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Edge Plasma Pressure Profile Evolution in Type I ELM Discharges on JET

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1. Introduction

An investigation is presented of the time evolution of the edge pressure profile in NB- heated ELMy H- mode discharges in JET. Discharges with parameters I = 1.6-2.5 MA, B = 1.7- 2.5 T, q_{95} = 3-3.3, ε = 1.7-1.8, δ = 0.22-0.45 have been analysed. Attention is paid to influence of P_{SOL} , δ and gas puffing on the pressure gradient ∇P(R,t) variation in the Edge Transport Barrier (ETB) area (where P_{SOL} is the power flux in scrape-off layer, δ is the triangularity). Measured ∇P is compared with the ideal ballooning mode threshold calculated using a generalised S-α formulation [1]. Results are presented on unconditional stability against ballooning modes revealed in pulses with high P_{SOL} (≈10 MW).

2. Measurement of Pressure at the Plasma Edge

Plasma pressure in the ETB area is derived from the relation $P = n_e T_e + (n_i + n_C) T_i$, where densities of electrons n_e , main ions n_i and main impurity ions (carbon) n_C were locally measured using Li-beam-emission spectroscopy [2], an Electron Cyclotron Emission (ECE) diagnostic and edge Charge-eXchange spectroscopy (CX). Location of the diagnostics is shown in Fig.1. The Li-beam system measures a 22 point electron density profile along the beam direction. Mapped onto the midplane the measurement covers a radial distance of 14 cm with r/a ≥0.8 including the separatrix. Spatial resolution is from 4 to 6 mm. Time resolution is 100 ms. Other plasma parameters are measured close to midplane with a spatial resolution of about 10 mm. Typical error bars are shown in Fig.2. Reliable electron and ion temperature measurements are not available at the separatrix. Therefore we assume that $T_i = T_e$ at the separatrix position and take the value from scaling established on JET from ReCiprocating Probe (RCP) data: $T_e(x_{sep})$ (eV) = $1.0 \times 10^{-20} \langle n_e(m^{-3})\rangle^{1.11}$. We also assume n_C = 0 at the plasma boundary. Before a deconvolution of the Li-beam emission profile and calculation of P and ∇P, the experimental distributions of T_e and T_i are fitted by smooth functions to eliminate a scatter of points within the error bar range.

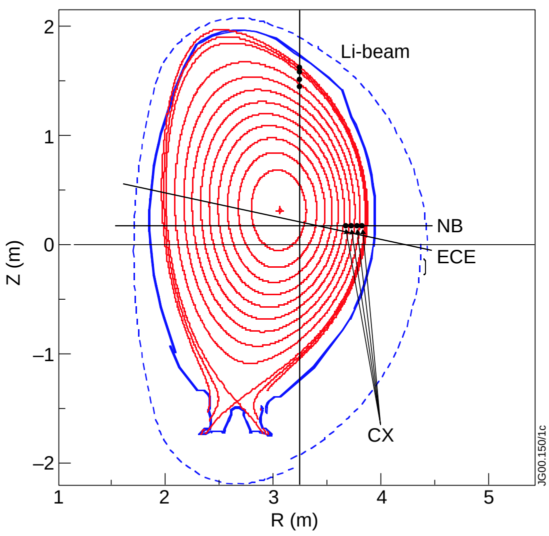

Fig.1: Location and lines of sight of the diagnostics involved in the measurements

We have checked the sensitivity of n_e, P and ∇P -profiles to uncertainty of the temperatures near the separatrix. In the example in Fig.2 a change of T_e and T_i is modelled by shifting the position of the separatrix by 5 mm inside the plasma. This changes the temperature in the vicinity of initial position of the separatrix by a factor of 2. Consequent changes of n_e, P and ∇P presented by dash curves do not exceed 12% anywhere except in an area of ≈1 cm around the separatrix position. Uncertainty in the carbon density does not contribute to the final accuracy because of low Z_{eff} in the pulses under study. As a result we estimate an accuracy of the ∇P-measurement in the radial range of interest as ± 25%.

Due to the restricted time resolution we investigate the behaviour of the pressure profile between ELMs and so choose discharges with ELM frequency $f_{ELM} < 5$ Hz.

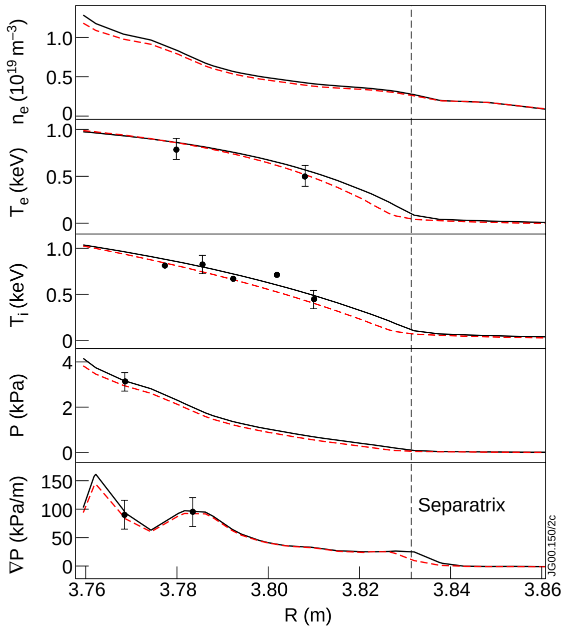

Fig.2: An example of measurement of P and ∇P (#48268, t=61.2 s). Dashed lines represent effect of a shifted separatrix.

3. Results and Discussion

Convenient parameters for classification of pulses according to the behaviour of ∇P(R,t) are P_{SOL} and δ. Figure 3 presents ∇P as a function of plasma major radius and time in the ETB area of Low Triangularity (LT) pulse with high P_{SOL}. Figure 4 shows a D_α -signal and time behaviour of the ∇P at the top of the ETB. The ideal ballooning limit ∇P_{crit} is also shown, which is calculated using a generalised S-α model [1]. The geometry of the flux surfaces necessary for the solution of the equation is obtained from the magnetic equillibrium code EFIT. Bootstrap current corresponding to our ∇P-measurement has not been taken into account; this would be expected to be stabilising for ballooning modes. From Figures 3 and 4 one can see that maximum ∇P occurs at the top of the ETB shortly before the onset of an ELM.

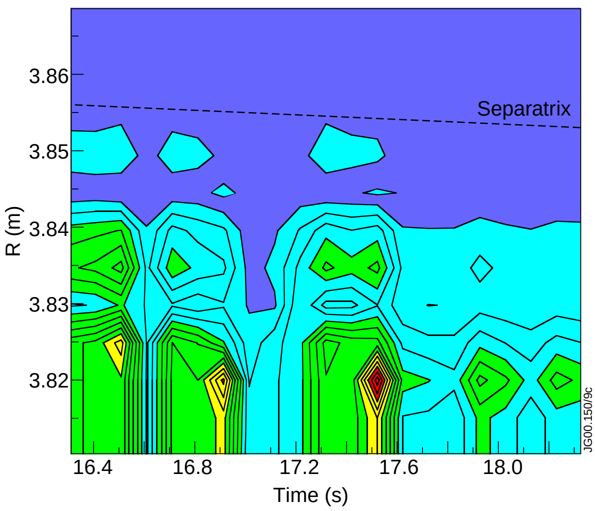

Fig.3: ∇P(R,t) in the ETB area of LT-pulse(#46246, I(MA)/B(T) = 2.5/ 2.4, $P_{SOL} \approx 8$ MW, δ=0.22)

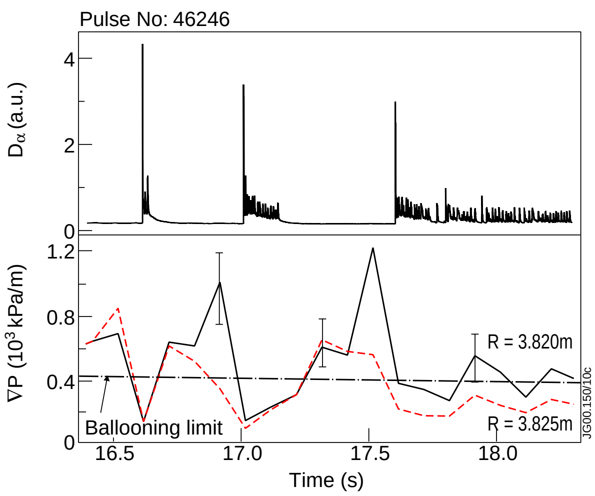

Fig.4: D_α-signal and time behaviour of ∇P at the top of the ETB corresponding to the case in Fig.3.

∇P_{max} is higher than the ideal ballooning limit ∇P_{crit} ($\nabla P_{max} \approx 2 \times \nabla P_{crit}$); it is expected that the edge bootstrap current would give direct access to second stability resolving the apparent paradox that $\nabla P >> \nabla P_{crit}$. After H-L transition at t = 17.6 s ∇P remains close to the ∇P_{crit} in a narrow region. Island-like structure with low ∇P exists at R = 3.83 m. The ∇P increases rapidly up to the maximal value when size of the island decreases. This structure is due to $n_e(R)$ which is measured with much better spatial resolution than the temperature, and could be due to a slowly rotating magnetic island. The EFIT code gives the q = 3-surface exactly at R=3.83 m between the ELMs. The transport code JETTO [3] which is believed to more accurately reproduce edge current profiles gives q = 4 very close to R = 3.83 m. In a discharge with the same parameters but with gas puffing (Fig.5) $\nabla P_{max} \leq \nabla P_{crit}$ before the ELMs. However the island-like structures remain. The energy content of the plasma is about 15% lower than in the discharge which exceeds the calculated ballooning limit. Notice that the ELM frequency does not change.

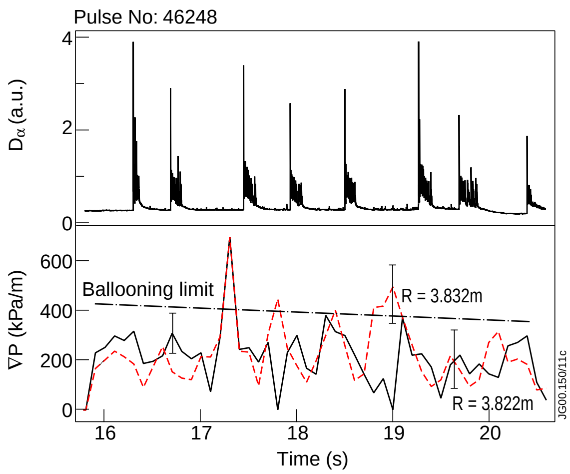

Fig.5: As figure 4 but for pulse with gas puffing

Figures 6 and 7 present a high triangularity (HT)-pulse with high P_{SOL} and without gas puffing. Such pulses differ significantly from LT- pulses. The ballooning limit is exceeded in a wide area (≈ 1 cm) near the top of the ETB and exists for a few hundred ms between the ELMs. ∇P_{max} can reach a peak value of 2.7 x ∇P_{crit} . ∇P achieves its maximal value very quickly after the ELM (the time resolution is not enough to resolve this process). There is no island-like structure in the ETB area (temperature at the edge is about twice that in the LT- pulses with the same P_{SOL}). The q = 3 resonance surface (from EFIT) is close to the location of the area with maximal ∇P during a period of type I ELMs.

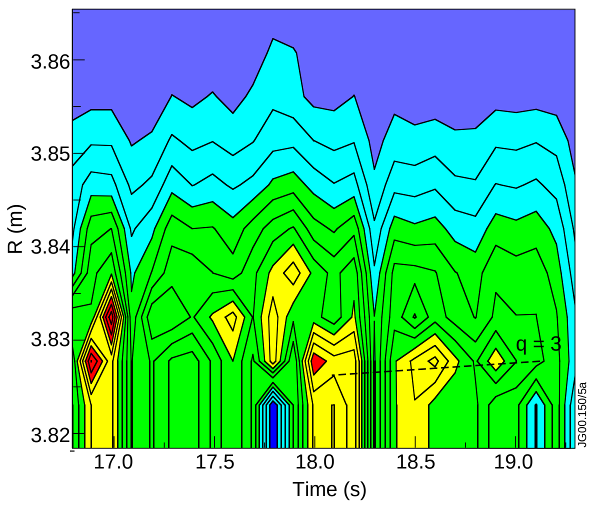

Fig.6: As figure 3 but for HT-pulse (#46316, I(MA)/B(T)=2.5/2.5, P_{SOL} ≈ 9 MW, δ =0.35).

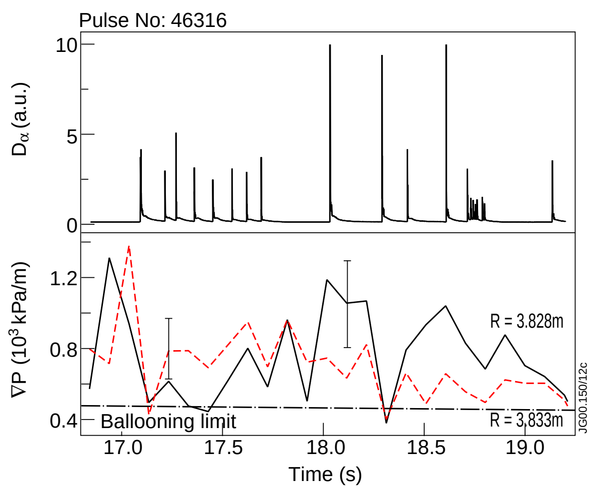

Fig.7: D_α-signal and time behaviour of ∇P at the top of the ETB corresponding to the case in figure.6.

The behaviour of ∇P in the HT-pulses with low P_{SOL} (< 5 MW) resembles very much that in LT-pulses with high P_{SOL} and gas puffing. ∇P is close to or can slightly exceed ∇P_{crit}. The observations are summarised in Fig.8, where maximal ratio $\nabla P / \nabla P_{crit}$ reached in the pulses with high and low P_{SOL} is presented as a function of triangularity. This ratio increases with P_{SOL} and δ. Data for pulse with high P_{SOL} but with gas puffing match points for low P_{SOL} - discharges.

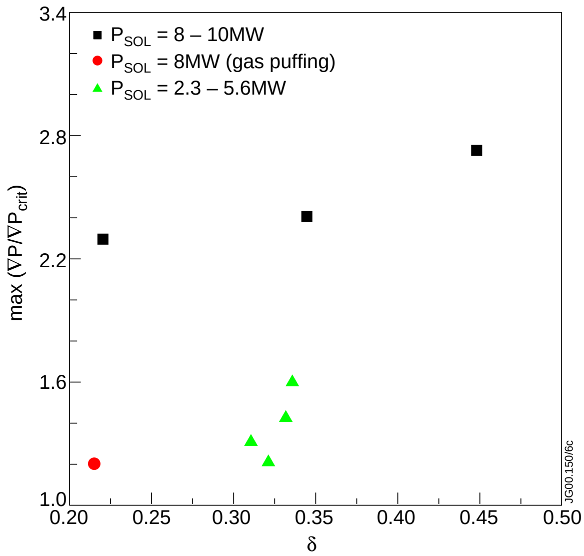

Fig.8: Maximal ration $\nabla P / \nabla P_{crit}$ reached in the pulses as a function of triangularity.

4. Conclusion

∇P at the top of the ETB reaches a maximal value just before type I ELMs. In HT- and LT- pulses with high P_{SOL} ($\approx$ 10 MW) and without gas puffing the calculated ballooning limit is significantly exceeded: $\nabla P_{max} \approx (2\text{–}3) \times \nabla P_{crit}$. In HT-discharges this occurs over wider area and exists much longer between the ELMs. This may imply that triangularity improves access to second stability. Gas puffing or insufficient power flux into the SOL lower measured edge pressure gradient to the calculated ballooning limit. In both cases a zone with low ∇P resembling a magnetic island is observed. Our measurement does not allow us to conclude on the trigger role of the ballooning instability for the ELMs in discharges with high P_{SOL} and δ. A preliminary analysis making use a better edge current profile from JETTO simulation [3] shows that operational point in discharge 46246 goes under the ballooning unstable zone in the area with low S and high α, i.e. the plasma is stable against ballooning modes before the ELM. Further studies are needed to fully resolve the impact of the edge current on the predicted ballooning mode stability.

Acknowledgments

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