Edge biasing experiments in RFX

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The existence of a spontaneous sheared plasma flow in the edge region of reversed field pinch (RFP) plasmas has been recently documented [1]. The shear of the **E**×**B** drift velocity has been found to be in a marginal situation for providing decorrelation of the electrostatic turbulence [2], although some evidence of a beneficial effect on the transport driven by electrostatic fluctuations has been put forward [2].

In this paper we report the results of edge biasing experiments performed on the RFX machine (R = 2 m, a = 0.457 m) aimed at modifying plasma rotation in the external region of the plasma. Two electrodes, whose characteristics are described in detail elsewhere [3], have been inserted into the plasma. Most of the data refer to an insertion at r/a=0.81. The electrodes have a carbon-carbon composite head whose diameter is 70 mm, placed in a shaft protected by a boron nitride tube. A set of capacitor banks provided up to 10 kA per electrode with a half wave sinusoidal pulse of duration around 10 ms, biasing the electrodes at a negative potential with respect to the vacuum vessel. The electrodes were located in two different toroidal positions (φ = 142° and 322° respectively). The duration of the electrode operation was chosen as an intermediate value between the plasma discharge length (which was typically 60 ms for the present conditions) and the typical particle and energy confinement times, which are around 1 ms.

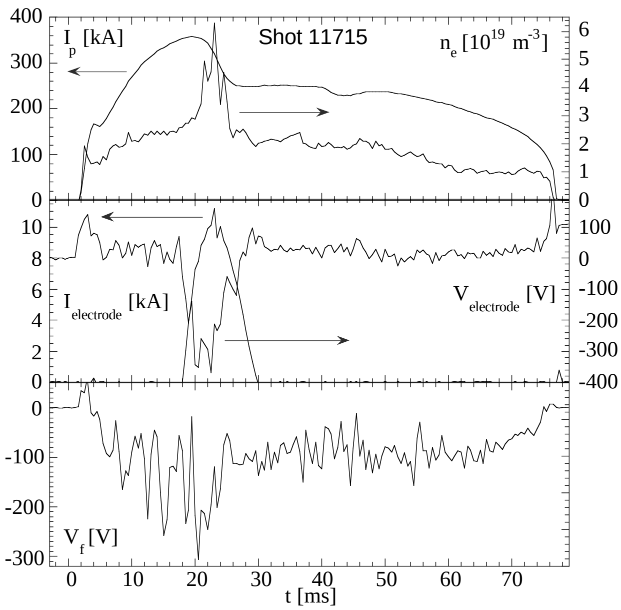

Fig.1: Plasma waveforms in an edge biasing experiment.

An example of a discharge where biasing was applied is shown in fig.1. In this case the electrode was acting in the interval 18-30 ms. In the first frame the plasma current I_p and the line-averaged electron density n_e are shown. In the second frame the current and the voltage of one of the two electrodes can be seen. In the last frame a floating potential measurement at r/a = 0.90 is shown. The floating potential becomes more negative during the electrode action. The plasma current undergoes a drop when the electrode is activated, in correspondence to an increase of the average density. This behavior has been interpreted as an increase of the plasma resistivity due to the plasma cooling occurring because of the sudden density rise. A detailed particle balance analysis is in progress to relate this density increase to the transport modification.

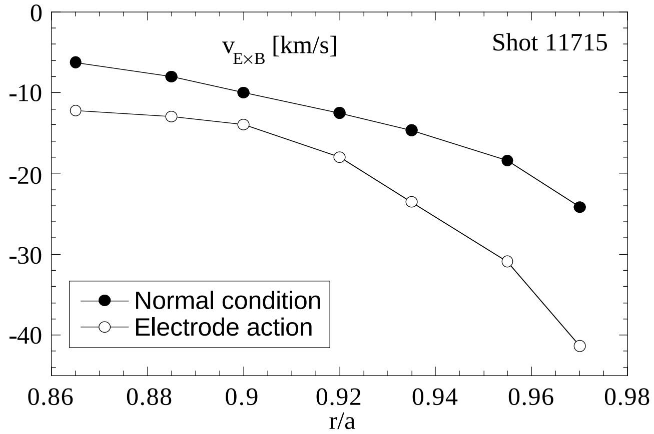

Fig.2: **E**×**B** velocity profile before and during edge biasing.

The change in the radial electric field profile induced by the biasing has been monitored by a rake probe, made up of seven pins measuring the floating potential V_f at $\varphi = 217°$ and at 7 different radial positions spaced by 8 mm. The derivative of the resulting profile can be assumed to be representative of the radial electric field and of its change, since the electron temperature gradient and its change due to the biasing are small. The resulting **E**×**B** velocity profile in standard conditions and during the electrode action is shown in fig.2. The velocity shear $dv_{\mathbf{E\times B}}/dr$ in the region $r/a > 0.92$ is almost doubled during the biasing, reaching values as high as 1.5×10^6 s^{-1}.

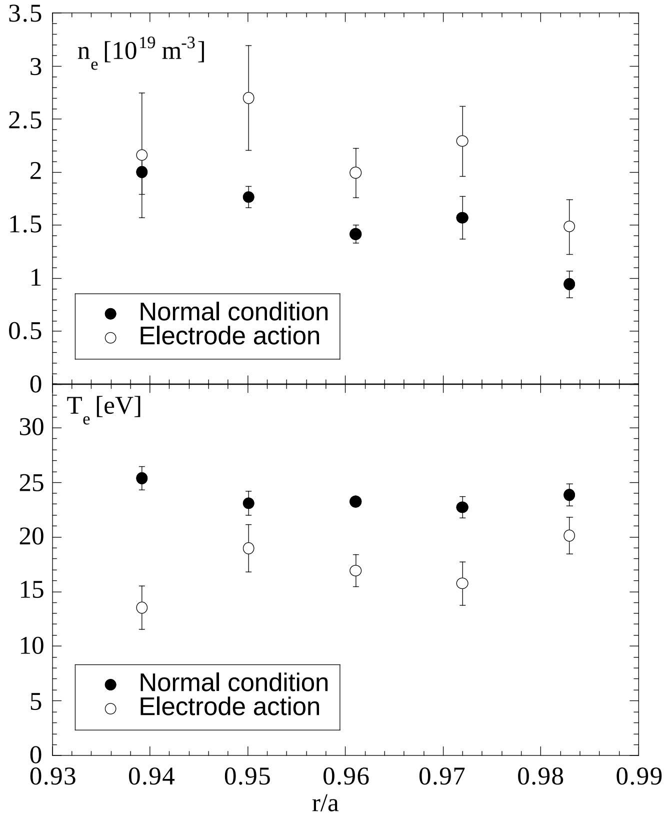

Fig.3: Profiles of electron density and temperature before and during the edge biasing.

The change in the edge density and temperature profiles during edge biasing, measured by a triple probe located at $\varphi = 247°$, is shown in fig.3. The edge density is increased, an observation consistent with the rise of the average plasma density. The edge density gradient remains almost unchanged in the region spanned by the probes. The edge electron temperature, measured by the triple probe, is reduced by the electrode action, probably as a consequence of the increase in density. The profile, which was rather flat in normal conditions, remains flat. Thus, the edge pressure gradient is unchanged by the biasing. An important consequence of this is that the diamagnetic velocity, which, according to the present data, is around 6 km/s, does not change. It is therefore possible to conclude that the beneficial effects on the particle transport reported below are due solely to the **E**×**B** velocity.

The effect of the edge biasing on plasma rotation has been assessed by looking at the CIII toroidal rotation velocity measured by the Doppler shift of the 229.6 nm line [4]. As shown in fig.4, during the electrode action the CIII toroidal velocity is doubled, consistently with the doubling of the **E**×**B** velocity. It has been evaluated that the CIII ion population is distributed in the region 0.9<r/a<1, so that this velocity change is consistent within a factor of two with the average value and change of the **E**×**B** velocity in the same region. Since the electron temperature is almost constant during the edge biasing, the effect on the CIII velocity change is not associated to a change in the radial localization of this impurity.

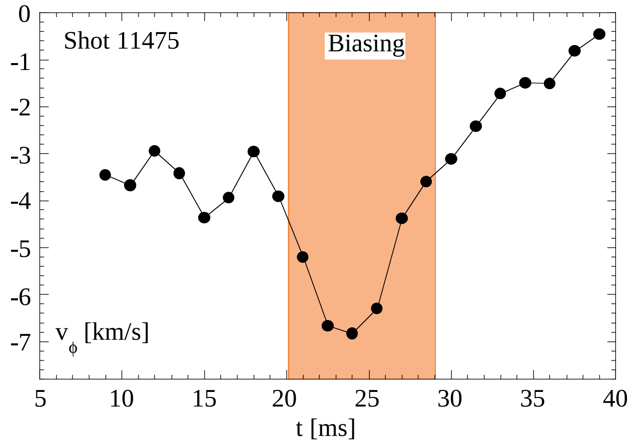

Fig.4: Toroidal velocity of CIII impurities.

The electrostatic particle flux is strongly affected by the increase of the velocity shear. The graph in fig.5 shows the frequency-resolved flux measured at r/a = 0.97. The measurement has been carried out with a 5-pin balanced triple probe and a V_f measuring pin 44 mm toroidally (i.e. cross-field) apart from the triple probe. Therefore the flux includes the effect of temperature fluctuations. The data, which are averaged over several discharges, show that the edge biasing reduces the edge particle flux driven by electrostatic turbulence over the whole frequency range. The frequency at which the flux peaks is almost unchanged. The summed particle flux is reduced from 6.6×10^{21} $m^{-2}s^{-1}$ to 2×10^{21} $m^{-2}s^{-1}$, i.e. to 30% of its original value. This result is confirmed by measurements made in other radial positions of the region where the velocity shear is increased. The energy flux driven by electrostatic turbulence,

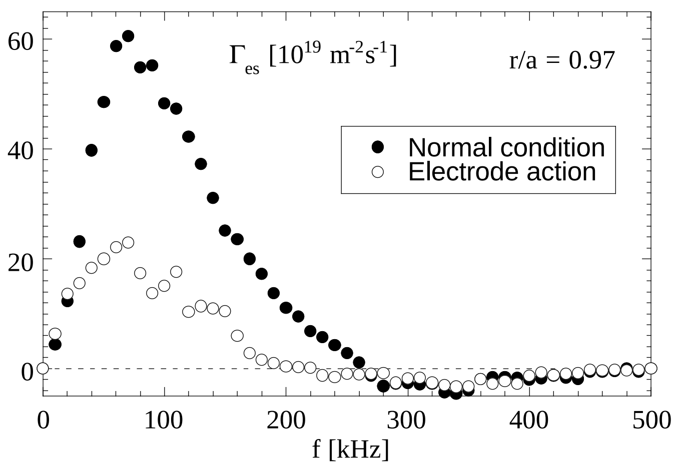

Fig.5: Frequency resolved particle flux before and during the edge biasing.

which in the RFX edge is convective and accounts at most for 30% of the total transport losses [5], remains convective during the biasing, so that it is reduced by the same fraction as the particle flux.

The main origin of the particle flux reduction is a change in the cross-phase $\alpha_{n\phi}$ between plasma potential and density [6]. An example of this is shown in fig.6, where sin $\alpha_{n\phi}$ resulting from wavelet analysis using the Morlet wavelet [7] is plotted as function of time and frequency. The graph clearly shows that during the biasing, which takes place between 20 and 30 ms, the sine of $\alpha_{n\phi}$ is reduced from a value very near to 1 to values near to 0 in the frequency range relevant for transport (10-200 kHz). A possible theoretical ground for the observed phase change induced by the velocity shear can be found in [8], where this effect is predicted for resistive pressure-gradient-driven turbulence. If confirmed, this would indicate that g-modes could play an important role in the RFP edge physics driving electrostatic turbulence. Indeed, these modes have long been considered as a principal candidate for RFP edge turbulence [9].

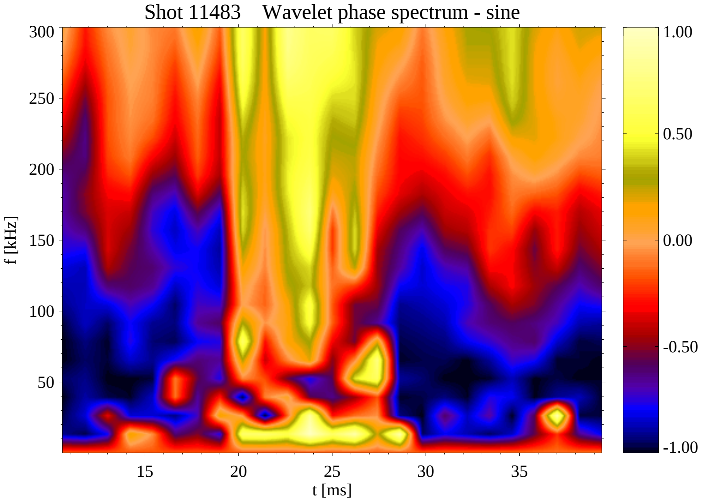

Fig.6: Sine of the relative phase between density and potential as a function of time and frequency (wavelet analysis).

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