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EDGE PLASMA TURBULENCE CHARACTERISTICS ON THE CASTOR TOKAMAK

F. ŽÁČEK, J. STÖCKEL, L. KRYŠKA, J. BADALEC, K. JAKUBKA,
J. MLYNÁŘ, P. MAGULA, P. KLETEČKA, V. SVOBODA[1]
Institute of Plasma Physics,
Prague, Czechoslovakia

Abstract

EDGE PLASMA TURBULENCE CHARACTERISTICS ON THE CASTOR TOKAMAK.

The role in the global confinement in tokamaks of turbulent electrostatic fluctuations in the tokamak edge region is presently well recognized despite the fact that there is still no adequate model describing all the measured dependences. Nevertheless, the poloidal velocity and its shear existing in the vicinity of the last closed flux surface seem to play an important role in the fluctuation driven radial particle fluxes. The paper presents some features of the density fluctuations and their poloidal velocity observed on the CASTOR tokamak in regimes with LHCD and with edge plasma polarization.

1. INTRODUCTION

Electrostatic fluctuations are generally assumed to be responsible for anomalous particle and energy losses in tokamaks [1]. Also, it has been proved that all regimes with improved confinement (including H modes), reached under different conditions, are generally characterized by a reduced level of edge plasma turbulence. The reduction of the fluctuation driven particle flux near the last closed flux surface (LCFS), followed by an improvement in the global particle confinement time τ_p, has also been observed in the CASTOR tokamak in LHCD regimes with frequency f = 1.25 GHz [2]. A clear correlation between the fluctuation level and τ_p follows from these measurements. It has to be noted that both observed effects — the reduction of fluctuations and the increase of τ_p — are still well pronounced in the regimes with densities near the LHCD limit, where a negligible number of superthermal current carrying electrons are present. In this way, the possibility of a decisive role of these fast electrons in the observed phenomena was excluded. The next measurements carried out on CASTOR in the LHCD regime proved the unambiguous correlation between reduction of fluctuation level, increase of poloidal rotation of fluctuations and change of the radial electric field in the LCFS region to a negative one [3]. Nevertheless, the mechanism responsible for the improvement of the particle confinement in the case of LH wave application is still not clear.

To obtain a better insight into the problem, we have attempted to use another method affecting the level and character of edge fluctuations [4]. This method, based on the experiment in Ref. [5], is edge plasma polarization (EP) (see Section 2). By using the EP method on CASTOR, some changes in the character of peripheral fluctuations, similar to those observed in the LHCD regime, have been found (see Section 3). At the same time, certain differences in the behaviour of edge fluctuations in these two cases have been observed. This fact indicates that the link between the global confinement and the level of edge fluctuations is more complex than is generally assumed. Section 4 gives some more general conclusions drawn from these facts.

2. EXPERIMENTAL ARRANGEMENT

Three types of experiment investigating electrostatic edge plasma turbulence have been performed on CASTOR ($R/a = 0.4/0.1$ m, $B_t = 1$ T, $I_p < 20$ kA, $\bar{n}_e < 1.5 \times 10^{19}$ m^{-3}):

- Standard Ohmic discharges at densities $\bar{n} < 1 \times 10^{19}$ m^{-3}.
- Lower hybrid wave ($f = 1.25$ GHz, $P < 40$ kW) launched into the Ohmic plasma.
- Ohmic plasma polarized by means of a voltage applied either to the circular limiter (radius $a = 85$ mm) [4] or to a special probe [6]. In the second case we have used an insulated graphite electrode immersed into the edge plasma.

Electrostatic fluctuations have been studied by means of several types of movable Langmuir probe distributed throughout the periphery region. The probe data have been processed either by an analog correlation technique or by digitizing.

The global particle confinement was determined from the average plasma density measured by a two channel 4 mm interferometer and from H_α line intensities measured in three different toroidal positions (at the limiter, at the grill mouth and in the cross-section opposite to the limiter, denoted as H_α^{CHAM}, see Ref. [7]).

3. EXPERIMENTAL RESULTS

In this section we describe briefly the main features of the edge electrostatic fluctuations measured during the quasi-stationary OH phase of discharges in CASTOR and their characteristic changes under the effects of LHCD and EP.

3.1. Lower hybrid current drive

A significant reduction of the electrostatic edge fluctuations

density fluctuations in the region $0.97 < r/a < 1.2$. It may be seen that the absolute level of density fluctuations $\tilde{n}$ is reduced throughout the SOL during the LH pulse, while their relative level $\tilde{n}/n$ remains without any noticeable change (owing to the decrease of peripheral density during LHCD, see Ref. [7]). The radial profile of the poloidal rotation velocity v_p changes significantly.

The fluctuations rotate in the ion diamagnetic drift direction.

3.2. Edge plasma polarization

The radial current j_r flowing across the outer magnetic surface modifies the radial electric field E_r at the tokamak plasma edge generally. However, the relation between j_r and E_r has been found to be strongly non-linear [8] and the possibility of a bifurcated solution of the poloidal momentum balance equation in tokamaks has been theoretically predicted [9]. As a result, two values of E_r and the corresponding v_p are possible for the same fixed value of j_r. The fast transition to the solution with more negative E_r (with suppressed turbulent fluctuations) is interpreted as the L–H transition observed in many tokamaks.

First we tried to polarize the edge plasma by biasing the electrode located at the radius $r_E/a = 0.8$. The electrode current was below 10 A owing to the rather small surface of the electrode. Thus we have not observed any changes in the evolution of the main plasma parameters during positive biasing. The global particle confinement remains on the Ohmic level. Nevertheless, the density fluctuations are noticeably reduced inside the SOL, as shown in Fig. 2. The significant increase of the poloidal velocity near the LCFS and the decrease of the autocorrelation time throughout the SOL should also be noted.

3.3. Density fluctuation data measured in OH, LHCD and EP regimes

Figure 3 shows the relative level of density fluctuations versus the poloidal rotation velocity. The data are taken from all the above mentioned tokamak discharges, regardless of the probe position and type of measured dependence (see figure caption). An unambiguous correlation between these two quantities in the form of exponential dependence $\tilde{n}/n = \exp(-v_p/v_0)$ with $v_0 \sim 5$ km/s is seen.

Another relevant result concerning the time–space properties of the edge fluctuations has been deduced by transition from the laboratory to the rest frame. Under the assumption of a Gaussian form of fluctuating formations ('blobs') in both time and space, a simple relation between the autocorrelation time in the laboratory τ_c^{lab} and that in the rest frame τ_c^{rest} is given by [10]:

$$(1/\tau_c^{lab})^2 = (1/\tau_c^{rest})^2 + (v_p/\lambda_c)^2 \qquad (1)$$

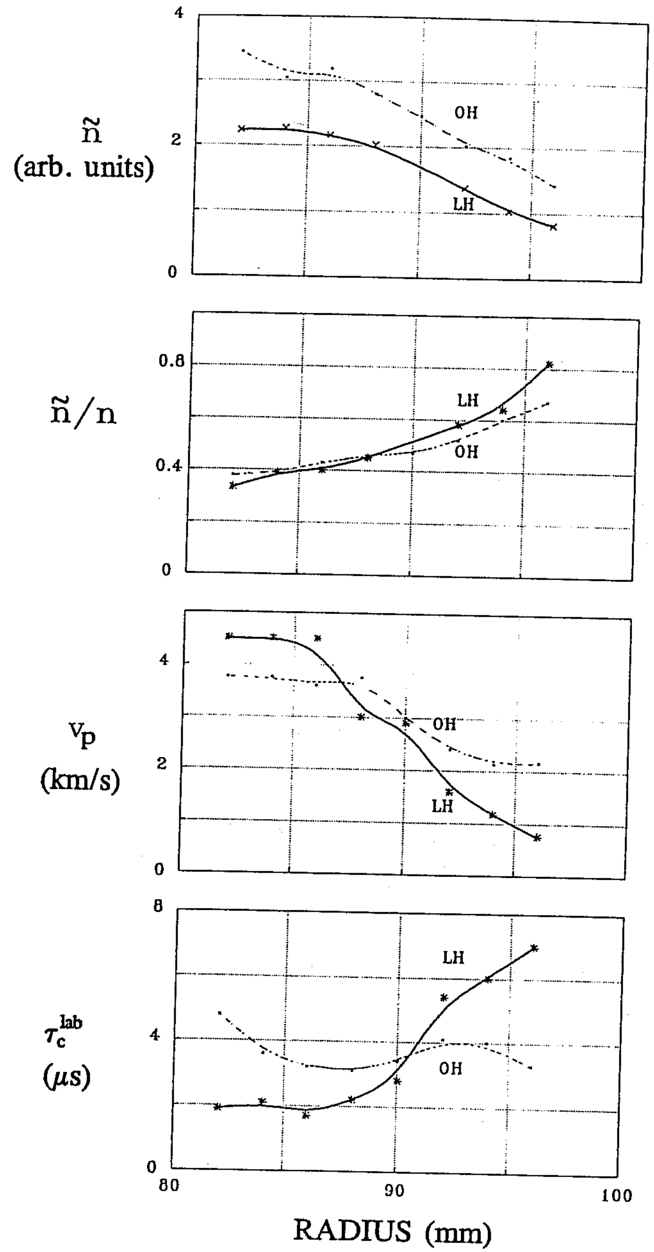


FIG. 1. Radial profiles of density fluctuations

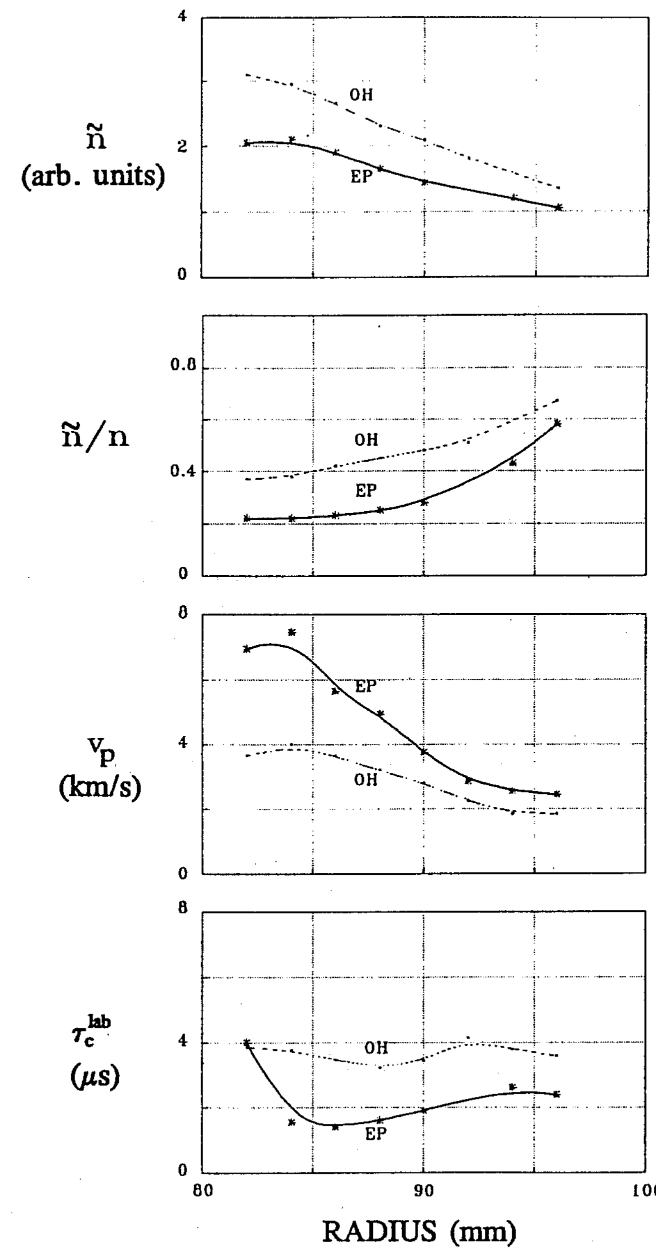


FIG. 2.

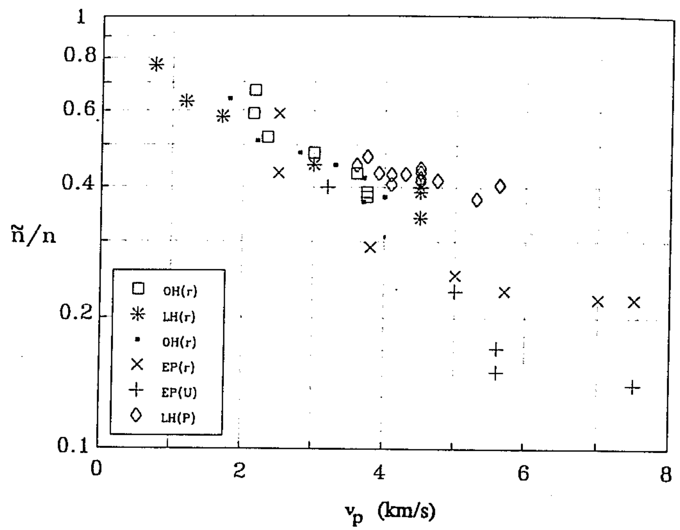


FIG. 3. Relation between the relative level of density fluctuations and their poloidal velocity obtained during measurement of the following dependences: OH(r): radial dependence in OH regimes just before LH wave (open squares) and EP (small filled squares) application; LH(r): radial dependence in LHCD regimes; EP(r): radial dependence in experiments with plasma polarization; EP(U): dependence on the voltage used for plasma polarization, r_p = 85 mm; LH(P): dependence on the LH power, r_p = 85 mm.

the form $(1/\tau_c^{lab})^2$ versus v_p^2. Dependences are represented by lines with different (but constant) derivatives $(1/\lambda_c)^2$ and quotients $(1/\tau_c^{rest})^2$, determining the real correlation length and time of fluctuations. This suggests that the correlation length and time of the density fluctuations are constant throughout the SOL. It should be noted, however, that two points which correspond to the EP case and to the probe positions r < 85 mm = a are out of line (the diamonds in Fig. 4).

3.4. Limiter biasing

To generate additional radial currents j_r in CASTOR, an alternative method of edge plasma polarization using the biased limiter has also been tested. As an example, the evolution of a shot with limiter biasing is given in Fig. 5. Two phases are distinct in this figure. The fast transition between them appears at the moment when the limiter current reaches 60 A. At this moment the limiter current suddenly drops (owing to a decrease of the perpendicular conductivity) and an improvement of the global particle confinement by a factor of 2 occurs. The first phase is characterized

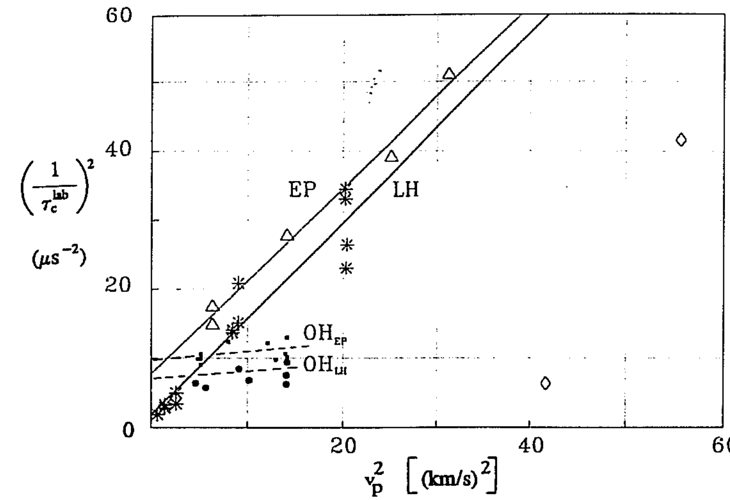
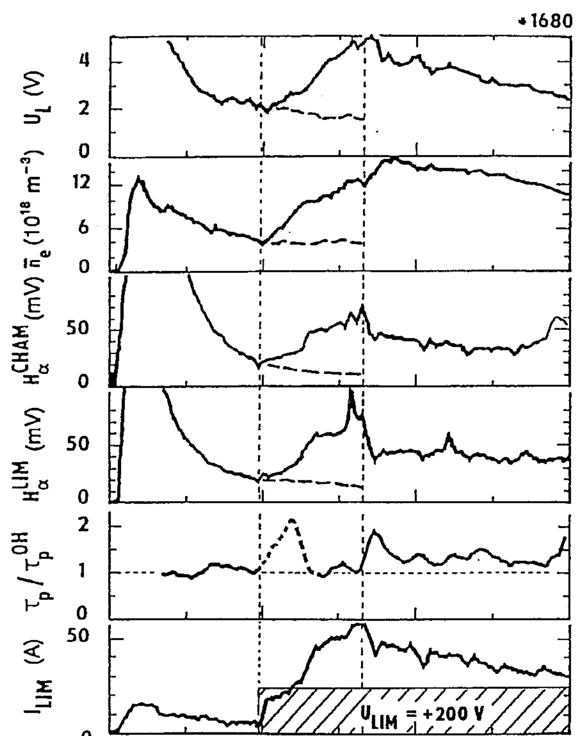


FIG. 4. Plots of measured autocorrelation time $((1/\tau_c^{lab})^2)$ versus measured poloidal velocity (v_p^2) in OH, LHCD and EP regimes.



4. SUMMARY

The analysis of three different regimes of CASTOR operation has shown that the behaviour of edge density fluctuations exhibits some characteristic features:

(a) A clear exponential dependence between the relative level of density fluctuations and their poloidal velocity, independent of the regime of tokamak operation and the probe position, is evident.
(b) The reduction of electrostatic fluctuations is not in every case accompanied by an increase of the global particle confinement.
(c) The electrostatic fluctuations can be described in every regime as fast changing but compact formations with only a single value of correlation time and length.
(d) The correlation characteristics of these formations can be substantially modified by both LHCD and EP application, independently of whether or not improvement of global particle confinement is observed.
(e) However, this modification seems to have a variable character: while the correlation length decreases substantially in both cases (from about 30 to 10 mm), the correlation time changes only in the case of LHCD (it increases from about 4 to 8 μs).

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