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Comparison of limiter and emissive electrode bias on the tokamak ISTTOK

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Abstract

Biasing experiments have been performed on the tokamak ISTTOK with both a moving limiter and an emissive electrode. We have observed that large currents (>15 A) can be drawn at negative applied voltage by both localized limiter and emissive electrode bias, leading to significant modifications in the edge plasma potential profile and to an improvement in particle confinement. However, compared with the localized limiter, the emissive electrode has the advantage of perturbing significantly less the plasma column. Furthermore, its use leads to the formation of stronger radial electric fields and consequently to a much larger improvement in particle confinement.

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1. Introduction

The understanding of transport and regimes with improved confinement is an important subject in fusion research. Earlier work has shown that improvement in confinement can be achieved in a controlled way by inducing radial electric fields in the plasma edge using biasing [1–7]. Experiments have been performed with different elements as electrodes [1,3,4], limiters [5,6] and divertors [7]. For electrode bias, improvement in particle confinement is in general observed for both polarities, being larger with negative bias [2]. However, confinement improvement is more difficult to obtain at negative bias as the collected current is limited by the electrode ion saturation current.

Electrode biasing experiments have been previously investigated in detail on ISTTOK [8]. For positive electrode bias, the plasma potential profile is strongly modified in the region between the electrode and the limiter (values of E_r larger than 10 kV/m have been measured), leading to improvement on gross particle confinement. However, for negative bias ($-250 < V_{\text{bias}} < 0$ V) no significant modification of either the global or the edge plasma parameters were observed due to the small current drawn by the electrode (~1 A).

In order to obtain the larger current necessary to modify confinement at negative applied voltages, two different approaches have been followed in biasing experiments: (i) use of a small limiter, inserted deep

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inside the main limiter radius and (ii) use of a small emissive electrode made of LaB_6. In this contribution, the detailed behaviour of the plasma, under both localized limiter and emissive electrode biasing is compared.

2. Experimental setup

A schematic illustration of ISTTOK (top view) is presented in Fig. 1(a), showing the main elements of the experiment. ISTTOK is a large aspect ratio circular cross-section tokamak ($R = 46\,cm$, $a = 7.8\,cm$, $r_{vessel} = 10\,cm$, $B_T = 0.5\,T$, $I_p \approx 4 - 6\,kA$), which has a fully poloidal graphite limiter at $r = 7.8\,cm$ grounded to the vessel and a small stainless steel localized limiter (with a radial extension of 3 mm and a toroidal extension of 30 mm) consisting of a section of a poloidal limiter centred on the top of the plasma, covering an angular extension of approximately 90°. In the limiter biasing experiments the localized limiter position (r_{lim}) has been varied between $r_{lim} = 8.0$ and $r_{lim} = 6.0\,cm$ and the bias applied between the limiter and the vessel.

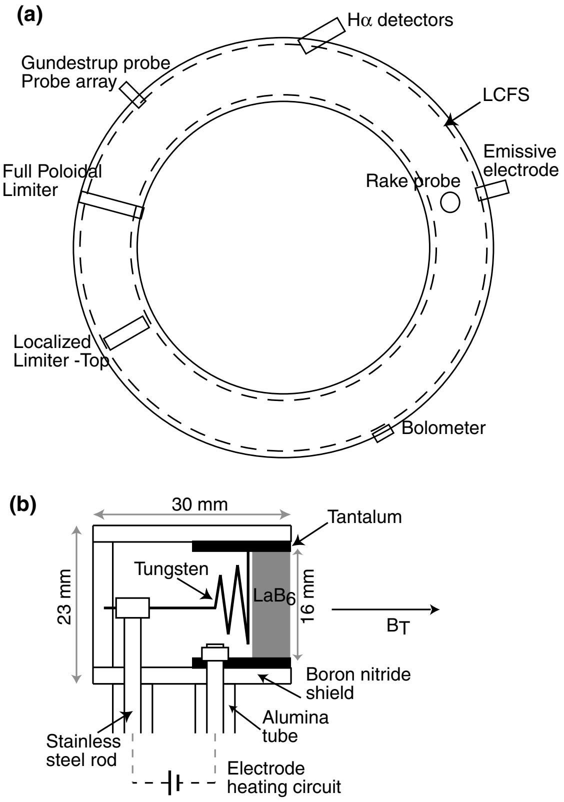

Fig. 1. Schematic illustrations of (a) ISTTOK (top view) showing the main elements of the experiment and (b) the emissive electrode.

A radial array of Langmuir probes (rake probe) has been used to study the influence of biasing on the boundary plasma. The rake probe consists of a boron nitride head carrying seven tungsten tips (unfortunately one of them is not working) with a spatial resolution down to 4 mm. A second radially movable array of Langmuir probes, toroidally located at about 120° from the rake probe and consisting of three probes poloidally separated, has been used mainly to estimate the turbulent particle flux.

A movable emissive electrode has been developed for the biasing experiments in ISTTOK (Fig. 1(b)) [9]. The emissive electrode consists of a LaB_6 (Lanthanum Hexaboride) disk with a diameter of 16 mm and covered by a Tantalum cylinder, which is protected by Boron Nitride cup as insulating material to be exposed to the plasma. For the biasing experiments, the electrode is heated with currents up to 24 A reaching a temperature of up to ~1700 °K. We find that the emitted current increases with the emitter temperature in rough agreement with the Richardson–Dushman formula. Up to 30 A of steady state current can be emitted when the bias voltage is applied between the electrode and the vacuum vessel.

3. Limiter bias experiments

A large variety of limiter biasing experiments has been performed on ISTTOK. In this work we report mainly on the effect of the limiter position as it has a strong effect on the bias current. It is important to note that the global plasma parameters are not substantially modified by the localized limiter (without biasing) for $r_{lim} > 6.5\,cm$, apart from a small reduction of the H_α radiation (measured by a photodiode looking tangentially to the plasma into the main limiter). The edge parameters and in particular the floating potential profiles, are also not significantly modified for $r_{lim} > 6.7\,cm$. We can assume, therefore, that the localized limiter does not act as a limiter in the region $r_{lim} > 6.7\,cm$. The perturbation of the discharge for $r_{lim} < 6.5\,cm$ includes a decrease of the line-averaged plasma density.

Alternating bias voltages (50 Hz, 120 peak voltage) provided by a transformer have been used to determine the limiter voltage–current characteristic in a single shot. This is illustrated in Fig. 2, which shows the variation of the limiter current and the modification in the floating potential [2] (ΔV_f) with the applied voltage for different limiter positions. Data points obtained with DC bias (full symbols) are also shown to extend the applied voltage range. When the limiter is at position $r_{lim} = 7.8\,cm$, we observed that the collected current (I_{bias}) at negative

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[2] Variation of the plasma potential in relation to its value at $V_{bias} = 0$.

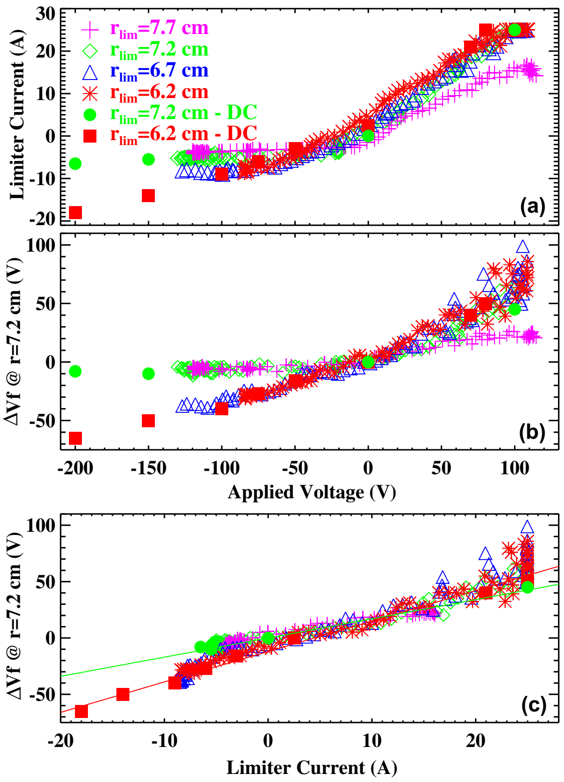

Fig. 2. Variation of the limiter current (a) and ΔV_f (b) with the applied voltage for different limiter positions and dependence of ΔV_f on the limiter current (c). Data represented by full symbols have been obtained in DC biased discharges while the open symbols correspond to data from AC biased discharges.

applied voltage (V_{bias}) is very small and that the floating potential is only modified for V_{bias} positive, as observed in previous experiments [8]. For negative bias, both I_{bias} and ΔV_f increase significantly as the limiter is inserted deeper into that plasma. Therefore, contrary to the observation at $r_{\text{lim}} = 7.8$ cm, a clear modification in the floating potential profile is observed during bias for $r_{\text{lim}} < 7.0$ cm, due to the larger collected current. For positive bias, the effect of the limiter position on I_{bias} and ΔV_f is small for $r_{\text{lim}} \leqslant 7.2$ cm.

Fig. 2(c) indicates that there is a roughly linear relation between I_{bias} and ΔV_f, suggesting that the electric field created at the edge plasma is a result of an increase in the plasma rotation due to the collected radial current. Furthermore, the modification in the floating potential is not only a function of the limiter current but also of the limiter position. This is clear at negative applied voltage, where, for the same current the variation on the floating potential increases as the limiter is inserted into the plasma.

The effect of the limiter bias at different positions on the overall plasma conditions has also been investigated. We have observed an improvement in confinement for both positive and negative limiter bias for $r_{\text{lim}} < 7.0$ cm. In Fig. 3, the time evolution of the main plasma parameters for positive ($V_{\text{bias}} = 70$ V), negative ($V_{\text{bias}} = -175$ V) and no limiter bias is compared for $r_{\text{lim}} = 6.4$ cm. Bias has been applied to the localized limiter in periodic pulses of 3 ms duration, with the same time interval between pulses. For both polarities, an increase in density is observed, which leads to a clear improvement on the gross particle confinement, as indicated by the rise in the ratio n_e/H_α. It is important to note, however, that the improvement in confinement is larger for negative bias as the positive one tends to increase recycling.

The floating potential in the plasma edge is modified in a short time scale (<50 μs) for both polarities. Close to the fixed limiters the floating potential does not change significantly, leading to an increase in the edge radial

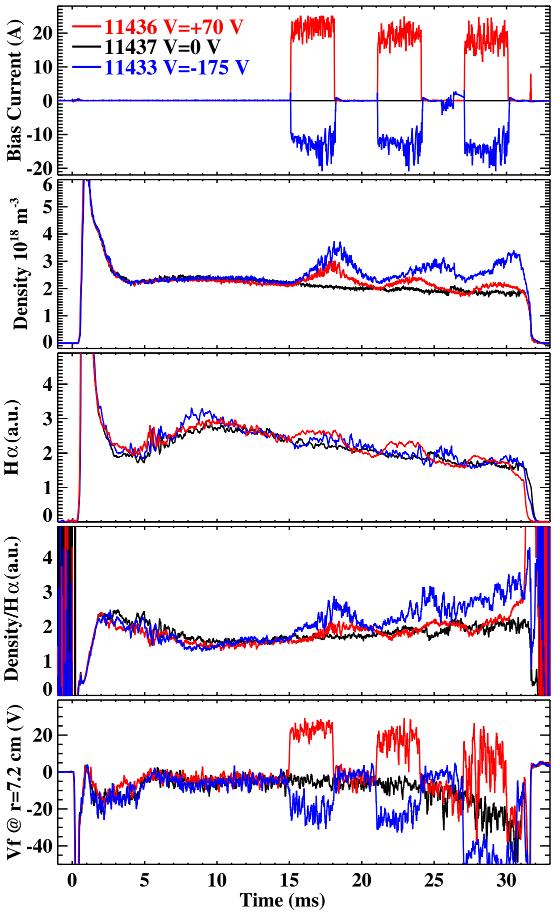

Fig. 3. Time evolution of the main plasma parameters for positive ($V_{\text{bias}} = 70$ V), negative ($V_{\text{bias}} = -175$ V) and no limiter bias for $r_{\text{lim}} = 6.4$ cm. Bias has been applied to the localized limiter at $t = 15$ ms in periodic pulses of 3 ms duration.

electric field for both positive and negative limiter bias (up to ±5 kV/m). The electric field has been derived from the plasma potential, V_p, which is given by $V_p = V_f + 3kT_e/e$, where $3kT_e/e$ is the approximate sheath potential drop. A detailed description of the E_r determination using probe data may be found elsewhere [8]. This modification in the edge E_r profile may explain the observed improvement in particle confinement.

4. Emissive electrode bias

The time evolution of the main plasma parameters for a discharge with negative ($V_{bias} = -200$ V) and positive ($V_{bias} = 100$ V) emissive electrode bias is compared in Fig. 4. For positive bias the emissive electrode behaves just as a non-emissive one as electron emission is fully suppressed for $V_{bias} > 50$ V. The bias voltage is applied at $t \approx 14$ ms for 2 ms and the axis of the electrode is located 12 mm inside LCFS. As the bias is applied, the bias current amplitude increases rapidly to a value around 20 A and the floating potential at the plasma edge is modified in a rather short time scale (<50 μs).

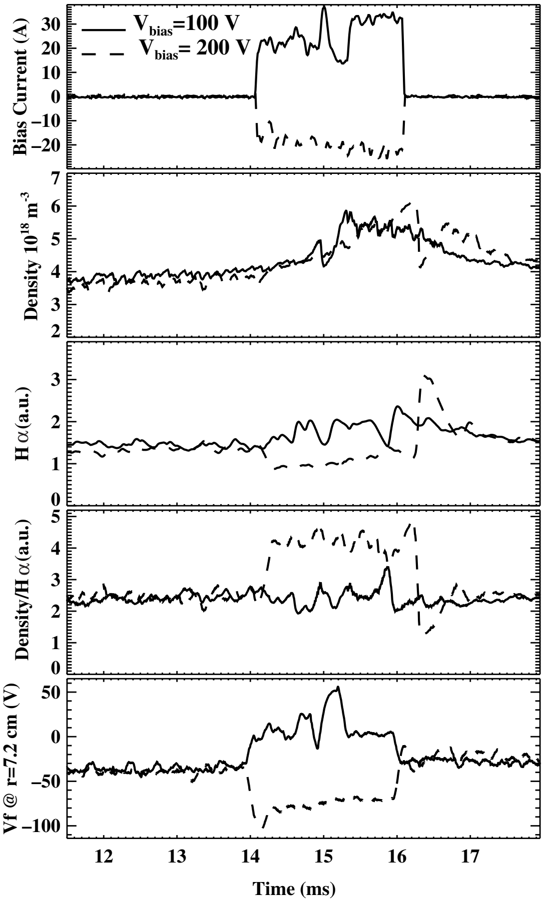

Fig. 4. Time evolution of the main plasma parameters for positive ($V_{bias} = 100$ V, #11374), negative ($V_{bias} = -200$ V, #11373) emissive electrode bias. Bias has been applied at $t = 14$ ms during 2 ms.

For negative bias, the floating potential decreases by about 40 V, at $r-a = -6$ mm, while close to the limiter it does not change significantly, leading to a strong modification in the edge radial electric field in the region just inside the limiter. The line-averaged density increases substantially, $\Delta\bar{n}/\bar{n} \approx 50\%$ and the radiation losses from the core also rise after the bias is applied. However, the rise remains roughly proportional to that observed in the density, so that there is no evidence for significant impurity influx during the bias. Furthermore, since the H_α radiation intensity decreases significantly, $\Delta I_{H_\alpha}/I_{H_\alpha} \approx -30\%$, after the bias is applied, there is clear indication of a reduction in recycling. The gross global particle confinement time almost doubles, as inferred from the ratio $\bar{n}/H_\alpha$.

As can be seen in Fig. 4, 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. As observed in previous experiments carried out in ISTTOK [8], the positive bias tends to increase recycling.

To better characterize the modifications introduced by the electrostatic polarization at the plasma edge, we have measured the evolution of the radial electric field (E_r) profile. The radial profiles of the floating potential and radial electric filed, measured by the rake probe, are shown in Fig. 5. As the bias is applied, a large electric field is observed for both polarities, reaching a value of around ±12 kV/m in the region near the limiter, associated with a strong E_r shear. Therefore, the velocity shear may be responsible for the improved particle confinement observed. This is corroborated by probe measurements, which show a decrease of the turbulent particle transport when the bias is applied.

5. Discussion and conclusions

In small tokamaks with relatively low plasma density, the current collected by negative biased cold electrodes is not sufficient to decrease the plasma potential because it is limited by its ion saturation current. Emissive electrodes produce a much larger current density (∼20 times higher than that of a cold electrode at negative V_{bias} for the ISTTOK case) and therefore allowing a more efficient way to control the edge radial electric field.

We have observed that large currents (>15 A) can be drawn at negative applied voltage by both inner limiter and emissive electrode bias, leading to significant modifications in the edge plasma potential profile and to an

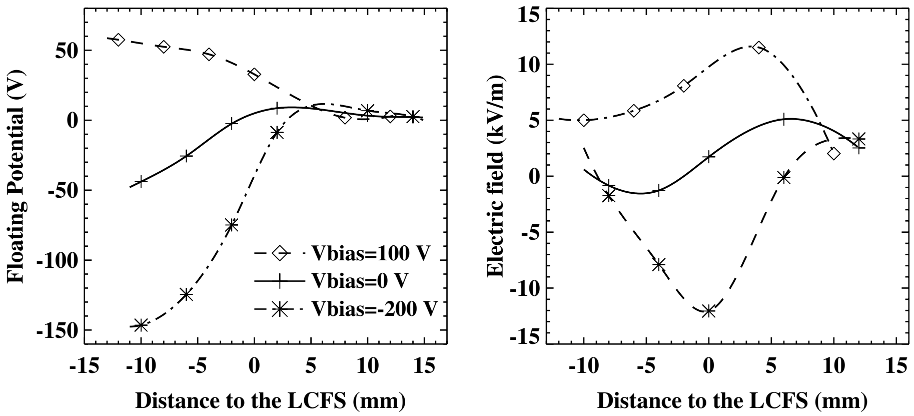

Fig. 5. Floating potential and radial electric field radial profile for positive ($V_{\text{bias}} = 100$ V, #11397) and negative ($V_{\text{bias}} = -200$ V, #11386) emissive electrode bias. Profiles with no applied voltage are also shown for comparison.

improvement in particle confinement. We have shown with limiter biasing that provided that the drawn current is sufficiently high (>6 A) the radial electric field can be modified for both polarities. Furthermore the modification of the plasma potential increases roughly linearly with the collected current.

Compared with the localized limiter, the emissive electrode has the advantage of perturbing significantly less the plasma column. In order to significantly improve confinement the localized limiter has to be inserted deep into the plasma ($r_{\text{lim}} < 6.7$ cm) leading to a clear perturbation of the discharge, which is characterized mainly by a decrease in the line-averaged plasma density. Furthermore, the use of emissive electrodes leads to the formation of stronger radial electric fields (up to a factor of two larger than that obtained with limiter bias) and consequently to a larger improvement in confinement.

We have also observed that for both limiter and emissive electrode bias, the improvement in particle confinement is larger for negative bias. A significant increase in the plasma density is observed for both polarities; however, positive bias tends to increase recycling as indicated by the clear increase in the H_α radiation. The edge density, measured by the rake probe, is observed to increase in the region $r-a > -10$ mm for positive bias, which is in agreement with the observed increase in recycling. This larger recycling may result from the substantial ion return current driven to the main limiter and wall (>20 A).

A rather modest increase in particle confinement is observed for positive electrode bias, when compared to that observed with limiter bias. However, as discussed before, the discharge is clearly perturbed for $r_{\text{lim}} = 6.4$ cm, the density being roughly 35% lower during positive limiter bias when compared with that for positive electrode bias.

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References

[1] R.J. Taylor et al., Phys. Rev. Lett. 63 (1989) 2365.
[2] R. Weynants, G. Van Oost, Plasma Phys. Control. Fus. 35 (1993) B177.
[3] R. Weynants et al., Nucl. Fus. 32 (1992) 837.
[4] H. Gerhauser, R. Zagórski, S. Jachmich, M. VanSchoor, J. Nucl. Mater. 313–316 (2003) 893.
[5] R. Doerner, J. Boedo, R. Conn, D. Gray, G. Tynan, W. Baek, K. Dippel, K. Finken, R. Moyer, Nucl. Fus. 24 (1994) 975.
[6] M. Shimada, A. Ozaki, P. Petersen, P. Riedy, T. Petrie, G. Janeschitz, M. Mahdavi, J. Nucl. Mater. 176&177 (1990) 821.
[7] G.M. Staebler, J. Nucl. Mater. 220–222 (1995) 158.
[8] C. Silva, I. Nedzelskiy, H. Figueiredo, J.A.C. Cabral, C.A.F. Varandas, G. Van Oost, Plasma Phys. Control. Fus. 46 (2004) 163.
[9] H. Figueiredo, I. Nedzelskiy, C. Silva, J.A.C. Cabral, C.A.F. Varandas, Rev. Sci. Instrum. 75 (2004) 4240.