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EDGE TURBULENCE DURING THE COMBINED LOWER HYBRID/OHMICAL HEATING REGIMES ON THE CASTOR TOKAMAK

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ABSTRACT

An electrostatic turbulence of the edge plasma is studied on the CASTOR tokamak by a triple Langmuir probe with an analog correlator, allowing to monitor the levels of density and poloidal electric field fluctuations together with a radial turbulent flux. A significant stabilization of the fluctuations during the combined lower hybrid/inductive current drive regime (LHCD/OH) suggests an improvement of the particle confinement. It is independently supported by spectroscopical data, indicating a substantial enhancement of the global particle confinement time (~ 2x) during the LHCD/OH part of the discharge.

1. INTRODUCTION

Recent OH-tokamak experiments (e.g. in /1/) suggest a close correlation between the edge particle transport and electrostatic turbulence. The radial turbulent particle flux $\Gamma = <\delta n.\ \delta v_r>$, caused by cross-field drift $\delta v_r = \delta E_p/B_t$ (δn, δv_r, δE_p are fluctuating parts of the plasma density, radial particle velocity and poloidal electric field respectively, B_t is the toroidal magnetic field) has been found outward. The turbulent flux Γ at $r = a$ is comparable to the total radial particle flux through the outermost closed magnetic surface $\Gamma_{spec} = a.\bar{n}_e/(2.\tau_p)$, τ_p is the global particle confinement time. The scaling of the both quantities is similar.

The study of transport processes during lower hybrid current drive (LHCD) regimes has only recently begun, but there are some indications that, namely in regimes with a combined lower hybrid and inductive current drive (LHCD/OH), the particle confinement is improving, when the additional RF power at moderate level $P_{RF} < P_{OH}$ is applied on the OH-target plasma /2, 3/.

An improvement of the particle confinement has been quantitatively observed on the CASTOR tokamak as well /4/, together with a simultaneous decrease of the level of the electrostatic turbulence. The experimental evidence of these facts is reported here in more details.

2. EXPERIMENTAL ARRANGEMENT

The experiment was performed on the CASTOR tokamak ($R = 40$ cm, $a = 8.5$ cm are the major and minor radii, $\tau = 9$ ms is the pulse length). Electrostatic fluctuations were studied in regime with the toroidal magnetic field $B_t = 1$ T and plasma current $I_p = 12$ kA. The operation without an impulse gas puffing is preferred to reach a reproducible low-density regime ($\bar{n}_e \leqslant 10^{19}$ m^{-3}, favourable for an efficient LH-current drive. The RF-power (P_{RF}=40 kW, $f = 1.25$ GHz) was launched via a 3-waveguide multijunction grill (the phaseshift $\varphi = 90^\circ$ between the adjacent waveguides) into the quasistationary target OH-plasma.

The electrostatic edge turbulence is experimentally investigated by a movable triple Langmuir probe, located 180° toroidally away from the grill. The tips of the probe are arranged in the form of a triangle with distances of 2mm. The two poloidally separated tips are on the floating potential and serve for the determination of poloidal electric field fluctuations. The density fluctuations are deduced from the ion saturated current on the third tip. Following /1/, the fluctuations of electron temperature are assumed to be negligible. But, for absolute measurement of turbulent quantities, the local value of T_e should be determined independently from the I - V characteristics of a probe. An analog correlator, connected to the triple probe, allows to monitor in autocorrelation mode the root-mean-square values of fluctuating quantities denoted by " $\sim$ ". By the second mode of operation of the correlator, the radial turbulent flux Γ can be determined as a cross-correlation between the n- and E_p-fluctuations.

The density fluctuations at four discrete wave numbers $k_\perp = 6, 12, 24, 34$ cm^{-1} are monitored by a microwave scattering apparatus ($\lambda = 2.6$ mm). The scattering volume can be vertically shifted, shot-by-shot, from the plasma centre to $r = a$.

3. EXPERIMENTAL RESULTS

3.1. Fluctuation-induced transport and particle confinement

OH-discharge: The particle losses can be characterized by a radial particle flux Γ_{spec}, deduced as usually from the density/spectroscopical data (an example of them is shown in Fig. 1a). The typical value of $\Gamma_{spec} \cong 1\text{-}2.10^{20}$m^{-2}s^{-1} (corresponding to the global particle confinement time 1 - 2 ms) should be compared with a turbulent flux measured at the outermost closed magnetic surface to estimate the role of the electrostatic fluctuations in the edge particle transport on CASTOR tokamak. However, in the case of CASTOR, the quantitative comparison is rather complicated due to the existence of poloidal asymmetry of the turbulent flux, as the turbulent flux measured at the bottom part of the torus $\Gamma^b(a)$, see Fig. 1b., is roughly three times lower than the flux $\Gamma^t(a)$, measured at the top part. Therefore, the comparison can be done only after a rough averaging of $\Gamma(a)$ in the poloidal plane $\Gamma(a) = (\Gamma^t(a) + \Gamma^b(a)/2 \cong 2.\ \Gamma^b(a)$. The satisfactory concordance between $\Gamma(a)$ and Γ_{spec} suggests that the electrostatic turbulence should represent an important contribution to the particle transport in the edge plasma on the CASTOR tokamak.

This and other features of the OH-edge turbulence on CASTOR are similar to those observed in the other low-β tokamak plasmas /1/.

LHCD/OH-discharge: After application of the additional RF-power to the OH-target plasma, typically more than one half of the plasma current is driven by LH-waves. It is demonstrated in Fig. 1a by a decrease of the loop voltage. Simultaneously, the density decay is substantially reduced during the combined LHCD/OH phase of the discharge. Spectroscopic data indicate that neither a neutral influx (from the wall, limiters or the RF-antenna), nor an additional ionization of impurity ions are responsible for such density behaviour. Therefore, the effect of density stabilization is assumed to be the result of an enhancement of the global particle confinement time by factor of two. The improvement of the particle confinement was independently deduced from a decrease of the density gradient scale length L_n at the plasma edge during the LHCD/OH /5/.

At the same time, the levels of fluctuations and consequently the turbulent flux decrease noticeably during the LHCD/OH, see Fig. 1b. It is consistent with the improvement of the global particle confinement time. However, for the present it is difficult to compare the suppression of fluctuations and the improvement of confinement more quantitatively, as the turbulent flux $\Gamma(a)$ was available only at one poloidal angle for the LHCD/OH regimes.

It should be emphasized here that the suppression of the edge turbulence is found to be roughly independent on the mutual position of the triple probe and RF-antenna, therefore the effect is supposed to be toroidally symmetric.

3.2. Characteristic features of the edge turbulence during LHCD/OH

Atpresent, we can not explain the observed effect without being too speculative. Therefore, in this subsection we present only a brief, point by point summary of experimental results, which may contribute to some understanding of mechanism of the edge turbulence suppression during LHCD/OH:

1/ Besides the decrease of fluctuation levels, a decrease of the correlation between the density and E_p-fluctuations is observed. The cross-correlation coefficient $C_{nE} = B_t . \Gamma / \tilde{n} . \tilde{E}_p$ decreases from ~ 0.3 (OH-value) to ~ 0.2 (LHCD/OH-value).

2/ Suppression of density fluctuations measured by microwave scattering (MS) technique is generally less pronounced comparing to the Langmuir probe data, see Fig. 2. It may indicate that namely low wave number fluctuations are influenced during LHCD/OH, since in our case the MS apparatus monitors only density fluctuations with $k_\perp \geqslant 6\ \mathrm{cm}^{-1}$.

3/ The relative drop of the poloidal electric field fluctuations during the LHCD/OH, defined as

$$\Delta = 1 - E_p^{RF} / E_p^{OH}$$

(meaning of $E_p^{RF,OH}$ see fig. 3a) shows a broad maximum in the limiter region, see Fig. 3b. It should be noted that the relative drop of E_p-fluctuations decreases smoothly towards the plasma centre. It demonstrates that the suppression of E_p-fluctuations takes place inside an essential part of the plasma edge.

4/ The spectral characteristics of the edge turbulence during the LHCD/OH regime are given in Fig. 4. The E_p-fluctuations and radial turbulent flux are suppressed in the broad frequency range, while the density fluctuations are suppressed only in the lower part of the frequency spectrum ($\omega/2\pi \leqslant 100$ kHz). Such behaviour seems to be rather peculiar from the point of view of the theory of the density gradient-driven turbulence.

5/ Together with suppression of electrostatic edge turbulence a significant stabilization of fluctuations of poloidal magnetic field (measured by an array of Mirnov coils in the limiter shadow) was observed (Fig. 5). Suppression of MHD-activity during LHCD/OH, but specified as m = 2 mode stabilization, has been reported earlier from Petula B tokamak /6/.

4. CONCLUSIONS

The suppression of the edge electrostatic turbulence is proposed as a candidate for an improvement of the particle confinement, which is rutinely observed on the CASTOR tokamak during the combined lower hybrid/inductive current drive. However, the understanding of the turbulence suppressing mechanism needs additional data about the edge turbulence in this regime of operation.

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Additional references concerning the CASTOR tokamak can be found in this report.

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Figure captions

Fig. 1 Typical time evolutions during the LHCD/OH regimes. The dotted lines correspond to the pure OH-regimes.

a) U_{loop} - loop voltage, $\bar{n}_e$ - line average density, H_α - an intensity of the H-alpha spectral line.

b) $\tilde{n}$, $\tilde{E}_p$ are the root-mean-square values of the density and poloidal electric field fluctuations, Γ is the turbulent flux. The triple probe was located at the bottom of the torus at $r = 85$ mm (limiter radius).

Fig. 2 Suppression of the density fluctuations as seen by the microwave scattering ($\tilde{P}_S$ curve) and by the Langmuir probe ($\tilde{n}^2$ (a) curve). The both diagnostics see the top part of the torus. The MS-data correspond to the wavenumber $k_\perp = 6$ cm^{-1}. The time evolution of the local electron density $\langle n_e$ (a)$\rangle$ is shown for comparison.

Fig. 3 a) An example of time evolution of the RMS-values of E_p -fluctuation for definition of the relative drop of fluctuation level Δ_{E_p} during LHCD/OH:

$$\Delta_{E_p} = 1 - E_p^{RF}/E_p^{OH}$$

Analogically, Δ_n Δ_Γ could be defined.

b) The radial profile of the relative drop of E_p-fluctuation level.

Fig. 4 The relative drop of the density Δ_n and poloidal electric field Δ_{E_p} fluctuations, together with the relative drop of the turbulent flux Δ_Γ versus frequency. Measured shot-by-shot using a bandpass filter $\omega/2\pi = 30$ kHz.

Fig. 5 The temporal evolution of the level of the magnetic fluctuations measured in the frequency range 35 - 65 kHz. $\langle \tilde{b} \rangle$ is an average of signals from a complete array of Mirnow coils.

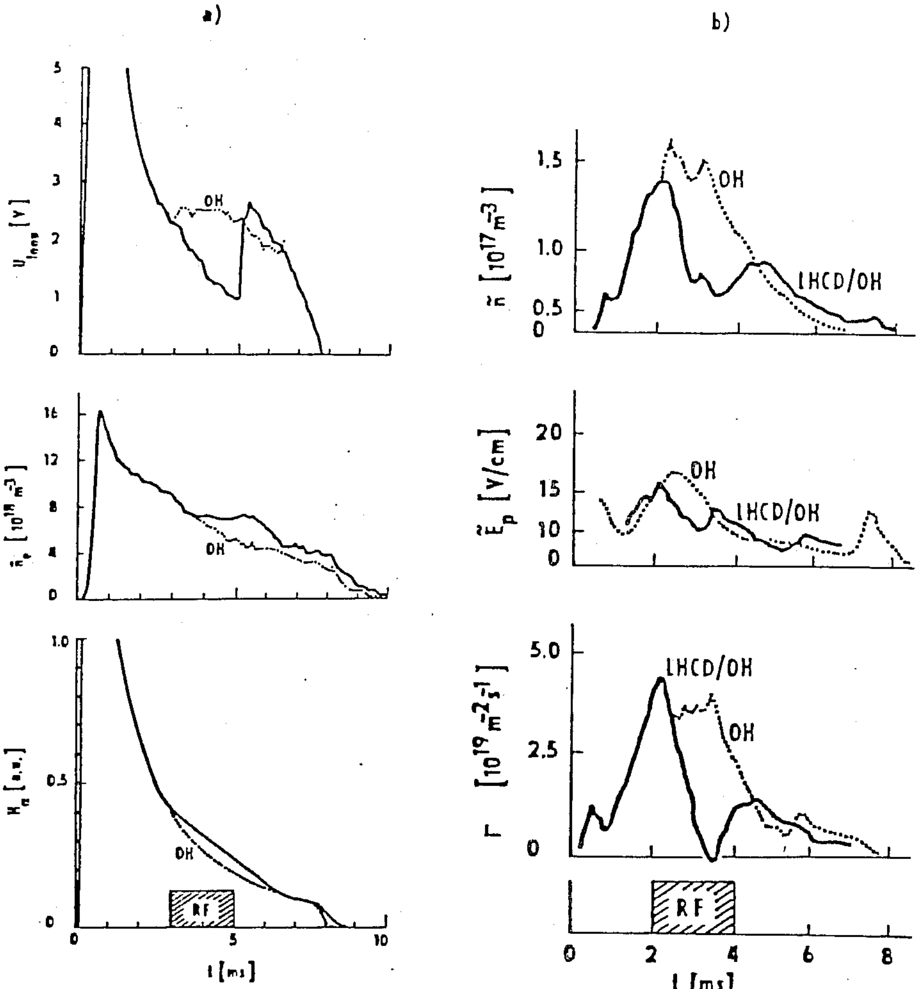
a)
b)
U_{loop} [V]
0
1
2
3
4
5
OH
$\bar{n}_e$ [10^{18} m^{-3}]
0
4
8
12
16
OH
H_α [a.u.]
0
0.5
1.0
OH
RF
0
5
10
t [ms]
$\tilde{n}$ [10^{17} m^{-3}]
0
0.5
1.0
1.5
OH
LHCD/OH
$\tilde{E}_p$ [V/cm]
0
10
15
20
OH
LHCD/OH
Γ [10^{19} m^{-2} s^{-1}]
0
2.5
5.0
LHCD/OH
OH
RF
0
2
4
6
8
t [ms]

Fig. 1

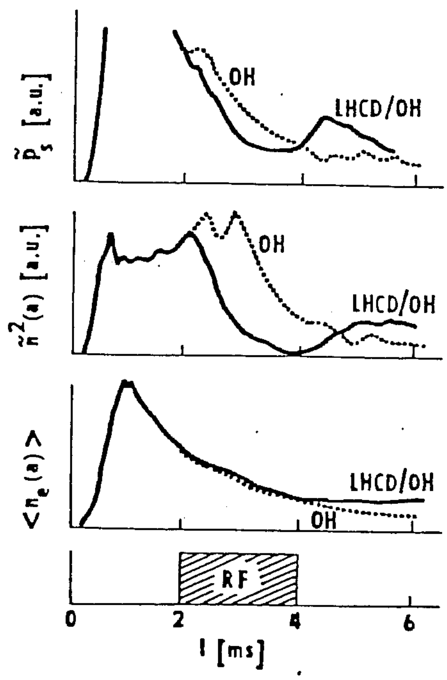
$\tilde{P}_s$ [a.u.]
OH
LHCD/OH
$\tilde{n}^2(a)$ [a.u.]
OH
LHCD/OH
$\langle n_e(a) \rangle$
LHCD/OH
OH
RF
0
2
4
6
t [ms]

Fig. 2

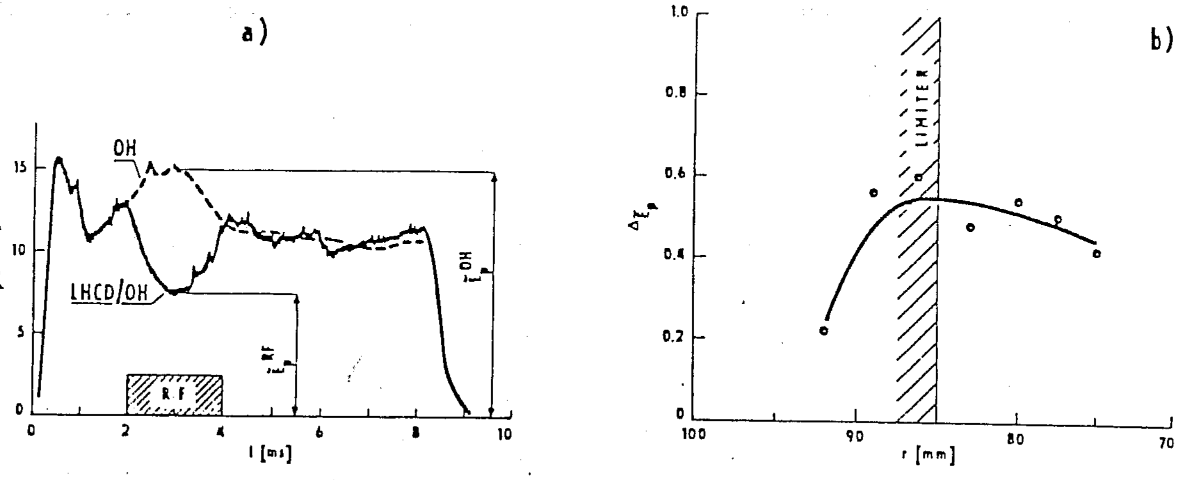

Fig. 3

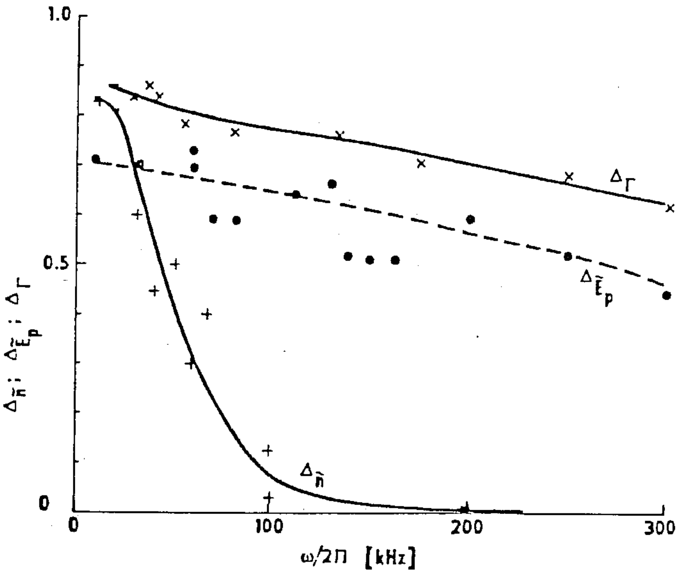

Fig. 4

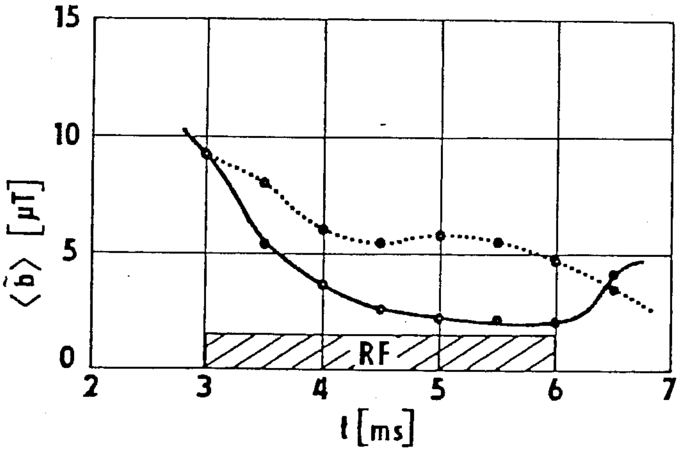

Fig. 5