Electrode and Limiter Biasing Experiments on the Tokamak ISTTOK

C. Silva, H. Figueiredo, J.A.C. Cabral, , I. Nedzelsky, C.A.F. Varandas
Associação Euratom/IST, Centro de Fusão Nuclear, Instituto Superior Técnico, 1049-001 Lisboa, Portugal

E-mail address of main author:csilva@cfn.ist.utl.pt

Abstract: In this contribution limiter and electrode biasing experiments are compared, in particular in what concerns their effects on the edge plasma parameters. For electrode AC bias a substantial increase (>50%) in the average plasma density is observed with positive voltage, without significant changes in the edge density, leading to steeper profiles. The ratio n_e/H_α also increases significantly (>20%), indicating an improvement in gross particle confinement. The plasma potential profile is strongly modified as both the edge E_r and its shear increase significantly. For positive limiter bias an increase in the average plasma density and the radiation losses is observed, resulting in almost no modification, or a slight, in particle confinement. Preliminary results of simultaneous electrode and limiter bias experiments show that the control of the plasma potential profile is very limited, since negative voltages do not modify the plasma parameters significantly.

1. Introduction

Radial electric fields (E_r) and the ExB velocity shear at the edge region are well known to play an important role in plasma confinement and transport. A technique used for the modification of the radial electric field consists in biasing plasma facing components like limiters or inserting biased electrodes in the edge plasma [1]. Biasing experiments performed in several devices (CCT [2], TEXTOR [3] and ISTTOK [4,5]) in the past decade have shown that biasing can modify the edge electric fields allowing the control of not only important aspects of the plasma-wall interaction as edge plasma profiles, particle exhaust and impurities retention, but also global properties as particle confinement. Furthermore, biasing has contributed significantly to the understanding of the improved confinement regimes such as the H-mode. H-mode has been triggered using biasing [2,3], proving the importance of the radial electric field in the transition to improved confinement regimes.

Limiter and electrode biasing experiments have been performed on tokamak ISTTOK in order to control the edge radial electric field and investigate its impact on confinement. In addition to the constant bias voltages used in most biasing experiments [1-3], AC bias has also been investigated on ISTTOK. In this paper, two different bias configurations, limiter and electrode, are compared in the same device, in particular in what concerns their effects on the edge plasma parameters.

2. Experimental Setup

ISTTOK is a large aspect ratio circular cross-section tokamak (R=46 cm, a=8.5 cm, B_T~0.6 T, $\Delta\Phi$=0.22 Vs), which has two small localized limiters, one at the horizontal external and the other at the vertical up positions.

An array of Langmuir probes, toroidally located at about 180º from the limiter, has been used to study the influence of biasing on the boundary plasma. This array consists of two sets of three Langmuir probes, radially separated by 4 mm. Two tips of each set of triple probes, separated poloidally (3 mm), were used to measure the floating potential, V_f. The third tip was biased at a fixed voltage in the ion saturation current regime, I_{sat}. Measurements were taken at different radial positions in a series of similar and reproducible plasma shots.

A movable electrode has been developed for biasing experiments on ISTTOK [6]. The electrode head is mushroom shaped and made of 2-D Carbon composite, having a height of 6 mm and a diameter of 20 mm, screwed to a stainless steel shaft, that is protected by boron nitride as insulating material to be exposed to the plasma. Different bias configurations have been studied on tokamak ISTTOK: Limiter bias (LB), Electrode bias (EB) and simultaneous EB and LB. Both DC (from -250 V to + 160 V) and alternating (50 Hz, 80-130 p.V) bias voltages have been used. AC bias has the advantage of allowing the investigation of the effect of two polarity biasing in a single shot. In the experiments reported here, the bias voltage is applied between the limiters/electrode and the vacuum vessel and the electrode tip is situated at r=7 cm (1.5 cm inside the limiter). A transformer is used to provide the alternating voltage and the phase is not synchronised with the discharge timer.

Taking a typical ISTTOK discharge (I_p~4-8 kA, τ_D~30-40 ms, $n_e(0)$~5-10x10^{18} m^{-3}, $T_e(0)$~150-250 eV, τ_E~0.5 ms, β~0.5 %, q(0)~1, q(a)~5) as a reference, we have made studies concerning the influence of limiter and electrode biasing on plasma confinement and stability.

3. Electrode Biasing

3.1 AC Bias Voltage

The time evolution of the plasma parameters during a discharge with AC electrode biasing is illustrated in figure 1. Analysis of a set of discharges with AC EB has shown that during the positive (negative) bias half-cycle, we may observe: (i) - a decrease (increase) of the plasma current, and of the electron temperature, (ii) - an increase (decrease) of the line averaged electron density, n_e, and of the intensity of the H_α radiation. The drop in the plasma current and electron temperature observed for positive bias is possibly a consequence of the rise in the radiation losses induced by the large increase in electron density and by the accumulation of impurities. The transition from a positive biasing half-period to a negative one impairs the discharge parameters, specially the plasma density, which drops considerably afterwards.

Changes in the gross global particle confinement time, τ_p, are inferred from the ratio of the line-averaged density to the H_α intensity, which is a rough estimation of τ_p. For large positive applied voltage, V>100 V, a substantial increase (>50%) in n_e is observed, without significant changes in the edge density, leading to steeper profiles. These results are corroborated by the Heavy Ion Beam diagnostic data, which shows steeper $n_e\sigma_{eff}$ profiles (where σ_{eff} is the effective cross section of the ionisation process) for positive bias when compared with negative bias, particularly at the plasma edge. Although the H_α radiation increases, the ratio n_e/H_α also rises significantly (>20%) indicating an improvement in gross particle

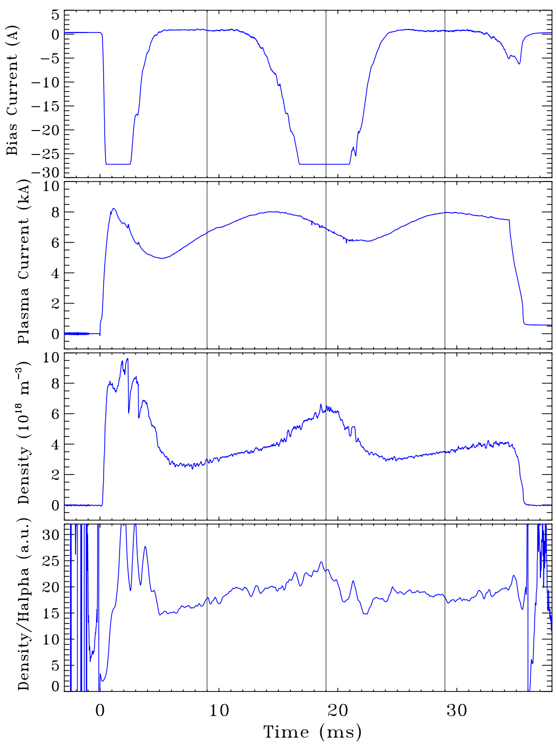

FIG. 1. Time evolution of the main plasma parameters during a alternating electrode bias discharge (V_{bias}=120 p.V).

confinement. Both the average density and the particle confinement decay rapidly after the applied voltage starts to decrease and do not vary significantly for negative bias.

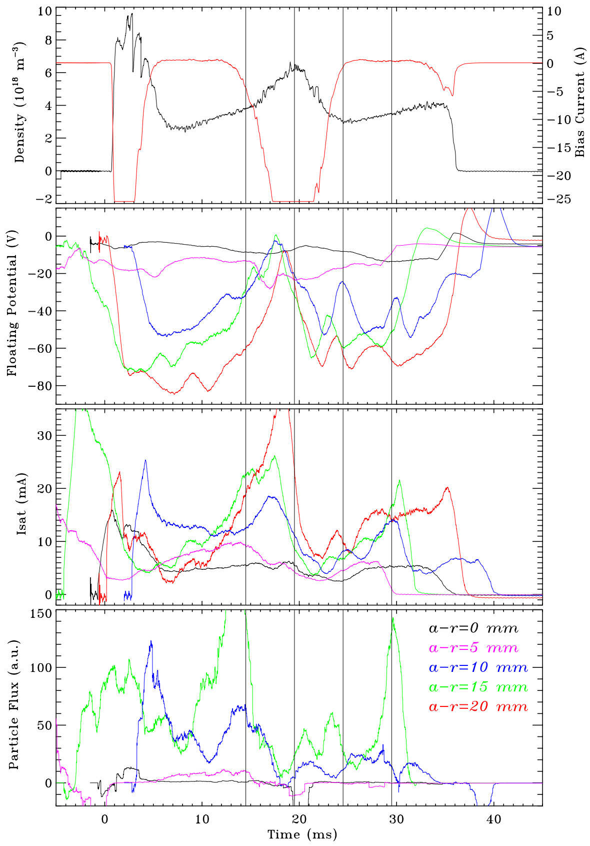

FIG. 2. Time evolution of the edge plasma parameters for a series of discharges with electrode bias.

Figure 2 shows the time evolution of bias current together with n_e, I_{sat}, V_f and the cross-field turbulent flux ($\Gamma_{ExB} = \langle \tilde{n}\tilde{E}_\theta \rangle / B$, where E_θ is the poloidal electric field and B is the toroidal magnetic field), 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. The floating potential near the electrode follows the applied voltage while close to the limiter the opposite behaviour is observed. The V_f profile is strongly modified by electrode bias. For V_{bias}<80 V, V_f is a monotonously decreasing function of the probe penetration into the plasma, while for V_{bias} >80 V a clear inversion is observed. The plasma potential (derived from $V_p = V_f + 3T_e$) profile is very flat for negative and zero applied voltage, while for positive bias a large electric field is observed just inside the limiter (values of E_r larger than 8 kV/m are measured) associated with a strong E_r shear ($dv_{ExB}/dr \approx 3 \times 10^6$ s^{-1} at r-a=-5 mm). During bias, the radial electric field is not strongly affected by temperature uncertainties because the contribution of the V_f gradient is larger than that from the temperature gradient.

Although the average density increases strongly up to t=19 ms, I_{sat} at the limiter position is observed to decrease for t>14.5 ms. This behaviour seems to propagate inwards; probes at a smaller radius observe this reduction later, leading to progressively steeper profiles. In contrast, the turbulent transport is observed to reduce strongly in the whole edge simultaneously, reaching its minimum at t=18.5 ms, when E_r and the E_rxB velocity shear attain their maximum. Results suggest that positive bias creates a region with strong ExB velocity shear inside the limiter, which may explain the strong reduction in turbulent transport and the improvement in particle confinement observed during that period.

3.2 DC Bias Voltage

Time evolution of two discharges, one with DC electrode bias (V_{bias}=120 V) and another with no bias is presented in figure 3. For the discharge shown, the bias consists of a square-wave with a period of 12 ms. The most striking change in the core parameters as a result of EB biasing is the large increase in the line average density. The density rise is accompanied by a temperature decrease and an increase in the radiation losses. A modest enhancement in confinement is observed, which is followed (~3 ms later) by a confinement degradation, probably as a consequence of the large increase in the radiation losses. These results are corroborated by probes measurements, which show a decrease in turbulent particle transport

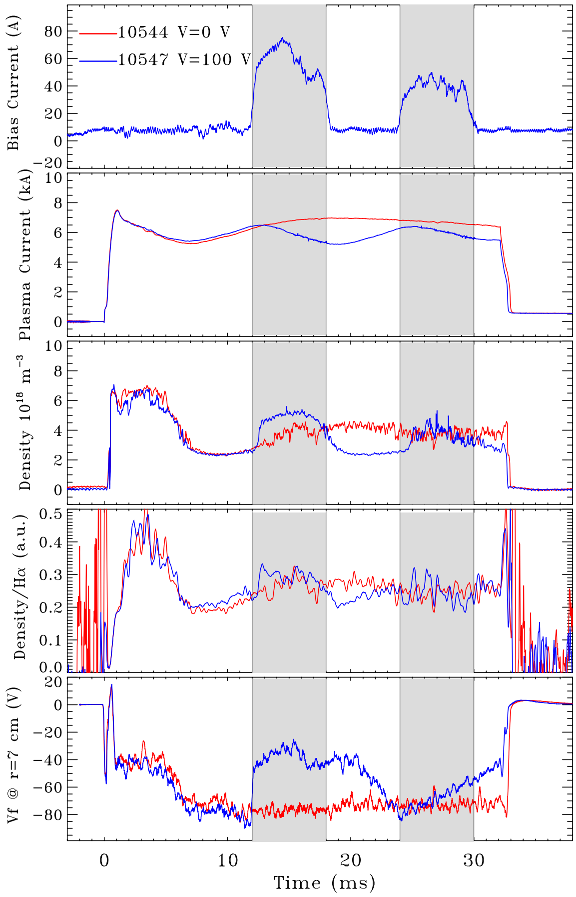

FIG. 3. Comparison of time evolution of two discharges with DC electrode bias (V_{bias}=120 V) and no bias. Shadowed regions indicate the times when the bias is applied.

when the bias is applied, and a strong increase ~2-3 ms later. For negative bias no significant modification on the global or edge parameters are observed. Results indicate that a better confinement is achieved for AC biasing when compared with DC. This is possibly a result of the slow increase in the applied voltage, which is less perturbative for the plasma.

For positive EB, the floating potential in the plasma edge is modified in a fast time scale (<100 µs). At the electrode position the floating potential increases by ~50 V, while close to the limiter does not change significantly, leading to an increase in the edge radial electric field (up to 6 kV/m). Furthermore, the V_f fluctuation level is reduced by a factor of ~2 when positive EB is applied.

4. Limiter Biasing

A comparison of the main plasma parameters during DC limiter and electrode bias discharges (V_{bias}=120 V) is presented in figure 4. The time evolution of the main plasma parameters during limiter biasing is similar to that observed in EB experiments. The perturbation induced by LB is stronger; as the increase in the visible radiation losses is much larger with LB. Although n_e rises for positive LB, both the H_α radiation and the turbulent particle transport also increase significantly, leading to very limited modifications in particle confinement when the bias is applied and a substantial confinement degradation a few milliseconds later due to a large reduction on the plasma current and temperature.

Analysis of the Langmuir probe data has shown that in the region inside the limiter (r<a) floating potential follows the applied voltage; V_f increases by ~30 V. However, the V_f modification is smaller than that observed for EB resulting in a modest modification in E_r (~2 kV/m), localized in the region around the limiter. An interesting observation is that the increase in V_f is slower for LB when compared with EB. The maximum floating potential is only reached 2 ms after the bias is applied. This means that when the maximum E_r is attained the radiation losses are already substantial, restricting considerably the effect of E_r on confinement.

5. Simultaneous Limiter and Electrode Bias

A velocity shear stabilization mechanism has been proposed to be responsible for an improvement in confinement. A clear correlation between reduction of turbulence and the modification of radial electric fields induced by bias was shown in several experiments. The control of the shear layer is therefore an important tool to modify transport in tokamaks.

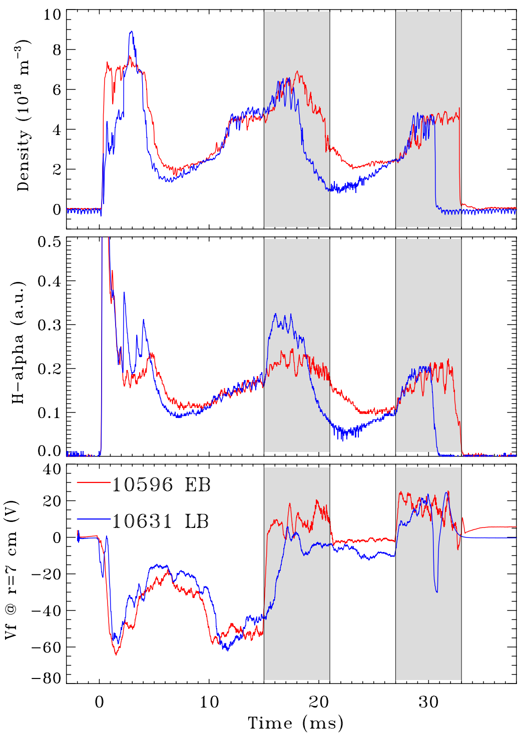

FIG. 4. Comparison of the main plasma parameters during DC limiter and electrode bias (V_{bias}=120 V). Shadowed regions indicate the times when the bias is applied.

Simultaneous limiter and electrode bias has been used on ISTTOK to investigate the possibility of shaping the plasma potential profile.

Preliminary results show that the control of the V_p profile by simultaneous limiter and electrode bias is very limited. Experiments indented to suppress/reinforce the shear layer, applying voltages with different polarities to the limiter and the electrode, were only partially successful. Experiments show that the plasma potential can be easily increased in the region between the limiter and the electrode with positive bias. In opposition, negative voltages do not modify the plasma parameters, in particular do not affect the V_p profile, strongly limiting therefore the possibility of shaping the shear layer. An interesting observation is that with negative EB the effect of the positive LB is strongly reduced.

6. Conclusions

The results presented have shown that both limiter and electrode bias can modify the plasma behaviour. However, it is clear that the best confinement is achieved for positive AC electrode bias. A good correlation between confinement modifications and E_rxB shear has been found for positive EB suggesting that confinement enhancement originates at the edge plasma as a consequence of the formation of a particle transport barrier just inside the limiter. As expected, EB is more efficient than LB in modifying the radial electric field and confinement. The stronger modification in V_p observed for EB results in larger electric fields and consequently larger alterations in confinement. A large increase in the visible radiation losses is observed for LB, leading to very limited modifications, or even a decrease, in particle confinement. Concerning simultaneous EB and LB, preliminary results show that the control of the V_p profile is very limited, since negative voltages do not modify the plasma parameters significantly.

Acknowledgements: *This work has been carried out within the framework of the Contract of Association between the European Atomic Energy Community and "Instituto Superior Técnico". Financial support was also received from "Fundação para a Ciência e Tecnologia" and "Programa Operacional Ciência, Tecnologia, Inovação do Quadro Comunitário de Apoio III".*

References

[1] – R. Weynants and G. Van Oost, Plasma Phys. Control. Fusion 35 (1993) B177.
[2] – T.J. Taylor, et al., Phys. Rev. Lett. 63 (1989) 2365.
[3] – J. Boedo, et al., Nucl. Fusion 40 (2000) 1397.
[4] – J.A.C. Cabral et al., Plasma Phys. Control. Fusion 40 (1998) 1001.
[5] – J.A.C. Cabral et al., Proc. 28th EPS Conference on Controlled Fusion and Plasma Physics, Funchal, 18-22 June 2001, ECA Vol.25A p.605.
[6] – C. Silva et al., Proc. 15th PSI conference, Gifu, Japan, May 2002