Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
Fusion Engineering and Design 74 (2005) 639–644
Fusion Engineering and Design
www.elsevier.com/locate/fusengdes

Configuration and perturbation dependence of the Neutral Point in JET

F. Villone [a,*], V. Riccardo [b], F. Sartori [b], A. Cenedese [c], D. Howell [b], B. Alper [b], P. Beaumont [b],

contributors to the EFDA-JET Workprogramme

[a] *Ass. EURATOM/ENEA/CREATE DAEIMI, Università di Cassino, Via Di Biasio 43, I-03043, Cassino (FR), Italy*
[b] *EURATOM/UKAEA Fusion Assoc., Culham Science Centre, Abingdon OX14 3DB, UK*
[c] *Consorzio RFX, Assoc. Euratom-ENEA sulla Fusione, Corso Stati Uniti 4, I-35127 Padova, Italy*

Available online 25 July 2005

Abstract

Previously the existence of a Neutral Point was clearly demonstrated for plasma disruptions following radiative collapses in JET. This paper extends such studies to different configurations and different perturbations (ELMs). The result is that a Neutral Point for ELM-type perturbations does not exists in the explored range. Nevertheless, a spatial dependence of the excitation of the unstable mode can be found in the experimental data. This feature can give useful information about simplified ELM modelling for control purposes.

Keywords: Neutral Point; ELMs; Plasma modelling

1. Introduction

Plasma disturbances, like radiative collapse or giant Edge Localised Modes (ELMs), induce eddy currents in the passive structures. These currents interact with the plasma, causing a perturbation in the plasma position. Since for elongated plasmas the $n=0$ mode is unstable, the vertical position of the plasma will then evolve exponentially in a preferential direction (i.e. upward or downward). The initial excitation of the unstable mode, and hence the direction of movement, will depend, in general, on the position of the plasma before the disturbance. In fact, we define the Neutral Point (NP) as the position where the unstable mode (regardless of its growth rate) is not excited by a given perturbation.

In a perfectly vertically symmetric device with a perfectly vertically symmetric plasma any point lying on the $z=0$ axis would be the NP according to this definition. In non-symmetric configurations, the existence and location of a NP is not obvious. In the past [1–3], the existence of the NP, as defined above, has been

* Corresponding author. Tel.: +39 0776 299 3674; fax: +39 0776 299 3707.
E-mail address: villone@unicas.it (F. Villone).

0920-3796/$ – see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.fusengdes.2005.06.088

experimentally demonstrated on JT-60U and confirmed numerically via Tokamak Simulation Code (TSC) simulations. Dedicated NP experiments have been carried out also in JET [4] and Alcator C-Mod [5]. These works have shown that the direction of vertical plasma movement consequent to a radiative collapse depends on the initial vertical position of the plasma. There is evidence of the existence of a NP also in several ASDEX-Upgrade disruptions [6]. Most of these are accidental, and because of that the NP location is seen to depend on the cause of the disruption.

In this paper, we want to extend the work reported in [4], limited to radiative collapse disruptions, to the case of ELMs as triggering perturbations, since they are more significant for high performance plasma operation. The experimental set up and the results are presented in Section 2, and discussed in Section 3, while in Section 4 we draw our conclusions.

2. Experimental results

The aim of this study is to assess the influence of the pre-ELM plasma vertical position on the dynamics of an ELM-triggered vertical displacement event (VDE). Hence, we produced a number of configurations with similar geometrical parameters (elongation, triangularity, centroid radial position), except for the centroid vertical position, which was intentionally scanned.

To do this, the plasma cross section had to be much smaller than in “high performance” configurations. In addition, the plasma current was limited to 1.5 MA, to keep disruption forces reasonably low and all the poloidal field circuits within allowable currents. Finally, the toroidal field was chosen as a compromise between maximising stability and minimising the H-mode power threshold to have sufficiently large and predictable ELMs. To this purpose, neutral beam (NB)

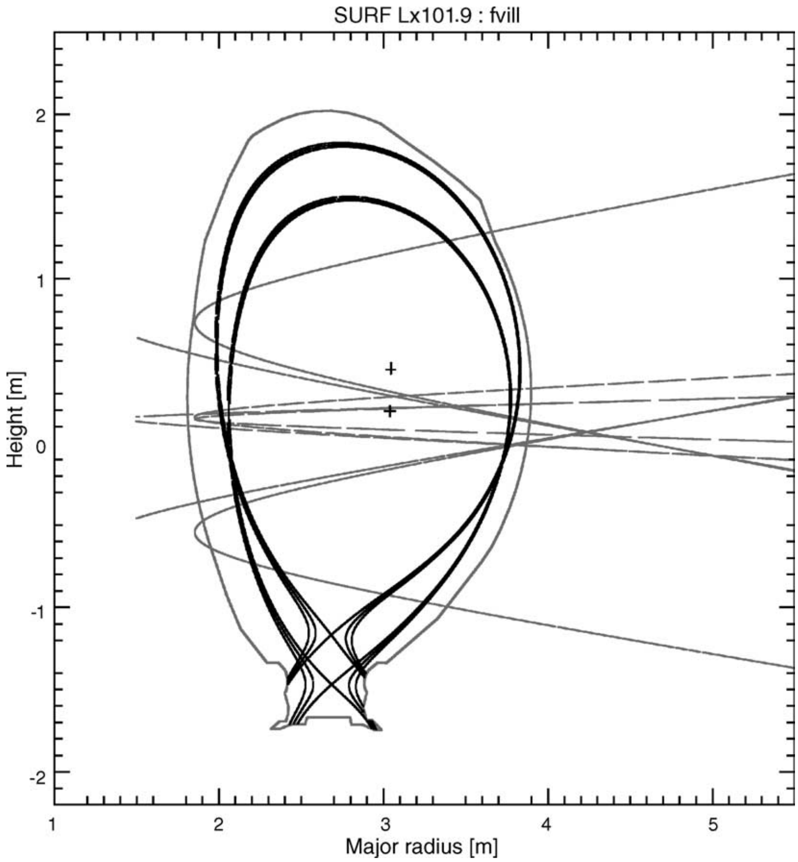

Fig. 1. Higher and lower configurations, together with Neutral Beams trajectories.

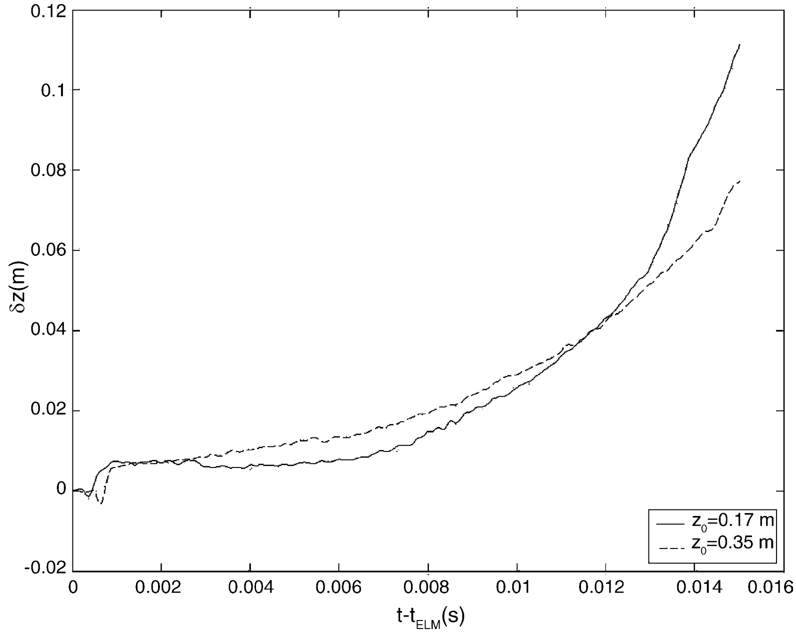

Fig. 2. Behaviour of the vertical position of the plasma centroid, as measured by soft X-rays emission, in the disruption of pulse 62801 (solid) and 62817 (dashed).

heating needs to be applied. Compatibility with NB injection introduces a limit to the range of the plasma vertical position that can be scanned. The achieved range is shown in Fig. 1 together with the NB trajectories.

In all discharges, the plasma was ramped to the final configuration before applying NB power. Only after 1.5 s in the NB heating phase, the vertical stabilisation (VS) system could be disabled after a significant spike of the divertor H_α light, which is a reliable sign of an ELM having occurred.

In Fig. 2 we report a typical behaviour of the plasma centroid vertical position, as measured by soft X-rays emission, as a function of t–$t_{\rm ELM}$, being $t_{\rm ELM}$ the instant at which the H_α light exceeds a given threshold. Two shots are reported; these correspond to different initial vertical positions z_0, and are representative of all the scanned z_0. We can observe the following:

- the vertical position experiences a sudden upward jump of approximately 1 cm, followed by an upward exponential movement;
- the plasma direction is the same for all vertical positions.

This last observation clearly illustrates that a Neutral Point for ELM perturbations does not exist in the explored range. We notice that we examined 13 different vertical positions of the centroid, ranging from 15 to 45 cm approximately.

3. Discussion

After an ELM, the plasma vertical position evolves as:

$$\begin{aligned}\delta z(t) &= \delta z_{\rm U}\ \exp(\gamma(t-t_{\rm ELM})) + \delta z_{\rm stable}(t)\\ &\approx \delta z_{\rm U}\ \exp(\gamma(t-t_{\rm ELM})) \quad t \gg t_{\rm ELM}\end{aligned} \tag{1}$$

where $\delta z_{\rm stable}(t)$ is the evolution along the stable modes, which becomes negligible with respect to the unstable part after a sufficiently long time interval, $\delta z_{\rm U}$ is the excitation of the unstable mode whose growth rate is γ. Hence, after a suitable time interval, we have:

$$\ln(\delta z(t)) \approx \ln(\delta z_{\rm U}) + \gamma(t-t_{\rm ELM}) \tag{2}$$

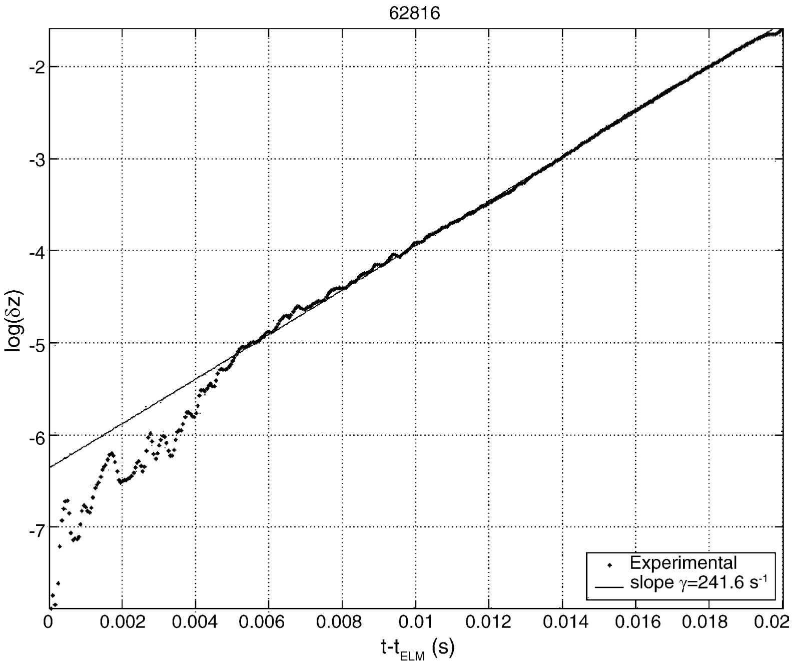

Fig. 3. Linear interpolation to retrieve δz_{U} and γ.

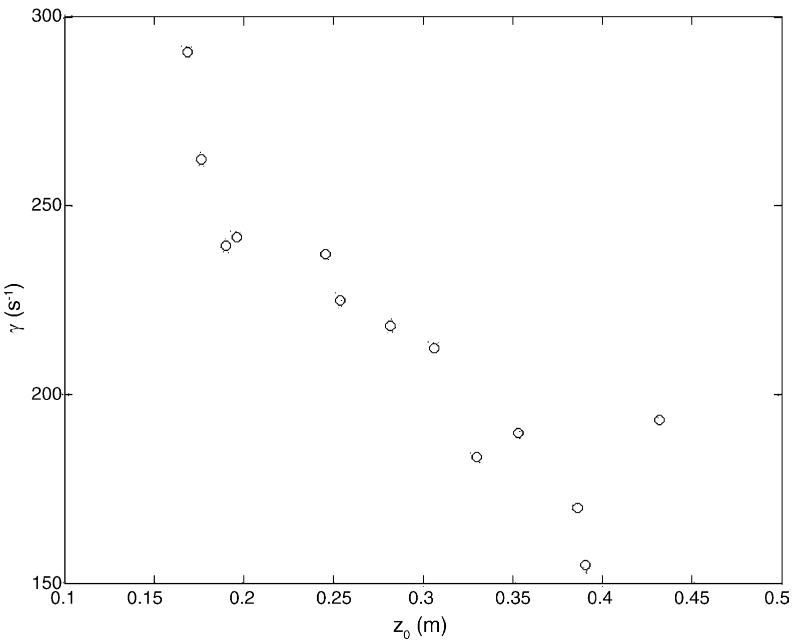

Fig. 4. Dependence of growth rate γ on the initial vertical position z_0.

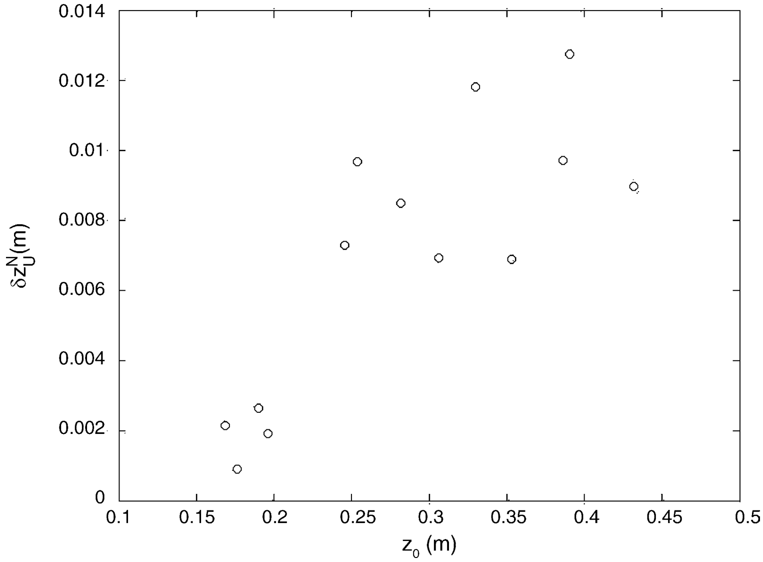

Fig. 5. Dependence of the excitation of the unstable mode δz_U^N on the initial vertical position z_0.

so that, we can easily retrieve both δz_U and γ from a linear interpolation of the quantity $\ln(\delta z(t))$, as depicted in Fig. 3. We must also notice that the ELMs that trigger the instability at each different position can be of different strength. Hence, to make a fair comparison, we decide to normalize the excitation of the unstable mode due to ELMs δz_U as:

$$\delta z_U^N = \delta z_U \frac{0.2\,\text{MJ}}{\Delta W_{\text{DIA}}} \tag{3}$$

where ΔW_{DIA} is the drop of diamagnetic energy due to the ELM.

In Fig. 4, we report the growth rate as a function of the pre-ELM vertical position. Evidently, lower configurations have a higher growth rate. This difference is likely to be due to variations of the distance between conducting structures and plasma, and of the field index experienced by the plasma.

Fig. 5 shows the dependence of the quantity δz_U^N on the pre-ELM vertical position. First of all, we notice that this quantity does not change sign, consistently with the observation that a Neutral Point does not exist in the explored range for perturbations due to ELMs. Nevertheless, δz_U^N has a clear trend: lower configurations, although having a higher growth rate, experience a substantially smaller excitation of the unstable mode. This is also evident when looking at Fig. 2.

This feature can be helpful, once analysed with evolutionary equilibrium linearized models like CREATE_L [7], in understanding how an ELM should be characterized from the point of view of simplified control models. Indeed, preliminary simulation results show that the usual reference ITER characterization of ELMs in terms of drops of poloidal beta and/or internal inductance [8] is not consistent with this experimental evidence, as it provides the wrong spatial dependence of the excitation of the unstable mode.

4. Conclusions and further work

The dependence on the initial vertical position of the excitation of the unstable $n = 0$ mode by ELMs has been systematically studied in a number of dedicated experiments on JET. Contrary to the case of radiative collapse disruptions, in this case no Neutral Point can be found in the explored range. Nevertheless, a clear trend, showing that lower configurations (with a higher growth rate) experience a smaller excitation of the unstable mode, is present.

This feature will be deeply analysed in the future with suitable modelling tools, to get important indications about a simplified modelling of ELMs for shape and position control purposes.

Acknowledgements

This work, supported by the Italian MIUR under PRIN contract and EURATOM Communities under the contract of Association between EURATOM/ENEA, was carried out within the framework the European Fusion Development Agreement. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

References

[1] Y. Nakamura, R. Yoshino, Y. Neyatani, T. Tsunematsu, M. Azumi, N. Pomphrey, S.C. Jardin, Nucl. Fusion 36 (5) (1996) 643–656.
[2] Y. Nakamura, R. Yoshino, N. Pomphrey, S.C. Jardin, Plasma Phys. Control. Fusion 38 (1996) 1791–1804.
[3] R. Yoshino, Y. Nakamura, Y. Neyatani, Nucl. Fusion 36 (3) (1996) 295–307.
[4] F. Villone, V. Riccardo, F. Sartori, A. Cenedese, Fusion Eng. Des. 66–68 (2003) 709–714.
[5] R.S. Granez, Y. Nakamura, E.S. Marmar, J.E. Rice, R. Yoshino, Neutral Point Disruption Studies on Alcator C-Mod, APS-DPP, Quebec City, Canada, 23–27 October 2000.
[6] Y. Nakamura, G. Pautasso, O. Gruber, S.C. Jardin, Plasma Phys. Control. Fusion 44 (2002) 1471–1481.
[7] R. Albanese, F. Villone, Nucl. Fusion 38 (5) (1998) 723–738.
[8] J. Wesley, H.W. Bartels, D. Boucher, A.E. Costley, L. De Kock, S. Gerasimov, et al., Nucl. Fusion 40 (3) (2000) 485–494.