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Effect of the relative shift between the electron density and temperature pedestal position on the pedestal stability in JET-ILW

E. Stefanikova[1], L. Frassinetti[1], S. Saarelma[2], A. Loarte[3], I. Nunes[4], P. Lomas[2], F. Rimini[2], P. Drewelow[2], L. Garzotti[2], U. Kruezi[2], B. Lomonowski[2], E. de la Luna[5], L. Meneses[2], M. Peterka[6,7], B. Viola[8], and JET contributors*

EUROfusion Consortium, JET, Culham Science Centre, Abingdon, OX14 3DB, UK

[1]*Division of Fusion Plasma Physics, KTH Royal Institute of Technology, Stockholm SE*

[2]*CCFE, Culham Science Centre, Abingdon, OX14 3DB, UK*

[3]*ITER-Organisation, St Paul Lez Durance,France;* [4]*Instituto de Plasmas e Fusao Nuclear, IST, Lisboa, Portugal*

[5]*Laboratorio Nacional de Fusion CIEMAT, Madrid, Spain*

[6]*Institute of Plasma Physics AS CR, Prague, Czech Republic*

[7]*Charles University in Prague, Faculty of Mathematics and Physics, Prague, Czech Republic*

[8]*ENEA, C.R. Frascati, Via E. Fermi 45, Rome, Italy*

* *See the Appendix of F. Romanelli et al., Proceedings of the 25th IAEA Fusion Energy Conference 2014, Saint Petersburg, Russia*

1. INTRODUCTION

The pedestal structure and its stability affect the performance of a tokamak fusion device. As it has been already observed in DIII-D in [1], the electron temperature (T_e) and density (n_e) pedestals tend to vary in their relative positions in correlation with ρ*. Change in the relative positions seem to have an impact on the pedestal MHD stability and hence on the pedestal height [2]. This work investigates the effects of the relative pedestal positions on the stability of JET-ILW. It shows that the increase of the pedestal relative shift is correlated with the reduction in the normalized pressure gradient. Experimental results are then compared with the peeling-ballooning (P-B) model. Normalized pressure gradient is then also calculated for extended dataset of JET-ILW baseline low δ pulses and compared with low δ JET-C pulses.

2. RELATIVE SHIFT DEPENDENCE ON GAS PUFFING

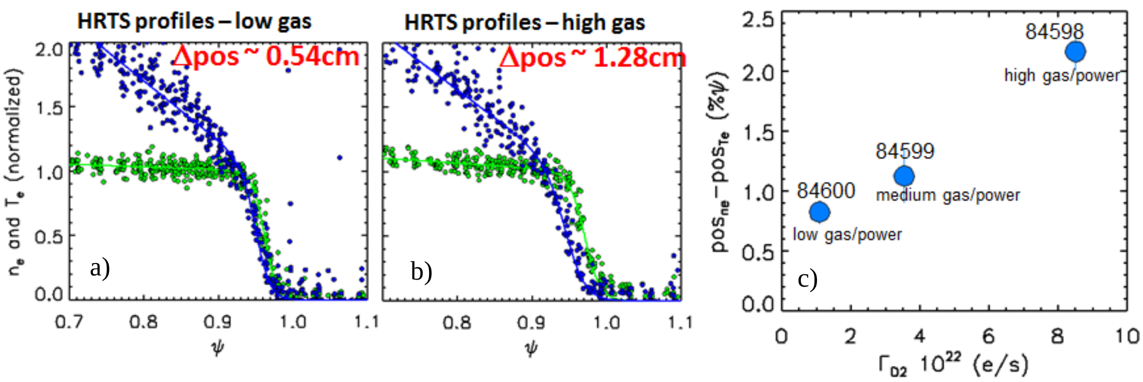

Figure 1. (a) Pedestal T_e and n_e profiles – low gas, (b) pedestal T_e and n_e profiles – high gas, (c) pedestal relative shift vs the gas for the gas scan pulses with constant β

Since β affects the pedestal stability, it is convenient for this analysis to keep it constant to reduce its influence. The effect of the pedestal relative shift on the stability is introduced using a dataset, where a gas scan was performed at constant β ($\beta=2\mu_0\langle p\rangle/B^2$), plasma current I_p=2MA, magnetic field B=2T, and safety factor $q_{95}\approx3$. For the different levels of gas puffing, the target β was achieved by increasing the additional input power (P_{NBI}). In order to keep β constant, the power is varied by ≈40% from 6.5 to 10.5 MW, while other parameters like the effective charge number Z_{eff}≈const, volume averaged collisionality $<\nu^*>$≈0.2, and the electron and ion temperature $Te \approx Ti$ (both in the core and in the pedestal region) were kept constant. It has been observed that the increase of gas puffing led to a degradation in the energy confinement time τ_E from 0.23 to 0.37 s (approximately 40%). The reduction of τ_E cannot be ascribed to the reduction in the stored energy, as both the core and the pedestal T_e and n_e have minimal and no systematic variation (≈6% and 9% respectively). A major difference is present in the pedestal structure. As shown in figure 1(c), the increase of the gas (and power) leads to the increase in the relative shift between the n_e and T_e pedestal position, as the pedestal n_e tends to move more outwards [figure1(a), 1(b)]. This has an effect on the experimental pressure gradient. For a more direct comparison with the theory, figure 2(a) shows the experimental pressure gradient α_{exp} calculated according to [3]:

$$\alpha = -\frac{2\partial_\psi V}{(2\pi)^2}\left(\frac{V}{2\pi^2 R_0}\right)^{1/2}\mu_0 p' \qquad (1)$$

where ψ is the poloidal flux, V is the plasma volume, R is the major radius, μ_0 is permeability in vacuum, and p' means the pressure derivative in ψ. With the increase of the relative shift, α_{exp} is reduced by ≈ 40% similarly to the energy confinement time reduction. Second, the pedestal pressure width is affected and tends to increase [figure 2(b)].

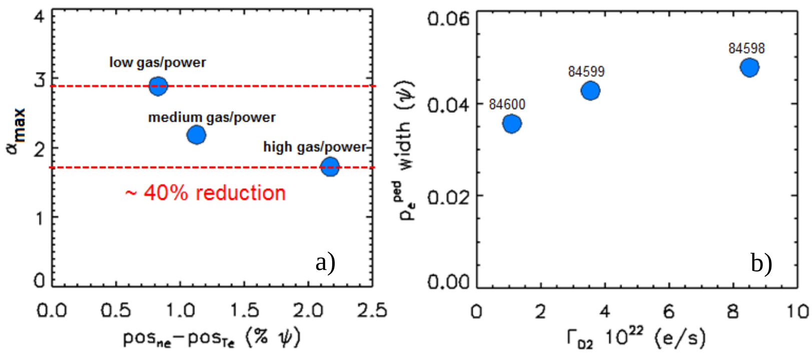

Figure 2. (a) α_{exp} vs the relative shift for the gas scan with constant β, (b) pedestal pressure width vs gas

3. STABILITY ANALYSIS AND COMPARISON WITH EXPERIMENTAL DATA

The P-B model has been used to study the pedestal stability and the P-B stability boundary has been determined using the ELITE code [4]. The boundaries for the three pulses described in Section 2 are shown in figure 3(a) along with the respective operational points. Results obtained from the stability analysis suggest an explanation of how the reduction in the relative shift leads to an improvement of the pedestal stability. The j-α diagram [figure 3(a)] shows that with the reduction of the relative shift both the operational point and the stability boundary move to higher α. This is mainly due to the reduction of the ν^* in the middle of the pedestal with reduced shift, leading to an increase of the edge bootstrap current [5], [figure 3(b)]. Also, as the n_e pedestal moves closer to the T_e pedestal, pressure gradient moves slightly inwards near the separatrix region [6]. Third, the reduction of the shift leads to an increase of the pressure gradient and hence to an increase of the bootstrap current density [figure 3(b)], further improving the pedestal stability [6].

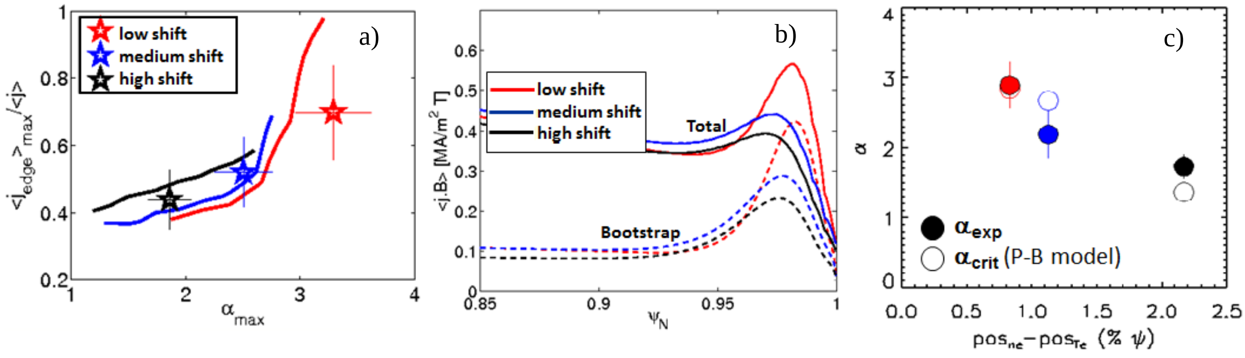

Figure 3. (a) j-α stability diagram, (b) parallel current densities - total and bootstrap, (c) experimental results and the P-B model

Furthermore, the pressure pedestal width is reduced, which tends to move the stability boundary to higher α [7]. Considering the shape of the stability boundary, moving the operational point in j-α diagram to higher j values allows the achievement of higher values of α_{crit} (intersection of the self-consistent path with the stability boundary) in favour of the stability improvement. Figure 3(c) summarizes the experimental results (α_{exp}) and results from stability analysis (α_{crit}), showing that P-B model is capable to predict the improvement of α with the reduction of the relative shift.

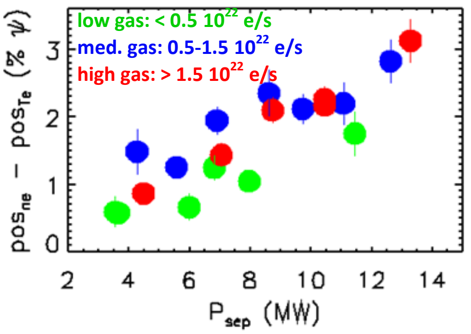

Figure 4. Relative shift vs the power through the separatrix

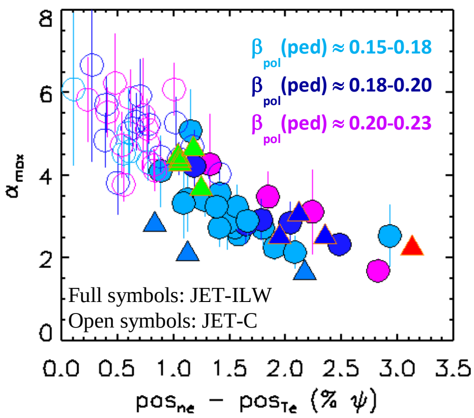

Figure 5. α_{exp} vs the relative shift for JET-ILW low δ baseline pulses (full dots), JET-ILW gas scan at constant β (light blue triangles), power scan at three gas levels (green, blue and red triangles) and low δ JET-C pulses (open symbols)

4. RELATIVE SHIFT DEPENDENCE ON POWER

The results of the previous section show that the relative shift is correlated with the increase in gas and/or power. To investigate which of these two parameters affects the shift, three power scans performed with different gas level have been analyzed (figure 4). Keeping the gas constant, the increase of the relative shift with increasing power through the separatrix (P_{sep}) has been observed. At constant P_{sep}, the increase of the relative shift with gas has been observed, although there is no major difference between the medium and high level of gas. This might suggest that there is a saturation level for the increase of the relative shift with gas.

5. COMPARISON OF JET-ILW WITH JET-C

Different plasma facing component materials might affect the atomic physics, the ionization source profile and hence the pedestal density position and consequently the pedestal stability. Therefore, the analysis has been extended to a larger set of JET-ILW plasmas and to a set of JET-C discharges with collisionality at the pedestal $\nu^*(ped)$ and $\beta_{pol}(ped)$ comparable to the JET-ILW dataset. Figure 5 shows α_{exp} versus the relative shift for all pulses analyzed in this paper. JET-ILW pulses from the extended dataset have plasma current in the range I_p≈2-3.5 MA, $\nu^*(ped)$≈0.1-0.35, $\beta_{pol}(ped)$≈0.15-0.23. The JET-ILW power scan pulses with matching $\beta_{pol}(ped)$ and $\nu^*(ped)$ have been added to this plot for comparison, as well as the three JET-ILW gas scan pulses described in the previous sections. The gas scan pulses have a similar trend, but due to the higher normalized collisionality at the pedestal ($\nu^*(ped)$≈1.1) they have a lower α. These results would suggests a scaling of α with ν^* for JET-ILW.

JET-C pulses (plotted with open symbols in figure 5) have plasma current in the range I_p≈2.5-4.5 MA. From figure 5, several observations can be made. First, α_{exp} shows a decreasing trend with the relative shift for both JET-C and JET-ILW for all three selected ranges of $\beta_{pol}(ped)$. Second, JET-C tends to have a smaller relative shift compared to JET-ILW. This might suggest that different plasma facing components can affect the pedestal density position. Finally, for similar values of the relative shift, α_{exp} of JET-C is comparable to α_{exp} of JET-ILW.

6. CONCLUSIONS

The role of the pedestal relative shift in the pedestal stability has been investigated. Analysis on a JET-ILW gas scan dataset at constant β has shown that the increase of the relative shift is related to the reduction in the normalized pressure gradient α. Stability analysis shows an improvement in the pedestal stability when the relative shift is reduced in agreement with the experimental results. This improvement seems related mainly to the increase of the edge bootstrap current, but also the inward shift of the pedestal pressure and the pedestal pressure width reduction might help the stability improvement. α_{crit} from j-α diagram shows a good agreement with α_{exp}. Comparison of JET-C and JET-ILW data with same $\beta_{pol}(ped)$ and $\nu^*(ped)$ shows that JET-C tends to have a smaller relative shift than JET-ILW, and that α tends to have a decreasing trend with the relative shift. Moreover, for similar values of the relative shift, α of JET-C is comparable to α of JET-ILW. As a final note, the degradation in pedestal confinement in JET-ILW does not always have to be related to the change in the relative shift. Preliminary analysis of 2MA, low and high δ pulses in the corner configuration has shown that the confinement degradation with increasing gas or change in the divertor configuration was not correlated with the relative shift. Similar preliminary results were obtained comparing nitrogen seeded and unseeded high δ discharges.

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