The Role of Power and Magnetic Connection to the Active Antenna in the suppression of Intermittent Structures by Ion Cyclotron Resonance Heating

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abstract The effect of the ion cyclotron resonance heating (ICRH) on the scrape-off layer (SOL) is still an open issue [G. Antar *et al.* Phys. Rev. Lett. 2010]. On the Tore Supra tokamak, the turbulence level is reported to drop from about 40% to 25% for $P_{ICRH} > 0.5$ MW. We also found that the toroidal connection by the magnetic field lines to the active antenna is not critical in the sense that turbulence in regions close to the antenna but not directly connected are affected. For regions, however, far from the active antenna turbulence does not change much when applying ICRH.

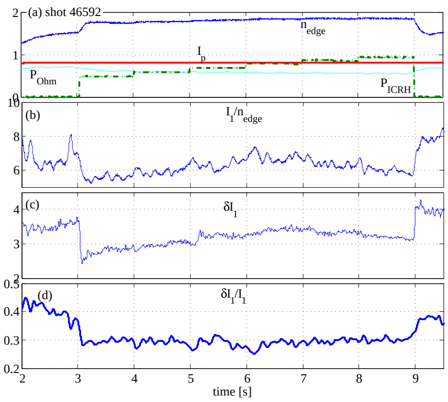

Figure 1: In (a) we inserted the plasma current, I_p in MA in thick solid line, the edge plasma density $n_{edge}/10^{19}$ m^{-2}, the ohmic power, P_{Ohm} in MW and the dash-dotted line the ICRH power P_{ICRH} in MW. In (b), we plot the average I_{sat} normalized to the edge plasma density. In (c), the standard deviation of I_1 is plotted as a function of time and in (d) the normalized level of fluctuations is shown to decrease from about 0.4 to 0.28.

Introduction The first study to report turbulence decrease in the presence of ICRH was done on the compact helical system (CHS) by Morisaki *et al.* who observed a decrease in the level of fluctuations outside the last closed flux surface (LCFS) for a threshold of 300 kW [1]. On the other hand, it was shown that intermittency in the SOL is caused by convective large-scale structures that are called avaloids [2, 3, 4]. In Ref. [5], the effects of ICRH on turbulence in-between ELMs and on the ELM-induced transport was studied on the ASDEX-Upgrade tokamak where it was reported that turbulence intermittent bursts in the SOL were suppressed leading to Gaussian distribution functions and a strong modification of the power spectra. The effects of ICRH on ELMs were observed to be important with a reduction of a factor of 3 in the induced transport with respect to NBI-H-mode plasmas.

The experimental procedure The experiments studied here are performed on the Tore Supra tokamak where L-mode discharges are either ohmically heated or additional ICRH is used. The plasma current ranges from 0.5-1.2 MA with a toroidal magnetic field about 3.8 Tesla and a major and minor radii respectively about 2.4 and 0.7 m.

Turbulence behavior as a function of the ICRH power The plasma current is set to 0.8 MA, this way we are certain that the field lines in front of the fixed mid-plane Langmuir probes are magnetically connected to the active antenna Q5. Fig. 1(a) shows that the main plasma parameters are rather constant throughout the plateau except for the ICRH power which is increased by steps lasting 1 s from 0.5 to 0.9 MW. As the ICRH power is switched on, the edge average plasma density, determined from the interferometer at $r/a = 0.8$, slightly increases. Consequently, we normalize the ion saturation current obtained from the Langmuir probe to this edge density, hence, taken as a reference. The result is plotted in Fig. 1(b). The level of fluctuations detected by the fixed probes is illustrated in Fig. 1(c) where it decreases sharply as the ICRH is switched on. The normalized level of fluctuations is shown in (d) as a function of time. As soon as the ICRH power is switched on, the turbulence level decreases from 0.42 to 0.28, that is by 30%. This decrease remains almost unchanged as the ICRH power is increased from 0.5 to 0.9 MW.

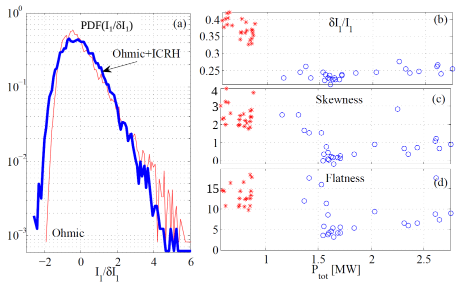

Figure 2: The PDF of the ion saturation current normalized to the standard deviation is plotted in (a) for ohmic and ICRH plasmas. In (b), (c) and (d) respectively we have the normalized level of fluctuations, the skewness and the flatness factors.

The probability distribution function (PDF). In Fig. 2(a), we illustrate two typical examples of the PDF for an ohmic discharge, in thin solid line, and in the presence of ICRH, in thick solid line. The high intensity positive events are occurring less frequently as the PDF there is narrower on the positive side. ICRH leads to a more symmetric distribution, hence a skewness factor closer to 0. The flatness factor characterizes the weight of the tail of a distribution and is equal to 3 for a Gaussian. For ohmic discharges without ICRH, $F \simeq 10$, but as ICRH is switched on, it drops to about 4, a value closer to 3.

The Cross-correlation Coefficient. In Fig. 3(a), we compare two cross-correlation coefficients with and without ICRH. Two aspects are readily noticed: the decrease of the amplitude of the cross-correlation and its width. The maximum value of Cx_{12} is plotted in Fig. 3(b) where a net decrease of the amplitude is recorded going from about 0.7 to 0.25. Because the cross-correlation amplitude is caused by the turbulent structures with size greater or equal than the distance between the two probes, its decrease directly reflects the decrease of events with scales greater than 1 cm. In Fig. 3(d), we show the full width ($\Delta\tau$) at $max(Cx_{12})/e$. It decreases from about 80 to about 20 μs when ICRH is on. The width in time is caused by (1) the spatial scales of the fluctuations and (2) their velocity. Here, we note a dramatic drop by a factor of 4. The increase in the velocity was assessed in Fig. 3(c) where it is estimated that it would lead to a drop of about 40% of the width far smaller than what is recorded.

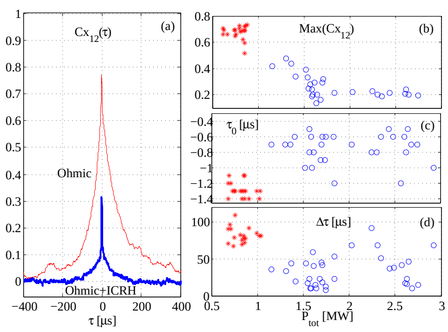

Figure 3: The cross-correlation coefficient between probes 1 and 2 , $Cx_{12}(\tau)$ as a function of time τ is plotted in (a). In (b), the maximum of Cx_{12} is plotted as a function of the total power. In (c), we illustrate the time corresponding to the maximum amplitude τ_0 as a function of P_{tot}. (d), the width of Cx_{12}, denoted by $\Delta\tau$ as a function of P_{tot}.

Modifying the plasma current. We modify the plasma current keeping the toroidal magnetic field constant leading to tilting the field lines and thus changing the probe connection to the active antenna. In Fig. 4(a), we plot as a function of time the ICRH power which is maintained constant about 1 MW, the plasma edge density which is observed to increase with plasma current and the latter. In (b), the normalized level of turbulence of probe 1 is shown to as a function of time. It decreases sharply from about 40% to 30% as the ICRH power is turned on. For I_p between 0.8 and 1 MA, the level of turbulence is not modified. Only when I_p is set to 1.1 that the fluctuation level increases slightly to 35%. We deduce that the level of turbulence tends to regain its ohmic value at high values of the plasma current most probably due to the magnetic connection to the active antenna but achieve it fully only after ICRH is switched off.

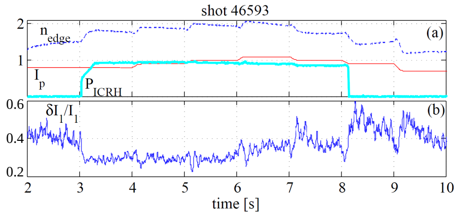

Figure 4: (a), the main plasma parameters for discharge 46593 where the ICRH power from the Q5 antenna (in MW and thick solid line) remained constant and the plasma current (thin solid line) is changed from 0.8 to 1.1 MA in plateaus each lasting 1 s. The plasma edge density is plotted (dashed line) is in 10^{19} m^{-2}. In (b) the relative level of the ion saturation current fluctuations as a function of time. Note that it does not change with plasma current.

Discussion and Conclusion. Turbulence level is detected to decrease by 30% and the convective structures are reduced but not completely suppressed. The PDF is closer to a Gaussian distribution and the behavior of the cross-correlation coefficient between the two toroidally distanced probes shows a net decrease of its amplitude and width. Furthermore, it was found that the decrease of turbulence and the modification of the structures in the SOL do not depend on the ICRH power as along as it is greater than some critical value. Changing the plasma current leads to closed field lines which may not be connected to the active antenna but remain in its vicinity. We do not detect a dependence above the experimental precision with respect to the plasma current. When the antenna is meters away, however, the effects on turbulence are rather weak.

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