ALTERNATING LIMITER BIASING EXPERIMENTS
ON THE TOKAMAK ISTTOK

J.A.C. Cabral, H. Figueiredo, B. Gonçalves, I. Nedzelskii, V.V. Plyusnin,
C. Silva and C.A.F. Varandas

Associação EURATOM/IST, Centro de Fusão Nuclear
Instituto Superior Técnico, 1049-001 Lisboa, Portugal

1. Introduction: ISTTOK is a large aspect ratio circular cross-section tokamak (major radius R=46 cm, limiter radius a=8.5 cm, vessel radius b=10 cm, B_T=0.6 T, ∆Φ=0.22 Vs), which has two small localized limiters, one at the horizontal external and the other at the vertical up positions.

Taking a typical ISTTOK discharge (I_p~4-8 kA, τ_D~30-40 ms, n_e(0)=3-6x10^{18} m^{-3}, T_e(0)=100-180 eV, τ_E~0.5 ms, β~0.5 %, q(0)~1, q(a)~5) as a reference, we have made studies similar to those already published in [1], concerning the enhancement (reduction) of the plasma confinement and stability by negative (positive) DC limiter biasing. In this paper we have used an alternating biasing voltage (50 Hz, 80-130 p.V) provided by a transformer. The aim of this work is, not only to confirm, in a single shot, the formerly reported results, but also to determine biasing thresholds for stability and confinement modifications.

2. Experimental results: (I) – Analysis of a large set of moderately biased (V_B~115 p.V) low density (n_e~3x10^{18} m^{-3}) low magnetic field (B_T=0.45 T) discharges has shown that, during the positive (negative) bias half-cycle, we may observe: (i) – an electron (ion) saturation current, I_s, attaining a value of the order of -12 (1) A (Fig. 1a); (ii) - a decrease (increase) of the plasma current, I_p, (Fig. 1b) and of the electron temperature, T_e, (Fig. 1c), (iii) - an increase (decrease) of the line averaged electron density, <n_e>, (Fig. 1d) and of the intensity of the H_α radiation, (Fig. 1e). (iv) - a decrease (increase) of the ratio n_e/H_α, suggesting degradation (enhancement) of particle confinement. Further, we note that there is usually a delay of about 3-4 ms between the observed modification of the behaviour of the plasma parameters and the instant of biasing polarity switch. (II) - For larger biasing voltages (V_B~130 p.V) on higher density (n_e~6x10^{18} m^{-3}) high B-field (0.6T) gas puffing discharges, the general parameter behaviour, for positive biasing, is similar, although with a somewhat lesser density growth. However, for negative biasing, the following effects were observed: (i) - the plasma density starts to grow in the middle of the negative biasing period (Fig. 2a); (ii) – the transition from a negative biasing half-period to a

Fig. 1 – Evolution of the main discharge parameters in shot #9469
positive one is made without significant loss of plasma confinement. On
the contrary, the inverse transition (positive to negative biasing) impairs
the discharge parameters, specially the plasma
density, which drops considerably afterwards
(Fig. 2b).

With the Heavy ion
Beam Diagnostic, using a
22 keV-0.7 µA Xe +
primary beam and a
multiple cell array
detector, the radial profiles
of the product \( n_e \sigma_{\text{eff}} \) were measured. The amplitude of these profiles shows good temporal
correlation with that of \( <n_e> \). Figure 3 shows the time evolution of the \( n_e \sigma_{\text{eff}} \) profile for an AC
biased low density discharge. We stress that, due to fact that the central electron temperature
is relatively low, \( \sigma_{\text{eff}} \) is almost proportional to \( T_e \) and that, therefore, the presented profiles are
more accurately related to the electron pressure, \( n_e kT_e \). This discharge clearly reveals the increase (decrease) of the “plasma density” for positive (negative) bias, formerly observed for
\( <n_e> \). Further, we observe the gradual passage from a large amplitude peaked profile at \( t=16 \)
ms (positive bias) to a much lower amplitude and flatter profile, at \( t=24 \) ms (negative bias).
The profile for \( V_B=0 \) (\( t=20 \) ms) has an intermediate amplitude and shape. We notice that the plasma column is temporarily shifted upwards (by ~0.7 cm) during positive biasing, and that it regains a centered position for negative biasing. This vertical shift has already been reported
in [1], by the analysis of the sin-cos coils signals, during a pulsed DC biased discharge.

An array of Langmuir
probes, toroidally located at
about 180° from the limiter, has
been used to study the influence of biasing on the
boundary plasma. Figure 4
shows the limiter current (a),
the floating potential (b),
the ion saturation current, \( I_{\text{sat}} \) (c)
and the cross field turbulent
flux (d), for five discharges,
corresponding to different
radial probe positions. The signals have been shifted in
time so that they became synchronised with the biasing
voltage. From this figure we
may note that: (i) - the floating
potential, \( V_{f} \), follows the biasing voltage, for the
discharge latter stages; (ii) - for negative biasing, the floating potential is a monotonously decreasing function of the probe penetration into the plasma, (a-r), a being the limiter radius. (iii) - for positive bias the floating potential profile is always positive, with a maximum at a-r=10 mm. The plasma potential profiles could be determined if $T_e(r,t)$ would be known. Measurements have shown that $T_e$ is of the order of 10 eV in the edge plasma. Therefore, the plasma potential is always positive in the analysed region. Due to the decrease of $T_e$ with radius, a poloidal drift velocity shear will always exist, independently of the bias voltage. For positive bias this shear seems to exist in the main plasma, at a-r=10 mm; (iv) - for negative bias the location of the shear will depend on the $T_e$ radial profile; (v) - in general, the $I_{sat}$ evolution follows that of $<n_e>$. (vi) – this current, for positive bias, almost doubles the value measured for the opposite polarity; (vii) – $I_{sat}$ (a measure for the edge plasma density), inside the main plasma (a-r>5 mm), clearly increases (decreases) for positive (negative) bias. However, in the edge plasma (0<a-r<-4 mm), $I_{sat}$ also increases for large negative voltages. This leads to a flatter edge density profile, in comparison with the more peaked ones obtained for positive biasing.

The turbulent particle transport, $\frac{G_{ExB}}{\theta} = \Gamma$, has been also computed from the probe data (Fig. 4d). The behaviour of the cross-field particle flux, during biasing, is similar to that of $I_{sat}$. For positive bias, particle losses in the scrape-off layer are strongly reduced while, in the main plasma, they are strongly increased. Therefore, the particle flux profile is very steep, leading to a large density gradient. When the applied voltage goes from positive to negative, the particle losses are strongly reduced inside the limiter and increase in the scrape-off layer, leading to flatter edge density profiles.

Figure 5a shows a typical spectrogram of the ion saturation current fluctuations as well as the evolution of the limiter current. Spectral analysis of both $I_{sat}$ (Fig. 5b) and $\Gamma_{ExB}$ (Fig. 5c), in the main plasma (a-r=10 mm), shows a large increase of the turbulence level for positive bias, in particular for frequencies between 20 and 50 kHz, when compared with results obtained for negative bias. Bi-coherence spectra, $b = \frac{E[X(\omega_1)X(\omega_2)Xconj(\omega_1+\omega_2)]}{(|E[X(\omega_1+\omega_2)]|E[X(\omega_1)X(\omega_2)])}$, reveals an important energy exchange between high frequency and low frequency modes, for positive biasing (Fig. 6a). For negative biasing these energy exchanges are less relevant (Fig. 6b).

Thresholds for confinement and stability improvement or degradation were determined. Results have shown that confinement modifications require a biasing voltage of the order of 30-40 V ~ 3-4 $kT_e(a)/e$. This is mainly seen in the time dependence of the plasma density,
which only reaches a minimum or a maximum a few ms after the biasing polarity switch. For the electron temperature, the biasing effect is usually suppressed 3-4 ms before the polarity reversal. Thresholds for other physical processes, such as modifications of the MHD activity were seen to be of the same order of magnitude.

3. Conclusions: The results presented above have shown that positive (negative) bias has lead to a lower (higher) ratio $n_e/H_\alpha$, thus to a degraded (improved) confinement. In what concerns plasma stability, positive (negative) bias has also lead to a poor (better) plasma column behaviour, revealed by an increase (decrease) of the magnetic as well as the electrostatic fluctuations, translated by an increase (decrease) of their spectral width and amplitude and of the frequency of the dominant tearing modes. Further, this work has shown that successful biasing experiments require voltages in excess of 3-4 $kT_e(a)/e$. Experiments with ramp-up and ramp-down biasing voltages will be performed to analyse, in detail, the plasma behaviour on the two types of biasing polarity switch.

References