ExB flow shear for both polarities (see figure 2).

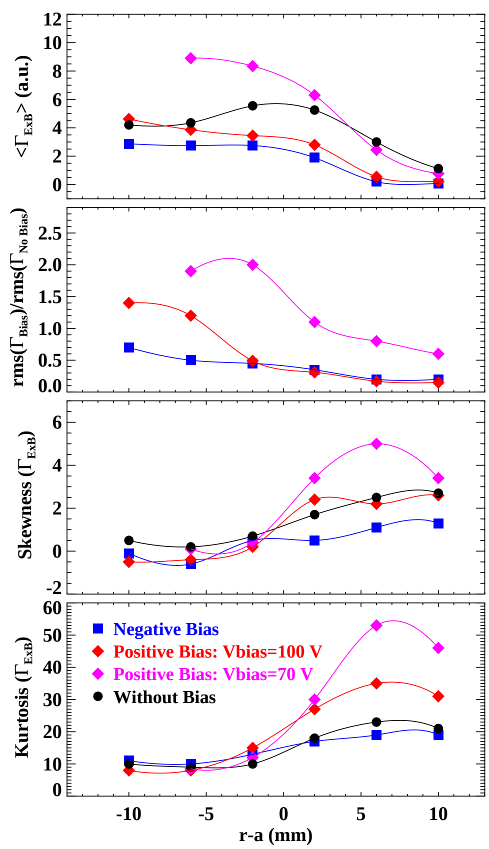

Figure 4: Radial profiles of the particle flux statistical properties for positive, negative and without bias.

Due to the strong intermittent character of the SOL parameters, the skewness and the kurtosis of the Γ_{ExB} fluctuations are large in this region, decreasing as we move towards the plasma centre. Negative edge biasing reduces the RMS, the skewness and the kurtosis of the $\tilde{\Gamma}_{ExB}$ distribution, particularly in the SOL, resulting in low amplitude near symmetric fluctuations across most of the scanned region. Negative bias makes therefore the distribution of the Γ_{ExB} fluctuations more Gaussian. Positive bias also reduces strongly the RMS of the flux fluctuations in the SOL, however, contrary to the observed for negative bias, an increase in the kurtosis is induced. In the core periphery $\tilde{\Gamma}_{ExB}$ exhibits a clear increase in its RMS value for positive bias, associated with a reduction of the skewness and the kurtosis. Note that in spite of the large increase in the fluctuation observed at r-a=-10 mm for positive bias the increase in the average transport is modest as large inwards transport events are induced.

5. Reynolds stress radial profile

Turbulent Reynolds stress plays a linking role between the turbulence and averaged flows [4]. It was found previously on ISTTOK that sheared poloidal flows can be generated in fusion plasmas due to radially varying Reynolds stress [5]. The Reynolds stress measures the degree of anisotropy in the structure of fluctuations. We expect therefore that the Reynolds stress profile is modified by biasing as the latter changes the characteristics of the edge fluctuations.

The electrostatic component of the Reynolds stress, Re, is given by $\mathrm{Re} = \left\langle \tilde{E}_r \tilde{E}_\theta \right\rangle / B$, where $\tilde{E}_r$ and $\tilde{E}_\theta$ are respectively the fluctuations in the radial a poloidal electric field, [5]. The radial and poloidal electric fields have been determinate using an array of Langmuir probes with pins separated radially and poloidally measuring the floating potential. It is typically observed that E_θ exhibits fluctuations with an average frequency higher than that of the E_r fluctuations. This different behavior of the fluctuations results probably from the large poloidal plasma rotation observed on the ISTTOK boundary plasma. Figure 5 shows the Re radial profile for discharges with positive, negative and without biasing. As observed previously on ISTTOK, the electrostatic component of the Reynolds stress shows a significant radial gradient ($\sim 10^8 ms^{-2}$) in the proximity of the velocity shear layer location [5]. We observe that biasing modifies the Re profile, being the changes different in the SOL and in the core periphery. In the SOL, Re is reduced for both polarities as a consequence of the strong reduction in fluctuations in this region. In the core periphery, an increase in dRe/dr is observed during biasing, particularly for negative biasing. Finally, in the region around the limiter position, dRe/dr is observed to increase significantly for negative bias and to decrease for positive bias.

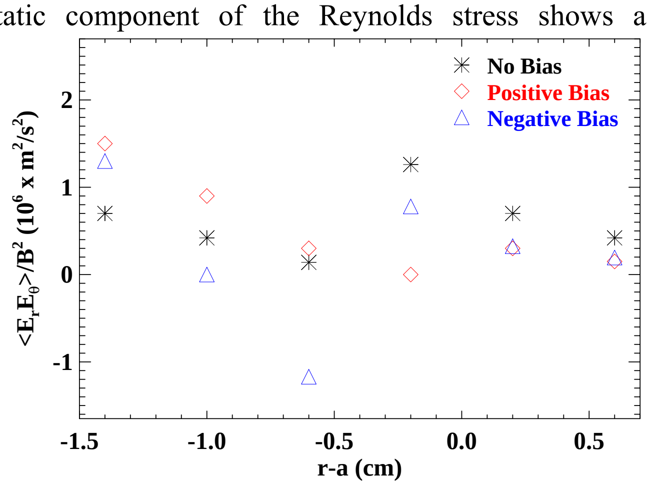

Figure 5: Radial profile of the electrostatic Reynolds stress in the plasma boundary region of the ISTTOK tokamak with positive, negative and without biasing.

6. Summary

In this work, the ExB flow shear has been estimated and we have observed that the ExB sheared flows induced by negative bias exceeds significantly the turbulence de-correlation time across most of the boundary plasma, while for positive bias this is only valid near the

LCFS. The importance of the ExB flow shear on the global particle confinement has been demonstrated by the good correlation between these two quantities for both polarities in a wide range of bias conditions. Results support therefore that the distinct particle confinement behaviour observed for positive and negative bias is related with the different ExB flow profile induced by edge biasing.

The effect of electrode bias on the edge turbulent transport has been investigated and we have shown that negative electrode bias reduces the large-scale events, resulting in low amplitude fluctuations with a near Gaussian distribution across most of the scanned region. For positive bias, a substantial reduction of the fluctuations is also observed in the SOL. However, large amplitude, broad spectrum fluctuations appear in the core periphery, which increase the cross-field transport and cause the observed asymmetry in particle confinement with the bias polarity. Finally, the electrostatic Reynolds stress was measured in the boundary plasma and results show that its radial gradient is reduced in the SOL and increased in the core periphery for both polarities.

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