INSTITUTE OF PLASMA PHYSICS
Academy of Sciences of the Czech Republic
Za Slovankou 3, P.O.Box 17, 182 21 Prague 8

Preliminary experiments with edge plasma biasing in tokamak CASTOR

Žáček F., Stöckel J., Kryška L., Jakubka K.,
Badalec J., Ďuran I.

Research Report

IPPCZ - 359

March 1998

Preliminary experiments with edge plasma biasing in tokamak CASTOR

Žáček F., Stöckel J., Kryška L., Jakubka K.,
Badalec J., Ďuran I.

Institute of Plasma Physics,
Za Slovankou 3, 182 21 Prague 8,
Czech Republic

IPPCZ-359 March 1998

Preliminary experiments with edge plasma biasing in tokamak CASTOR

Žáček F., Stöckel J., Kryška L., Jakubka K., Badalec J., Ďuran I.

Institute of Plasma Physics, Za Slovankou 3, 182 21 Prague 8,
Czech Republic

Abstract

To study a role of radial electric field in the particle confinement, preliminary experiments with an edge plasma biasing have been carried out in tokamak CASTOR. For the biasing, an insulated graphite electrode with the surface $1500mm^2$, injecting into the plasma current up to one hundred ampers, has been used. The first measurements proved an increase of the global particle confinement time nearly two times, however, for the positive polarity of the biasing only. A regular modulation (up to 50%) of the injected current with a frequency about $10kHz$ has been observed. Oscillations highly coherent with those oscillations of the injected current, but having a still stronger modulation (up to 80%), exhibits also ion saturated current of a Langmuir probe placed in the limiter shadow.

INTRODUCTION

An importance of the electric field $\vec{E}$ in the global confinement of energy and particles in tokamaks is generally recognized. However, due to the existence of a strong confining magnetic field $\vec{B}$, the problem is complex and not fully described up to now. Therefore, continuous studies of possible mechanisms are object of intensive investigations, both theoretical (see e.g. review article [1]) as well as experimental (see e.g.[2-4]). Namely, if a $L \rightarrow H$ confinement mode transition in tokamaks appears, an increase of radial electric field is currently observed. This increase is accompanied by an increase of a poloidal rotation velocity ($\vec{E} \times \vec{B}$ drift) resulting in a lowering of the turbulent fluctuations of plasma parameters as density and floating potential (see e.g. review article [5]). Similar effects, followed by an increase of the global particle confinement, have been observed also in the case of Lower Hybrid Current Drive (LHCD) in CASTOR tokamak [6]. One speaks, in such case of confinement improvement, about the formation of a transport barrier somewhere inside the tokamak plasma, probably just in the place of an enhanced radial electric field.

There is a little known about the physics of the transport barrier in tokamaks. On the other side it is clear that mastering of a method of external electric field formation and following control of the transport barrier position (and even its value), should help significantly to suppress an undesirably high anomalous transport in tokamaks and in this way to increase substantially the chance of this devices to become an economically acceptable source of thermonuclear energy for the future.

An external application of electric field using a massive biasing electrode, placed in the tokamak plasma inside the Last Closed Flux Surface (LCFS), brings such a possibility. Namely, the voltage applied between the electrode and metallic vacuum vessel of the tokamak results in the injection of radial electrical current, which can generate a significantly enhanced radial electric field somewhere in the region between the electrode and wall of the device. The preliminary biasing experiments, described below, try to contribute to a better understanding of the radial particle transport due such mechanism in the tokamak CASTOR.

The structure of the report is following. The Section 1 shows a set-up of the CASTOR experiment, including construction of the biasing electrode, power supply and system of data registration. The Section 2 brings the experimental data obtained and in the last Section 3 it is made an attempt to draw some preliminary results and conclusions concerning changes in the global particle confinement.

1. SET-UP OF THE PLASMA BIASING EXPERIMENT

CASTOR is a small limiter tokamak with the following parameters:

major radius	$\mathbf{R = 0.4m}$
wall radius	$\mathbf{b = 0.1m}$
limiter radius	$\mathbf{a = 0.085m}$
magnetic field on the axis	$\mathbf{B(0) \leq 1.5T}$.
plasma density on the axis	$\mathbf{n(0) \leq 3 \cdot 10^{19} m^{-3}}$
length of the discharge	$\tau \leq \mathbf{40ms}$

For the biasing experiments a rectangular graphite electrode with dimensions $50mm$ (poloidal direction)$\times 26mm$(toroidal direction)$\times 12mm$(radial direction) has been constructed. The plasma facing surface is cylindrically curved in poloidal direction with radius $60mm$ (to follow the magnetic surface if the electrode is placed on the corresponding radius). The total conducting surface of the electrode (surface collecting charged particles from the plasma) is about $1500mm^2$. The electrode is radially movable in the range $r = 100 \div 60mm$ ($r = 73mm$ has been chosen for the preliminary experiments described below).

As a source of energy for the plasma biasing, a battery formed by electrolytic capacitors with maximum energy $1.5kJ$ is used (in two possible variants: $8mF/600V$ or $32mF/300V$; $C = 8mF$ has been used in this work). The battery C is switched to the biasing electrode by a powerful thyristor T223-400 ($400A/3kV$, Czech production), in the moment given by a trigger impulse without any possibility to interrupt the electrode current during the rest of tokamak discharge. Schematic arrangement of the experiment is given in Fig.1, including the measurement of biasing electrode voltage U_B and current I_B. Inductance $50\mu H$ in the circuit assures that maximum current rise doesn't exceed a permitted value for the thyristor used ($20A/\mu s$ for our thyristor type). The polarity of the biasing voltage U_B is possible to be changed between two tokamak discharges using a mechanical commutator, see Fig.1 as well.

Measured data have been stored in the common CASTOR database using several transient recorders:

- 16-channel system with sampling rate $100\mu s$, 12 bits resolution and memory $0.5kB$/channel (i.e. total recorded time $50ms$) for slowly changing macroscopic quantities (i.e. loop voltage U_{loop}, plasma current I_p, average plasma density $\bar{n}$,
- 4-channel system with sampling rate 10 or $5\mu s$, 8 bits resolution and memory $4kB$/channel (i.e. total record 40 or $20ms$ resp.);
- 2-channel system with sampling rate $1\mu s$, 12 bits resolution and memory $16kB$/channel (i.e. total record $16ms$) for registration of fast phenomena.

All data are processing using IDL programme.

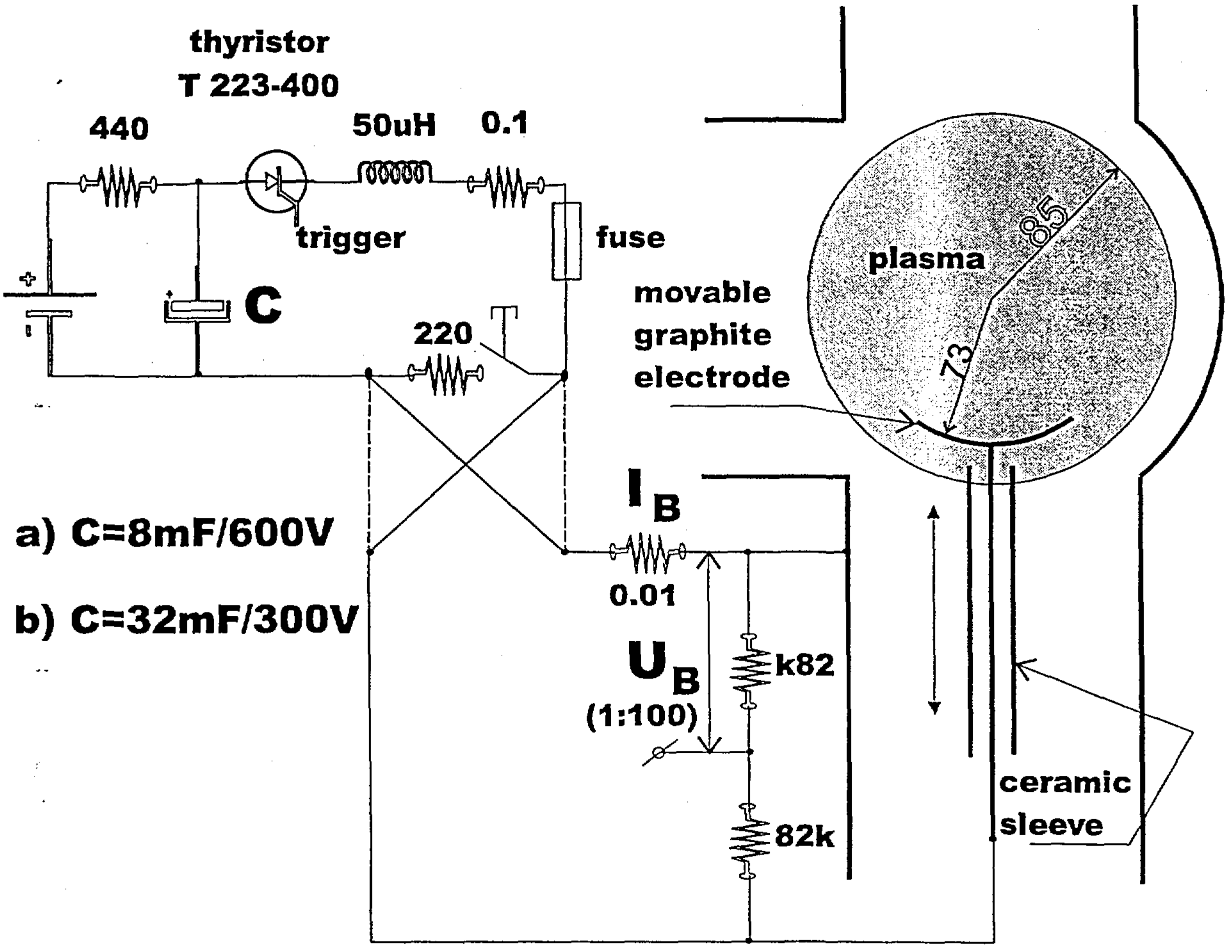

Figure 1: Schematical arrangement of the biasing experiment.

2. EXPERIMENTAL RESULTS

A typical discharge of the tokamak CASTOR (without plasma biasing) is shown in Fig.2. It may be seen from this figure that discharge can reach a quasistationary phase at $t \geq 10ms$ after the discharge beginning. This quasistationary phase is finished by short-circuiting of the transformer primary winding at $t \doteq 20ms$ in this case. The value and time evolution of plasma density can be controlled by an impulse gas puffing during the tokamak discharge (by means of a piezoelectric valve). Three macroscopic characteristics of the discharge are displayed in the upper part of the figure (with sampling rate $100\mu s$):

- loop voltage U_{loop};
- average electron density $\bar{n}$ (measured by $4mm$ interferometer);
- plasma density I_p.

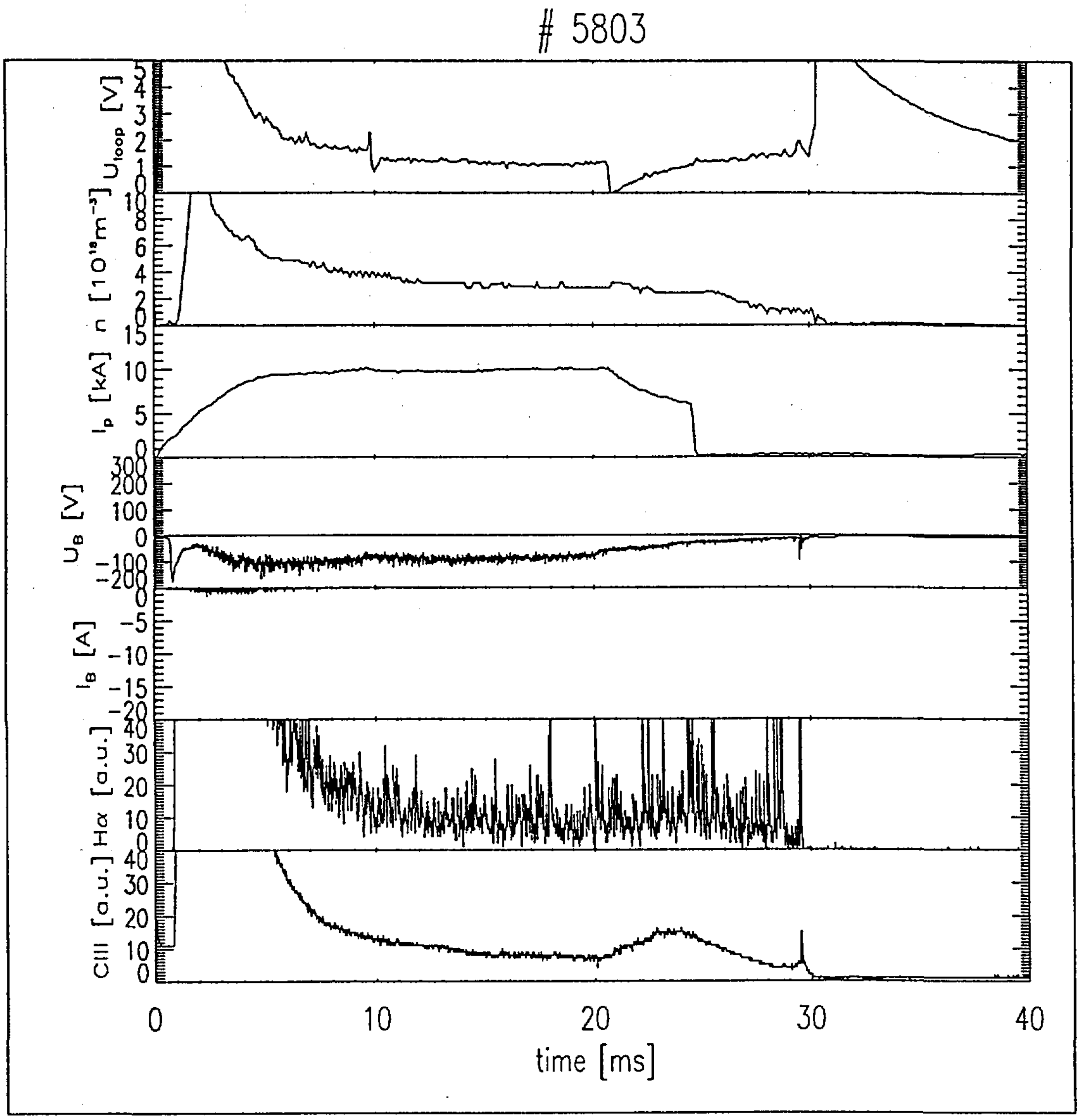

Figure 2: A typical tokamak CASTOR discharge without plasma biasing (the biasing electrode is, however, placed inside the plasma at working position $r = 73mm$).

Because only small impulse gas puffing has been used in the shot given in Fig.2, the plasma density is continuously decreasing during the whole discharge. Note, that this decrease is nearly exponential. It is evident, that in the case without any impulse gas puffing this exponential has a time constant $\tau_p/(1 - c_r)$, where τ_p is the particle confinement time and c_r is wall recycling coefficient, because stationary filling of working gas is negligible during the discharge in comparison with the charged particle loses. A peak observed at $t \doteq 10ms$ is manifestation of a fan-like instability (anomalous Doppler instability), observed often at low density regimes (regimes with unsufficient impulse gas puffing) due to existence of fast runaway electrons accelerated by U_{loop} in direction of the confining magnetic field. The value of the plasma current $I_p = 10kA$ is determined by a voltage on the transformer primary winding (voltage of the Ohmic Heating line). This value has not been changed during the experiments reported below.

The lower four traces (with sampling rate $10\mu s$) are quantities important for the biasing experiment itself:

- biasing electrode potential U_B and current I_B (without biasing U_B=floating potential of the plasma at the biasing electrode location and $I_B \equiv 0$);
- intensity of hydrogen line H_α from the region of limiter (a measure of the working gas influx);
- intensity of carbon line $CIII$ radiated from the region of the graphite biasing electrode (a measure of the main impurity influx).

Observation of two last spectroscopic quantities allows us, together with the measurement of average electron density, to judge of the global particle confinement τ_p [7]. Namely, if no impurity influx is quaranteed, then $\tau_p \sim \bar{n}/H_\alpha$.

A) Positive biasing

The same quantities as those given in Fig.2 for $U_B = 0$ and for the same impulse gas puffing are displayed in Fig.3 for the case of a positive biasing voltage $U_B = +200V$. It may be seen that the current injected into the plasma during the biasing didn't exceed a value $15A$ in this case. The capacity $C = 8mF$ seems to be sufficient because practically no decrease of U_B is registered. For a better effect evaluation, $\bar{n}$ and $CIII$ line intensity for the case without biasing (Fig.2) are given in Fig.3 as dotted curves as

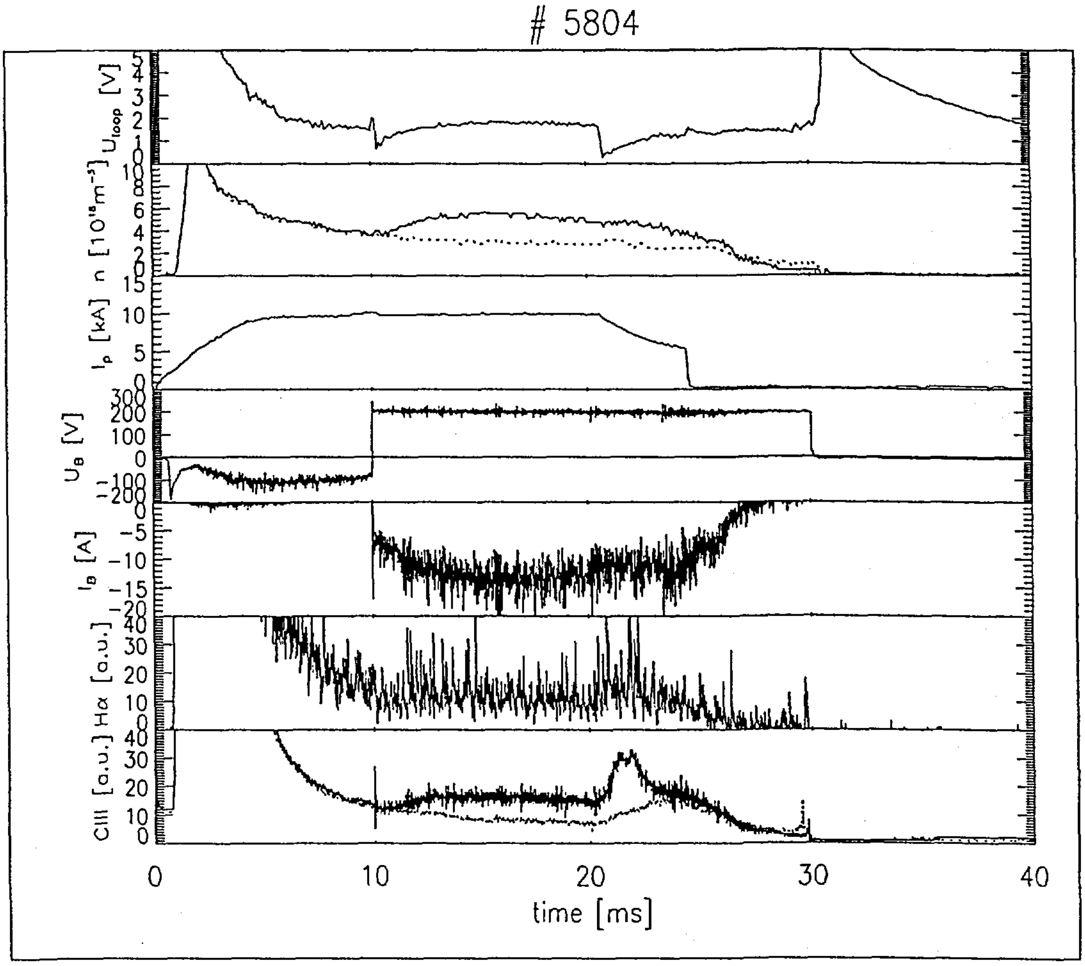

Figure 3: The same discharge as in Fig.2 but with plasma biasing $U_B = +200V$.

well. Because the plasma biasing doesn't exhibit any effect on the plasma current I_p during the biasing, we don't display I_p more in the figures following below.

Several conclusions can be driwn from Fig.3:

- a significant increase of the average plasma density $\bar{n}$ (up to 80% in this case) is observed during the biasing;
- on the other hand, no increase of H_α is observed at that period;
- a certain enhancement of *CIII* line radiation is registered during the biasing; however, because only several per cents of carbon impurity are present in the CASTOR plasma, this enhancement can contribute to that increase of $\bar{n}$ observed in negligible degree only;
- it can be deduced from all above given facts that τ_p increases up to 80% during the positive biasing with $U_B = +200V$.

It must be noted, however, that value of τ_p increase during the positive biasing depends on the plasma average density (controlled by the level of impulse gas puffing). This fact is quite understandable because the value of density influences the radial resistivity of the plasma and in this way the value of current injected into the plasma (the value of the current depends, of course, also on the value of the applied biasing voltage). Fig.4 shows the situation for the biasing voltage $U_B = +200V$ but with a

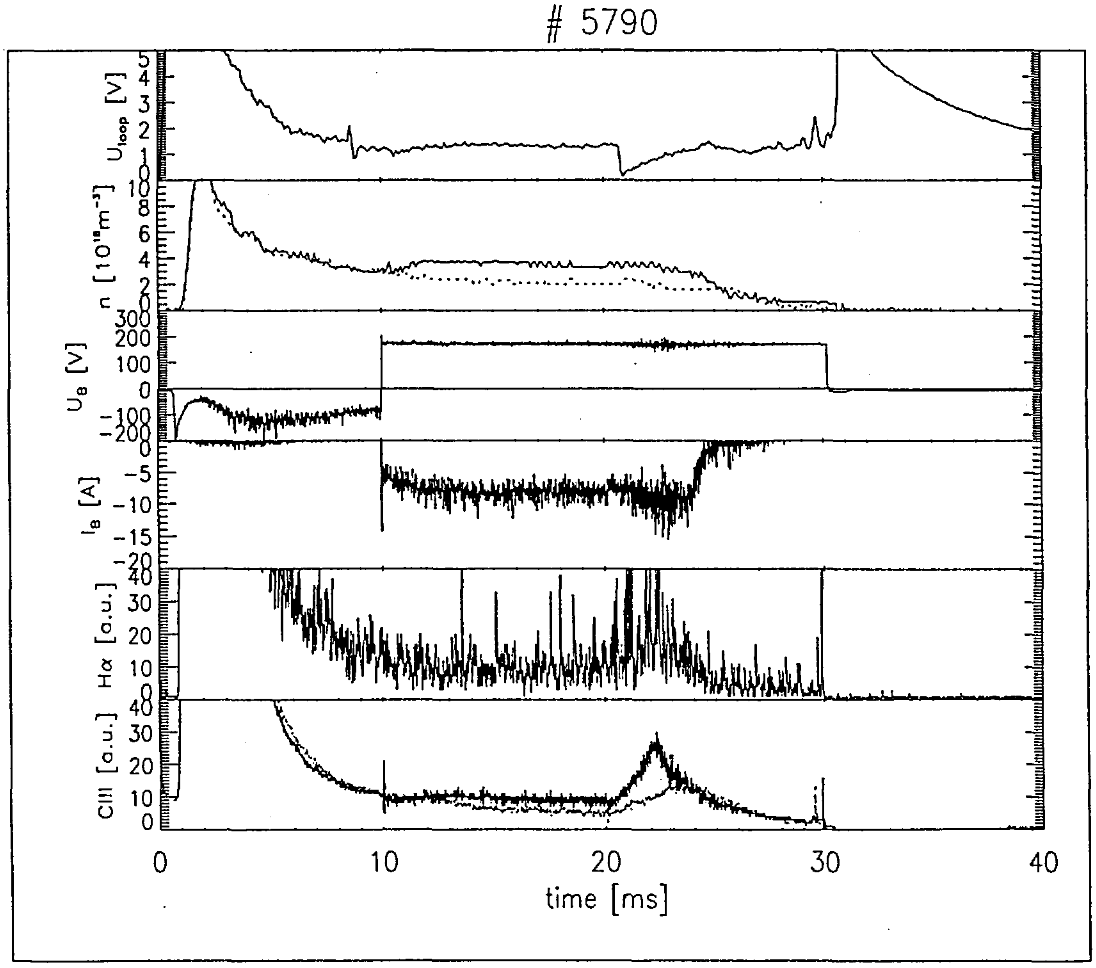

Figure 4: Plasma biasing at a small impulse gas puffing and $U_B = +200V$.

slightly lower average density ($\bar{n} = 3 \cdot 10^{18} m^{-3}$) in the moment when biasing has been switched on ($\bar{n}$ increases up to 50% during the biasing), Fig.5 shows the situation for a higher average density ($\bar{n} \doteq 11 \cdot 10^{18} m^{-3}$) and $U_B = +300V$ ($\bar{n}$ increases up to 90%).

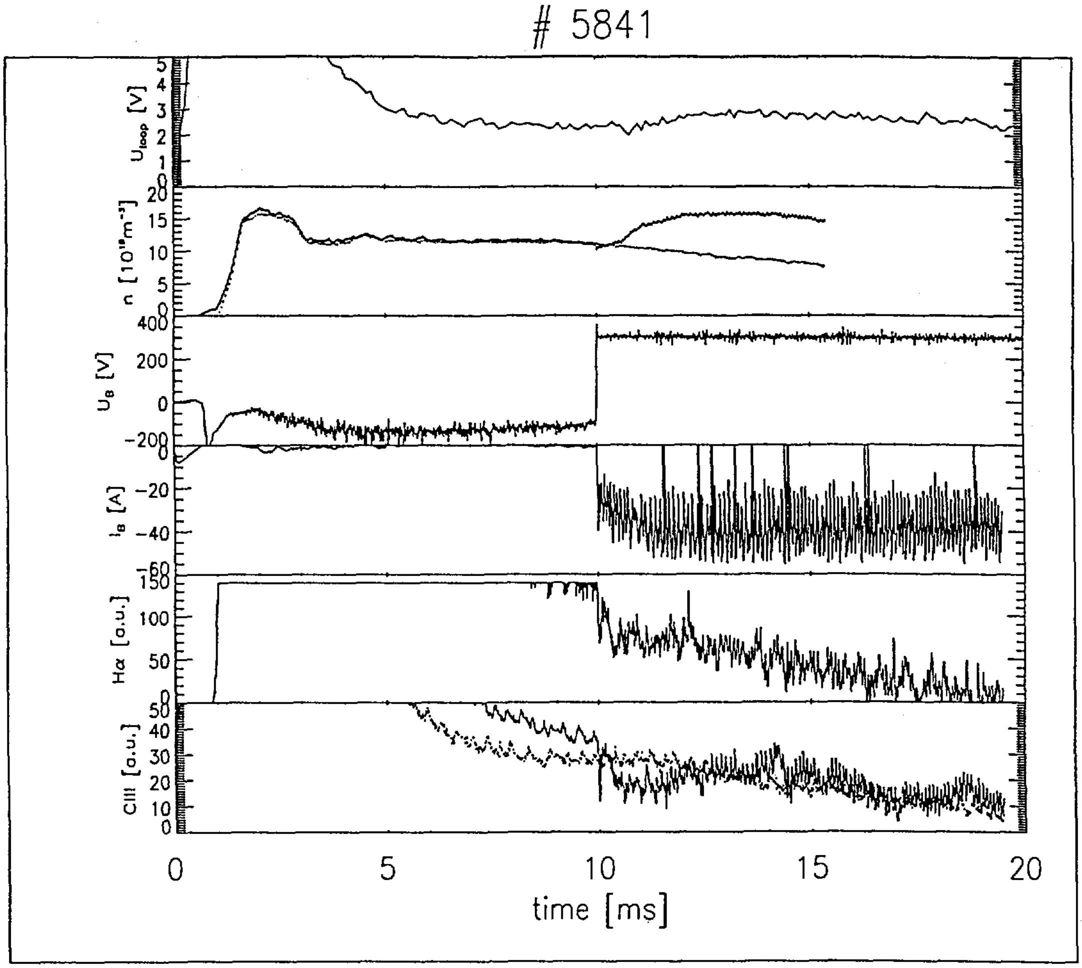

Figure 5: Plasma biasing at a high impulse gas puffing and $U_B = +300V$.

B) Negative biasing

In the case of negative biasing no effect on the plasma parameters has been observed in a broad range of voltage ($U_B = -420V \div 0$), density ($\bar{n} = 2 \div 12 \cdot 10^{18} m^{-3}$) and even toroidal magnetic field ($B_t = 0.6 \div 1T$). This fact is demonstrated in Fig.6 for biasing voltage $U_B = -360V$ and low density case $\bar{n} \doteq 4 \cdot 10^{18} m^{-3}$.

C) V-A characteristics of the biasing electrode

Fig.7 shows $V - A$ characteristics of the biasing electrode in a broad range of $U_B = -420V \div +300V$ for the high density case ($\bar{n} \doteq 11 \cdot 10^{18} m^{-3}$). It may be seen that no saturation is achieved in this voltage region and, therefore, the value of current injected into the plasma can be still increased by using a higher biasing voltage.

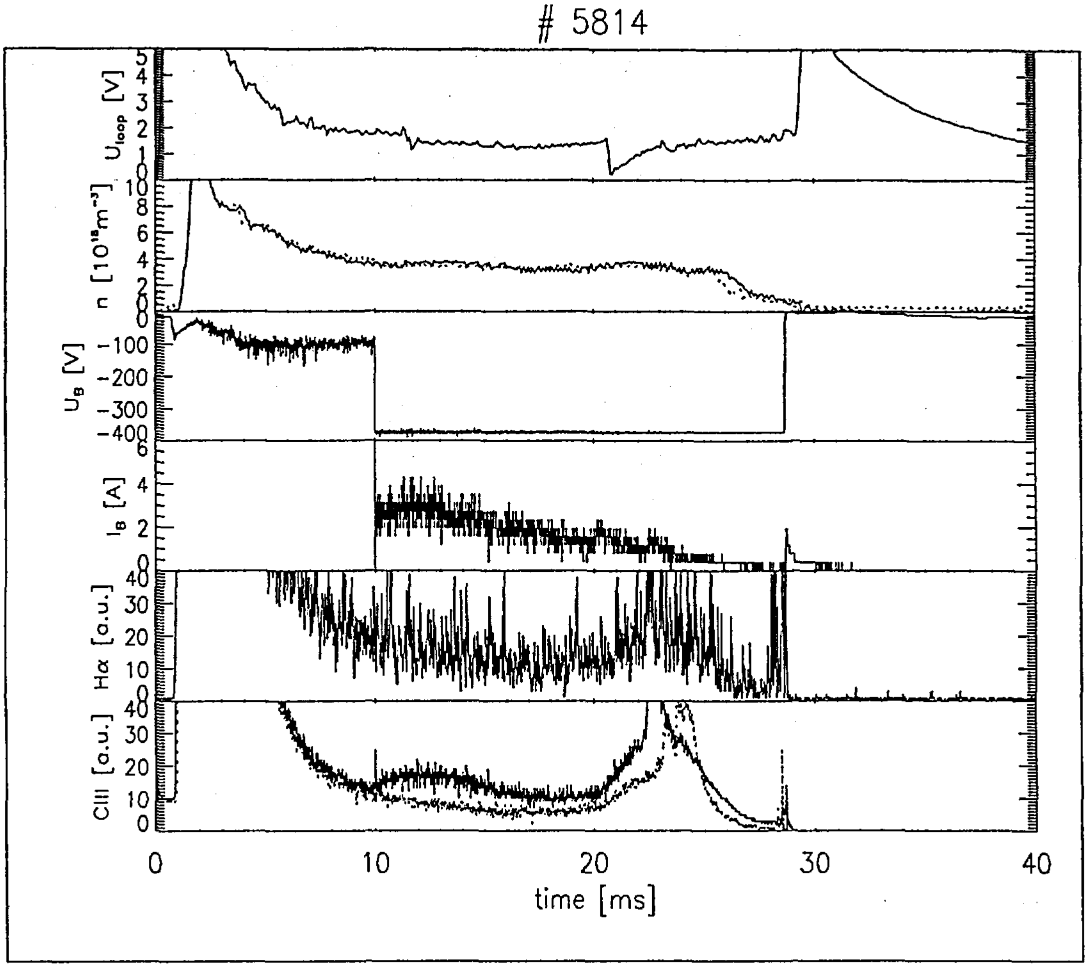

Figure 6: Plasma biasing at negative voltage $U_B = -360V$.

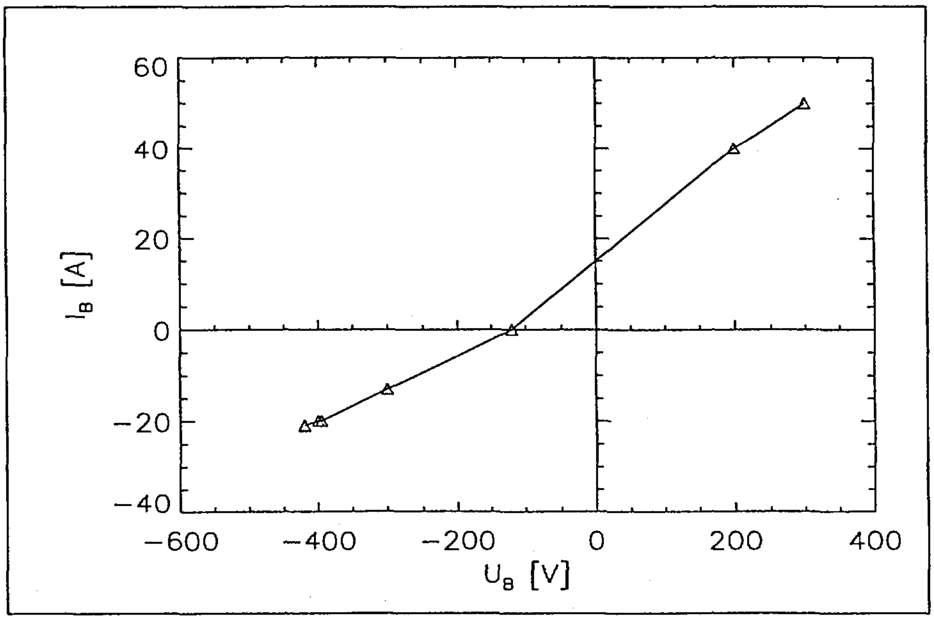

Figure 7: V-A characteristics of the biasing electrode.

D) Oscillating regime of the plasma parameters triggered by the negative biasing

A very interesting oscillating phenomenon has been revealed during the negative plasma biasing, i.e. in the regimes with increase of τ_p. The higher value of I_B is reached, the more profound is the effect. Namely, if we look the Fig.5, it is observable a very good expressed structure of nearly regular oscillations on the course of electrode current. Fig.8 shows the situation around the instant of the biasing application in a shorter time scale ($\bar{n}$ is registered with a sampling rate $1\mu s$ and all other quantities with $5\mu s$). A quantity I_{sat} brought in the figure 8 is ion saturated current collected by a small Langmuir probe (i.e. a quantity proportional to the plasma density in the probe position). The probe is a cylinder with diameter $0.5mm$ of $2mm$ length and it is placed roughly at the limiter radius (i.e. at $r = 85mm$). It may be seen that after biasing application, the edge plasma density decreases very fast and the electrode current stabilizes at a value about $20A$. It indicates a fast improvement of particle confinement during this phase (a strong reduction of the particle flux from central region to the periphery. However, such favourable situation persists only about $200\mu s$.

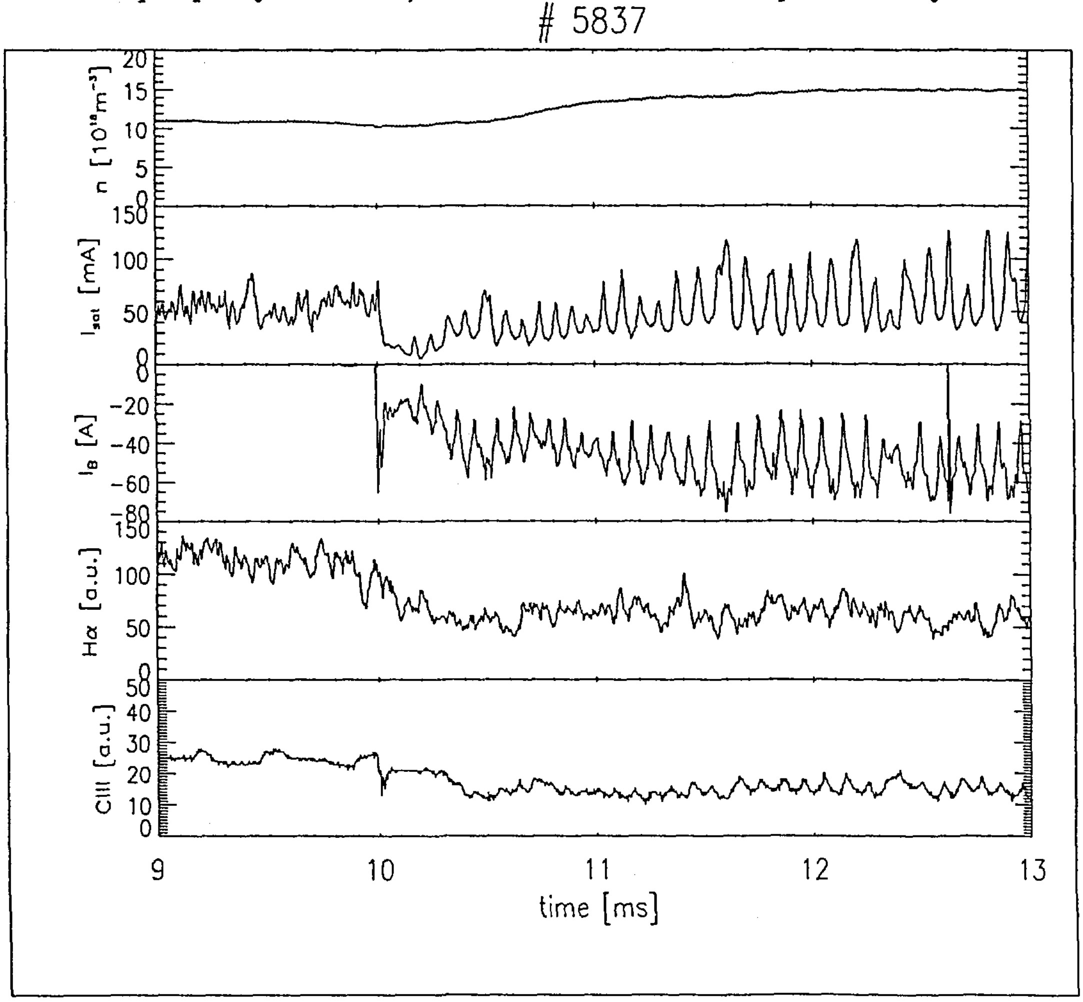

Figure 8: Oscillating regime of the plasma triggered by positive biasing ($U_B = +300V$, high level of the impulse gas puffing).

Afterwards the particle confinement starts to be periodically deteriorated (and improving again), which results in the both observed phenomena:

- the peripheral density, measured by Langmuir probe at limiter radius, is periodically increasing (and decerasing again);
- the electrode current is periodically increasing and decreasing as well (due to the periodical decrease of plasma radial resistivity).

A still shorter time period of the same discharge is depicted in Fig.9. Note the high level of correlation observed between oscillations of I_B and I_{sat} (maximum of I_B corresponds to the maximum of I_{sat} and vice versa). The oscilations have nearly stable frequency $f \doteq 10kHz$. An indication of a certain correlation may be traced even between I_B/I_{sat} and optical radiation (especially $CIII$ line), see Fig.9 as well. It must be said that the same frequency of I_B oscillations (with a little smaller modulation only) is observed also at lower plasma density and lower positive biasing, see e.g. Fig.4.

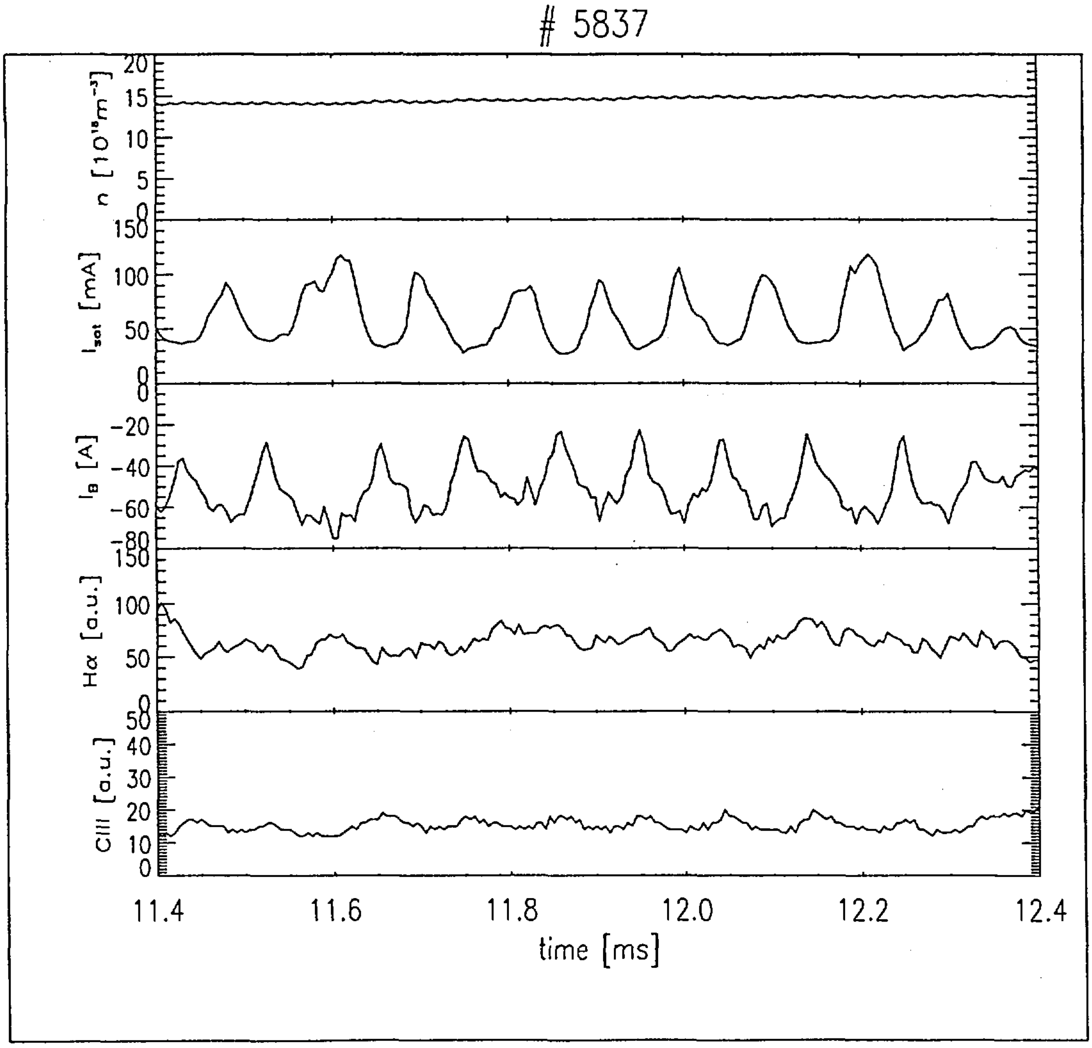

Figure 9: The same oscillating plasma regime as in Fig.8, only in a shorter time scale ($U_B = +300V$, high level of the impulse gas puffing).

3. BRIEF SUMMARY AND DISCUSSION OF THE RESULTS

The results obtained during the preliminary experiments with edge plasma biasing on CASTOR tokamak (using a large electrode placed at $r = 0.86a$) can be summarized as follows:

1. Only positive biasing exhibits a well expressed effect on the macroscopic plasma parameters (probe is collecting the electron current).
2. Using a positive voltage of a several hundreds *volts* and current several tens of *ampers*, an increase of the line average density (i.e. increase of the total number of charged particles in the device) nearly up to 100% has been achieved.
3. This increase of the plasma density can be interpreted, on the basis of the particle balance, as a result of the global particle confinement time improvement.
4. After some starting phase, the electron current collected by the bising electrode starts to be strongly modulated (up to 50%) by a nearly regular oscillations with a frequency about $10kHz$.
5. Still more expressed modulation, quite correlated with that modulation of the electrode current, exhibits also ion saturated current collected by a Langmuir probe (i.e. plasma density) placed at the limiter position ($r \doteq a$).

Comparison of the results obtained at CASTOR with similar experiments carried out at other tokamaks demonstrates a complexity of the problem studied. Namely, while some devices (PHAEDRUS, ATF torsatron) exhibit similar improvement of τ_p at positive biasing as it is in the case of CASTOR, other devices exhibit τ_p improvement for just negative biasing only (TdeV, CCT, ISTOK). There are also experiments where improvement of τ_p has been observed for both polarities (STOR-M, TUMAN-3, TORTUS, TEXTOR). On the basis of this fact, it seems to be highly probable that for transport barrier creation there is decisive a formation of any strong radial electric field E_r, independing on its direction. An explanation of ambiguous results obtained in different devices may simply consist in different geometrical conditions. These conditions can certainly influence the possibility to form such region of high E_r in the device under a given polarity. The existence of the oscillating regime in CASTOR, described in the paragraph 3.D, could be just a proof of this statement. Namely, it is very important to form the layer of high E_r in a MHD stable region of the tokamak. The opposite situation can result in observed instability of the system. However, to prove this statement, an additional systematic measurements of the geometry influence must be only done.

Acknowledgement

Work was supported by the grant of the Czech Academy of Sciences No AV K 1043601/97.

References:

[1] Itoh K., Itoh S.: "The role of the electric field in confinement", Plasma Phys. Contr. Fusion 38(1996), 1-49

[2] Taylor R.J. et al.: "H-mode behavior induced by cross-field current in a tokamak", Phys. Rev. Lett. 63(1989), 2365

[3] Weynants R.R. and et al.: "Edge biasing in tokamaks", Plasma Phys. Contr. Fus. 35(1993), B177

[4] Cornelis et al.: "Predicting the radial electric field imposed by externally driven radial currents in tokamaks", Nuclear Fusion 34(1994), 171

[5] Tendler M.: "Different scenarios of transitions into improved confinement modes", Plasma Phys. and Contr. Fusion, Vol.39 (Dec. 1997), Supplement 12B (Special issue), p. B371 (Invited paper for the 24th EPS Conf. on Controlled Fusion and Plasma Phys., Berchtesgaden 1997)

[6] Žáček F., Stöckel J., Badalec J., Dvořáček L., Jakubka K., Kletečka P., Kryška L., Magula P.: "Density fluctuations and particle confinement during OH/LHCD on tokamak CASTOR", 18th EPS Conf. on Contr. Fus. and Plasma Physics, Berlin 1991, Proc. Vol. III, 341

[7] Badalec J., Stöckel J., Kryška L., Žáček F..: "Regimes with improved particle confinement on CASTOR tokamak", IAEA TCM on Research Using Small Tokamaks, Sept. 1992, Würzburg, Proc. 53