Pedestal structure in high current scenarios in JET-ILW and JET-C

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INTRODUCTION

Developing a reliable high performance baseline scenario compatible with D-T operation has been one of the major objectives during recent JET experimental campaigns. During the 2014 experimental campaign, JET-ILW has reached up to 4.5MA in the baseline scenarios in quasi-stationary conditions.

During the 2016 experimental campaign, the performance of JET-ILW was improved by pellet injection, reaching confinement comparable to JET-C at 3MA. Study of the pedestal structure of these high performance pellet fueled discharges will be objective of future work. Instead, the earlier high current JET-ILW results showed lower confinement than in JET-C [1,2]. This was mainly ascribed to a lower pedestal temperature (T_e^{ped}), while the pedestal density (n_e^{ped}) was comparable. The origin of this difference is not fully understood. The goal of this work is to compare the pedestal structure in these earlier JET-ILW discharges with JET-C in order to investigate if a possible difference might influence the pedestal stability.

So far, only one significant difference has been observed in the pedestal structure of JET-ILW and JET-C discharges. In JET-ILW the pedestal density position is not aligned with the position of the pedestal temperature [3]. This so called 'relative shift' (separation between the middle of the density and temperature pedestals) seems to play a role in the pedestal stability, as the increase of the relative shift leads to the reduction of bootstrap current which might then reduce the normalized pressure gradient [3]. In JET-C, the relative shift tends to be lower than in JET-ILW. However, other parameters of the pedestal structure, such as pressure width, position and separatrix density, can influence the stability [4,5,6]. The behavior of these parameters will be investigated in this work, focusing on phenomenological differences between JET-ILW and JET-C from the experimental point of view. The pedestal behavior will be further investigated in terms of the peeling-ballooning (P-B) stability.

PEDESTAL PARAMETERS AFFECTING THE PEDESTAL STABILITY

The pedestal parameters that might play a role in pedestal stability are (i) pedestal relative shift, (ii) pressure pedestal width, (iii) pressure pedestal position (p_e^{pos}), (iv) separatrix density (n_e^{sep}). Analysis has been carried on a dataset of JET-ILW and JET-C low δ, baseline unseeded discharges with large variation of operational parameters – plasma current range I_p=2.0-3.5MA, gas rate Γ_{D2}≈1-10 10^{22} e/s, NBI power P_{NBI}≈4-26MW. Analysis of the pedestal structure has been performed using profiles of electron temperature and density from high-resolution Thomson scattering diagnostics on JET.

(i) Relative shift. Operational parameters (gas fueling and heating power) affect the relative shift [3], so restrictions in the datasets were made where possible, in order to have comparable ranges between JET-ILW and JET-C. Figure 1a) shows the correlation of the experimental normalized pressure gradient (α_{exp}) calculated according to [7], with the pedestal relative shift for three levels of plasma current. α_{exp} is roughly proportional to pressure gradient divided by I_p^2 and can be used for comparison with P-B model. For each I_p, there is an increasing trend of α_{exp}, when the relative shift is reduced. The reduction of the relative shift produces an increase in the bootstrap current in the middle of the pedestal [3]. This might lead to an increase of the pedestal stability. (ii) Pressure width. The increase of the pressure pedestal width can lead to reduction of the P-B stability [5]. Figure 1b) shows the correlation of the pedestal pressure width with I_p, for a subset of discharges. Pressure width for JET-ILW discharges tends to be higher at each I_p level, again suggesting reduced pedestal stability compared to JET-C. (iii) Pedestal position. An inward shift of p_e^{pos} leads to improvement of the P-B stability due to a reduction of the separatrix bootstrap current [6]. On JET, there is not a major difference in the experimental p_e^{pos} between JET-ILW and JET-C, although p_e^{pos} of JET-C tends to move slightly outwards with increasing I_p and gas fueling [figure 1c)]. This might be caused by the fact that JET-C has a smaller pedestal width compared with JET-ILW. (iv) Separatrix density. Experimental results from ASDEX suggest that energy confinement might decrease with increase in the scrape-off layer density [8], and that there is experimental correlation between the decrease of the pressure pedestal top and increase of n_e^{sep} [4]. In JET, n_e^{sep} is estimated as a value of the electron density at normalized poloidal flux ψ=1. Both HRTS temperature and density profiles are shifted in order to have T_e =100eV at the separatrix. Initial results suggest that n_e^{sep} tends to increase with I_p for both JET-ILW and JET-C, and that n_e^{sep} of JET-C tends to be slightly lower than in JET-ILW [figure 2a)]. The difference between JET-ILW and JET-C is more significant in ratio between n_e^{sep} and n_e^{ped} [figure 2b)]. n_e^{sep} has been compared with density at the bottom of the pedestal as estimated from lithium beam and the reflectometer. Unfortunately, very few JET-C discharges have Li-beam or reflectometer measurements available. The density at the bottom of the pedestal was estimated by linear fits. Results are shown in figure 3a) for the lithium beam, and in figure 3b) for the reflectometer. Both diagnostics show a similar qualitative trend to the trend of n_e^{sep} with I_p. Moreover, despite the few data, the density at the bottom of the pedestal for JET-C tends to be lower compared to JET-ILW, consistently with observation for n_e^{sep} from figure 3.

STABILITY ANALYSIS

In order to compare the experimental findings on pedestal stability with the theory, the pedestal stability has been also studied in terms of the peeling-ballooning (P-B) model [9].

The aim was to compare critical values of the normalized pressure gradient (α_{crit}) obtained using ELITE code, for both JET-ILW and JET-C at each I_p (where possible). α_{crit} can be considered as the maximal α expected by the P-B model, and can be used for direct comparison with α_{exp}. The discharges were selected to have values of engineering parameters (P_{NBI}, gas, q_{95}), and other parameters like T_e^{ped}, n_e^{ped}, $\nu^{*,ped}$, and β_{pol}^{ped} close to the average in their corresponding I_p levels. Figure 3c) shows correlation of α_{crit} with I_p. For I_p=2MA, there is no JET-C data available in sufficient quality that could be used for stability analysis. α_{crit} for both JET-ILW and JET-C tend to increase. The increase with I_p seems stronger for JET-C.

CONCLUSIONS

In this work, parameters of the pedestal structure that might play a role in pedestal stability of JET-ILW and JET-C have been studied in low δ, baseline unseeded discharges. Experimental results show that the pedestal relative shift, pedestal pressure with and separatrix density tend to be higher in JET-ILW than in JET-C. In principle, all of these factors can contribute to a decrease of the pedestal stability. The behavior of the pedestal stability seems to show a qualitative agreement with these experimental results. The objective of the future work will be a further investigation of these experimental differences and a comparison with theory in order to determine the exact role of these parameters in the pedestal stability.

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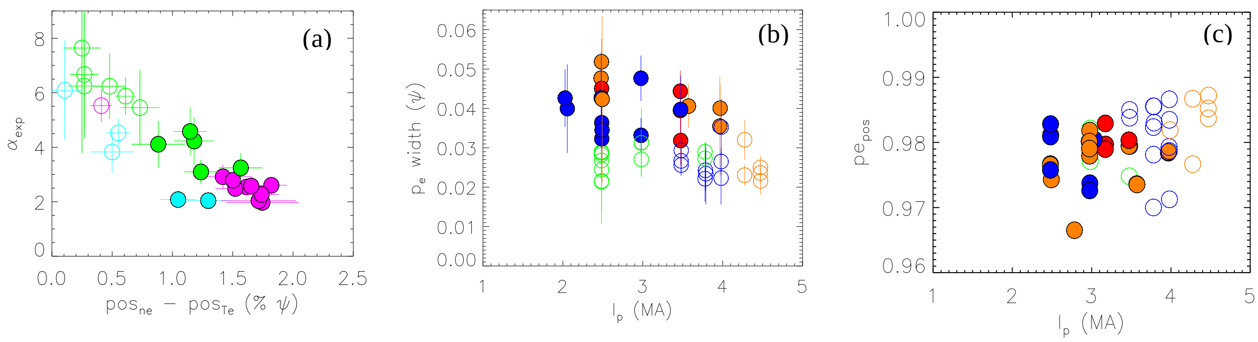

Figure 1. (a) Correlation of the experimental normalized pressure gradient with the relative shift for JET-C (open symbols) and JET-ILW (full symbols) for I_p = 2.5MA, 3MA and 4MA (green, magenta and light blue, respectively). (b) Pressure pedestal width and (c) pedestal pressure positions vs I_p for four gas levels (Γ_{D2}<1.10^{22}e/s, Γ_{D2}=1-3.10^{22}e/s, Γ_{D2}=3-4.10^{22}e/s, Γ_{D2}>4.10^{22}e/s, green, blue, orange and red, respectively).

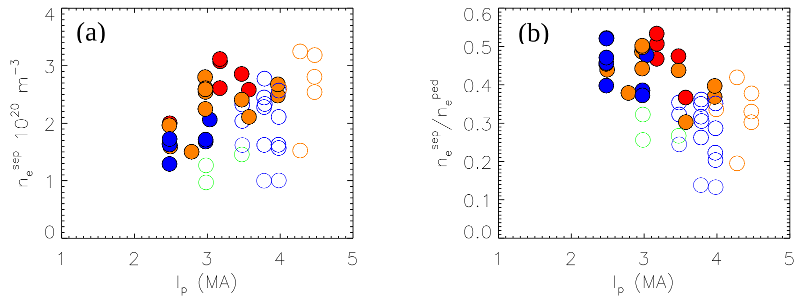

Figure 2. (a) Separatrix density and (b) ratio between separatrix density and the density at the pedestal top vs I_p for JET-C (open symbols) and JET-ILW (full symbols) for four gas levels (Γ_{D2}<1.10^{22}e/s, Γ_{D2}=1-3.10^{22}e/s, Γ_{D2}=3-4.10^{22}e/s, Γ_{D2}>4.10^{22}e/s, green, blue, orange and red, respectively).

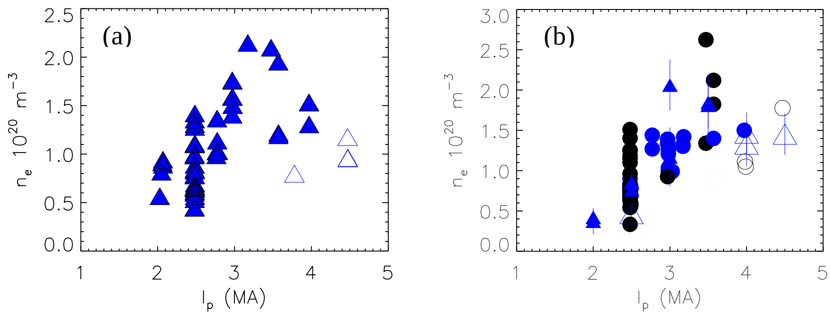

Figure 3. Density at the bottom of the pedestal from (a) lithium beam, and (b) reflectometer vs I_p for JET-C (open symbols) and JET-ILW (full symbols). Blue symbols indicate linear fit, black symbols are for modified tangent fit of the experimental data.

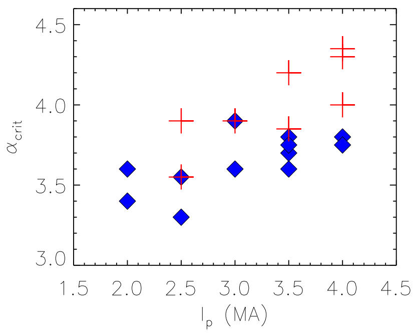

Figure 4. Comparison of normalized pressure gradient α_{crit} vs I_p for JET-C (red symbols) and JET-ILW (blue symbols).