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** See annex of F. Romanelli et al, "Overview of JET Results", (Proc. 22nd IAEA Fusion Energy Conference, Geneva, Switzerland (2008)).*

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INTRODUCTION

At low Scrape-Off-Layer (SOL) density n_{SOL}, a gas puff is frequently applied at Lower Hybrid (LH) heating at JET, in order to increase the LH density and to decrease the reflection coefficient R. However, in absence of a sufficient amount of the neutral gas in front of the grill, the observed reflection coefficient R of the grill can increase as a function of the LH power PLH. This R increase is caused by a decrease of the SOL density nSOL just in front of the grill mouth. Similar effects observed on ASDEX [1] and recently on Tore Supra [2] were explained by expulsion of the plasma from the grill mouth along magnetic field B-lines by ponderomotive forces of the launched LH wave [1,3]. In order to explore the ponderomotive force effects on JET, the EDGE2D code was now modified in order to include the ponderomotive forces: In the momentum equation for the electron fluid, a net time averaged force [1, 3] acting on electrons due to the LH field gradient was included in EDGE2D. This force expels electrons away from the grill mouth, the ions follow due to the Coulomb charge separation force.

1. ASSUMPTIONS AND METHOD:

The electric field of the LH wave and the corresponding ponderomotive force value is computed for each time step of the EDGE2D code, using the modified LH wave propagation code and the boundary conditions [1]. This value of the ponderomotive force is used by EDGE2D for computation of the density profile in the next time step, and then the density profile is returned into the LH propagation code, etc. A new equilibrium taking into account ponderomotive force effects is reached usually after a time interval of about 50ms. A reduction of n_{SOL} by ponderomotive force effects in front of the grill mouth [1-3], and enhancement of n_{SOL} by direct LH SOL ionization [4] are thus taken into account. Let us note that the ponderomotive force [1,3] is proportional to the negative value of the gradient of the square of the LH electric field intensity E, and that the density depletion explored in a stationary equilibrium depends only on the ratio of the ponderomotive potential $W \sim E^2$ and on the plasma temperature, not on the characteristic length L of W or E decrease along the magneto-static field on the sides of the grill. This decrease was modeled as a linear decrease. We choose for modeling a series of similar shots with a wide SOL. For these shots, it was possible to create a wide enough SOL in the code up to about 8 cm in the OMP (Outer Mid-Plane), for which the far SOL temperature is of the order of several eV, comparable to the ponderomotive potential. In agreement with this, the parasitic absorption (input of the EDGE2D code) is assumed to take place between 5 and 8cm from the separatrix, with a maximum plateau between 6 and 7cm. The enhanced ionization arises due to enhanced far SOL temperature by the local parasitic LH wave absorption. The radial extension of the limiters is variable in the modeling: When the grill side limiters do not protrude from the wall, with their top at the same level with the wall at 8cm from the separatrix, the computed ponderomotive density depletion is found negligible. The computed ponderomotive density depletion is significant only with the variable length limiters protruding from the wall to an extent, in which a part (or all) of the parasitic absorption is radially inside the limiters, i.e. in the grill private space. It is assumed in all the computations presented here that the nearest grill limiters are protruding from the wall, with their top located 5cm from the separatrix.

2. RESULTS

In the figures, we show results for the JET Pulse No: 66972. It was found that the computed density depletion in front of the grill almost does not depend on L, when L was varied from about 10 to about 30cm, in agreement with the analytical results obtained for the stationary equilibrium [1,3]. The ponderomotive density depletion was computed for various PLH values and gas puff rates; of course, the code computes in the same time also other plasma parameters, like plasma and neutral particle temperature, velocity, ionization rate, etc. The blue (diamonds) line and black (rectangles) line curves (Fig.1) are plotted for the case of a zero puff and assuming no direct ionization by the LH wave.

While the LH power is zero for the case of the blue (diamonds) curve, the ponderomotive forces are switched-on for the black line, and the LH power is 20MW/m^2 (about 5MW for the whole launcher). The red (triangles) curve shows the case with ponderomotive forces and ionization. The green (circles) curve in Fig.1 then shows a hypothetical case of ten times higher ponderomotive forces and ionization accounted for. The average E computed in the code near the grill mouth is E ~ 2kV/cm. It decreases from the grill mouth in the direction of the separatrix. As the temperature increases in the same direction, the ponderomotive effects are most emphasized just in about 1 or 2cm layer in front of the grill mouth. It is obvious that the ponderomotive force effects decrease the plasma density significantly in this case, what may lead to the LH coupling deterioration. For the case of the red curve (triangles), it is assumed that the plasma is ionized directly by the LH wave, and it is assumed that 150kW is parasitically absorbed in front of the grill mouth. It is obvious that the ponderomotive forces are now not strong enough to decrease the density in front of the grill. On the contrary, the density increases because of the direct ionization in front of the grill. A significant decrease of the density arises when one assumes about ten times higher value of the ponderomotive force: This case is shown by the green (circles) curve.

The effect of ponderomotive forces is shown in Fig.2. for the case that the ionization is accounted for: The red (triangles) curve again as in Fig.1. shows the case with ponderomotive forces and ionization, while the blue (diamonds) curve in Fig.2 shows the case with ponderomotive forces switched off. The green (circles) curve in Fig.2 again as in Fig.1 shows a hypothetical case of ten times higher ponderomotive forces and ionization accounted for. The Fig.3 then shows effects of the gas puff (5.e21 el/s) in front of the grill, the direct ionization by the LH wave in front of the grill is accounted for. The blue (diamonds) curve shows the case without ponderomotive forces, while the black (rectangles) curve shows the case with ponderomotive forces switched on in the code. The red (triangles) curve then shows the same, but again assuming ponderomotive forces ten times higher. One can see that also in the case of the gas puff, similarly as for the zero puff, only ponderomotive forces about ten times stronger than computed can expel the plasma from in front of the grill mouth, when the direct ionization by the LH wave is taken into account.

CONCLUSION:

(i) Without taking into account the gas ionization in front of the grill mouth, the computed density in front of the grill can decrease significantly due to the ponderomotive depletion for launched LH powers of about 5MW (about 20MW/m^2). (ii) The ponderomotive forces are not strong enough to expel the plasma from in front of the grill mouth, when the direct ionization by the LH wave is taken into account. (iii) For ponderomotive forces about ten times higher, the plasma density would decrease in front of the grill mouth even with the gas puff directly ionized there. Such strong expelling effects could be perhaps provided by locally in front of the grill generated fast electrons, which escape from the grill and create an electric field of charge separation, pushing ions from the locations in front of the grill mouth [5]. The expelling effect of the fast particles needs to be accounted for in future modeling, but the way how to do this is not obvious.

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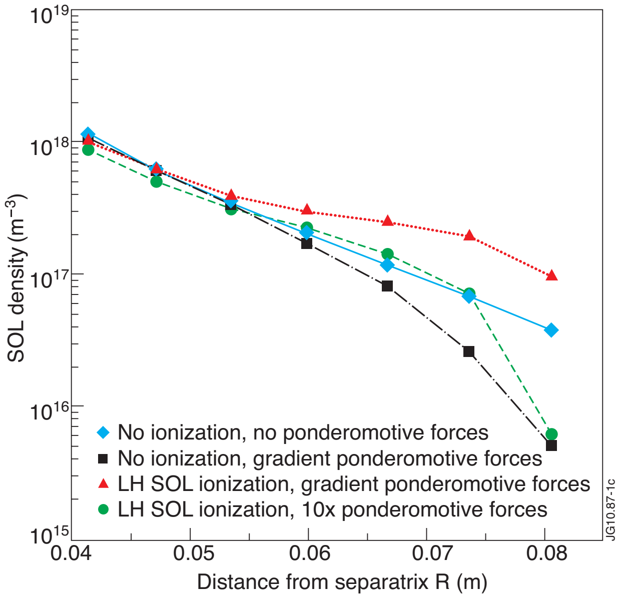

Figure 1: Density depletion due to ponderomotive forces, no gas puff.

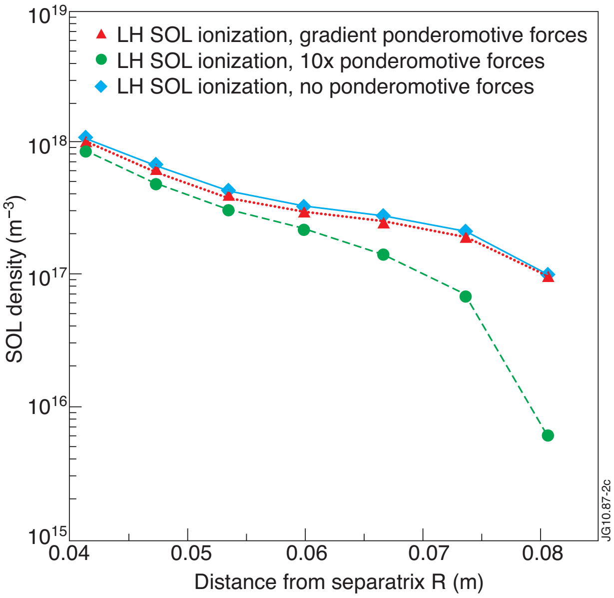

Figure 2: Density depletion, ponderomotive forces, ionization, no gas puff.

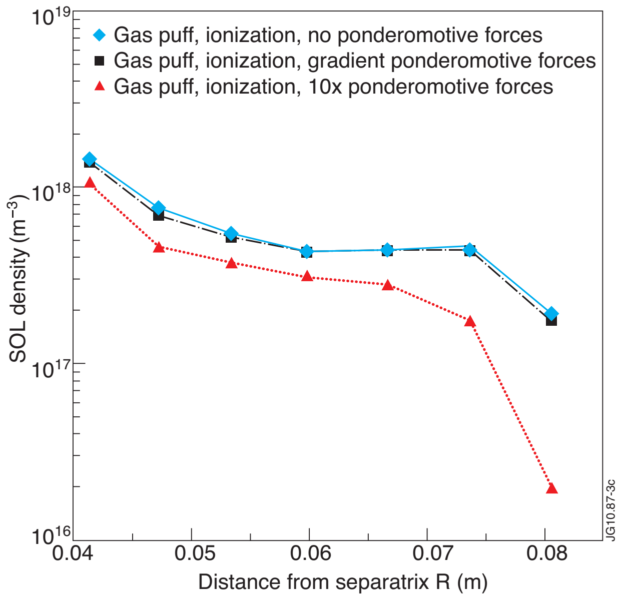

Figure 3: Effects of the gas puff.