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The Effects of Target Density, Plasma Shaping and Divertor Configuration on the H-Mode Pedestal in ITB Experiments on JET

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ABSTRACT.

In plasmas with an optimised current profile, where internal transport barriers (ITBs) can be generated, the best performance has previously been found on JET for plasmas with low target density, low triangularity and a divertor plasma configuration chosen for maximum pumping. In contrast, on DIIID, the highest performance for plasmas with ITBs is found with strong shaping. The Advanced Tokamak regime for ITER requires high density, and assumes high triangularity. This paper describes systematic experiments which have recently been performed on JET on the effect of plasma shape, target density and divertor pumping in plasmas where the target q profile exhibits strong shear reversal obtained by the application of Lower Hybrid Current Drive (LHCD) during the pre-heat phase [4 and 5].

1. TARGET DENSITY EXPERIMENT

In the experiments on target density, gas fuelling was used to raise n_e/n_{GW} from the usual 0.1 up to 0.35 during the preheat phase. In order to offset the increased current penetration, the Lower Hybrid Current Drive was increased from 2 to 3MW and both off axis Ion Cyclotron Resonance Heating (ICRH) and Neutral Beams (NB) were added during the preheat phase. Despite this, the q profile changes from deep shear reversal ($q_0>q_{95}$) to weak shear reversal and qmin moves in from r/a of 0.4 to 0.3. In each case the timing of the high power phase (see fig.1) is adjusted so that qmin is in the vicinity of 2.

The low density case of fig.1 starts with Type III ELMs, low pedestal density, and high pedestal T_e. The ITB is formed at 5.5s, and ITB expansion can be seen on ∇Te(R=3.3m). The reduced power flow across the separatrix allows pedestal T_e and n_e to fall, and the ELMs to decrease in amplitude. The core density rises to 30% of Greenwald. After the first few type 1 ELMs the ITB disappears. From 6.7s the behaviour is characteristic of a conventional unfuelled ELMy H-mode where the core density rises to 50% of Greenwald.

The high density case starts with a clear L mode phase, then a dithering H (increased pedestal parameters), then short type III (reduced pedestal density and electron pressure). The ITB forms here, see ∇T_e(R=3.3m) on fig.1, and lasts 1sec. During the ITB phase, the edge shows type I ELMs (larger amplitude, lower frequency and higher pedestal parameters). During this phase the core density is 50% of Greenwald, significantly higher than during the ITB phase of the companion pulse. However, the ITB at high density is weaker with $\rho^*_{T_e} \approx 14\times10^{-3}$ (the ratio of ion Larmor radius to electon temperature scale length), close to the threshold of detectability [4].

Reference [6] shows that a high power threshold for the type III to type I ELM transition is only found with low edge density. It is therefore of some significance to demonstrate a ITB scenario in which an ITB can co-exist with high frequency type I ELMs at high density.

2. SHAPE EXPERIMENT

For the experiments on shape, 4 new plasma configurations were explored, varying elongation and triangularity separately over the range κ =1.61-1.81 and δ =0.21-0.5. These should be compared with κ =1.61and δ =0.21 for the usual JET scenario. The LH preheat scheme was used to generate a shear reversed target. The companion paper [7] discusses the effect of shape on the core magnetic topology and the dynamics of ITB formation. This section concentrates on the effect of shaping on the H mode pedestal.

At low triangularit y, $\delta < 0.23$, the variation in elongation from 1.61 (standard scenario) to 1.67 and 1.76 has negligible effect on the ELMs and H-mode pedestal. The ELMs remain type III, though there is a reduction in frequency (from 350Hz to 120Hz for 16MW at 2.2MA/2.6Tesla)) with increasing elongation. The electron pedestal pressure remains around 5kPa (similar to the low density case of fig.1). There is however evidence for an improved core ion temperature suggestive of a beneficial effect of elongation on the ITB [7].

However, at low elongation (κ =1.62) and higher triangularity (δ = 0.36) the H mode behaviour is very different as shown in fig.2. In this case, with only 8MW across the separatrix, there is a transition from type III ELMs to an ELM free phase where the pedestal electron pressure increases to 10kPa. The temperature drop at the first and subsequent type I elms is sufficiently large as to generate bursts of type III ELMs. During one such burst, an ITB forms and thereafter the ELMs remain type III. Note that the pedestal density, temperature and separatrix power are very similar at the start of the ELM free phase and at the beginning of the long type III phase.

With higher triangularity and elongation (δ =0.5,κ =1.81 similar to proposed ITER values) the transition from L mode to Type III and thence to Type I and ELM free occurs over a narrow range of power flow across the separatrix, 4-5MW, as shown in Fig.3. During these ELM free phases the electron pedestal pressure rises even higher up to 20kPa and in all such cases the first ELM triggered a Vertical Displacement Event (VDE). In conventional ELMy H-modes with ITER-Like shapes [8] a similar problem occurs which can be avoided by deuterium gas fuelling. This has not yet been attempted in this scenario.

3. VARIATION OF DIVERTOR PLASMA GEOMETRY

On the MKIIA divertor it was possible to establish ITB plasmas at high power with either an L-mode or ELMy edge, for example [8]. It is noteworthy that the MKIIA divertor permitted configurations with the strike points on the horizontal targets immediately in front of the pump throats. However, on MKIIGB the threshold for type III ELMs is below the threshold for ITBs [4], and moreover transitions to type I ELMs can occur if the clearance between divertor plasma channel and the septum is too small [10]. The septum limits the strike points such that, for the standard configuration, the diverted scrape off layer is partly in the pump throat and partly on the vertical target. In the experiment described in this section, the geometry of divertor plasma channels was varied relative to the divertor targets. Four configurations were compared with the standard geometry; (1) both strikes on vertical target clear of pump throat, (2) outer strike on horizontal target in front of pump throat, (3) inner strike on horizontal target in front of pump throat and (4) a configuration with the outer divertor leg close to the septum. In each case LH preheat and then 16MW of combined heating in the high power phase was employed. In all cases the edge first showed type III ELMs and then an ITB was formed. During this phase the evolution of pedestal density was nearly identical (provided the appropriate region on the target was well conditioned), though there were variations in divertor and main chamber neutral pressure. Variations in electron temperature pedestal were fairly small <10%. However three of the configurations showed, typically 2sec after the start of the high power phase, a gradual increase in ELM amplitude and reduction in ELM frequency and eventually a transition to a type I phase similar to that reported in [10]. This change in behaviour was not triggered by any heat pulse from the core. During the phase where the type III ELM amplitude increased the pedestal density, and electron temperature also increased, and continued to do so between the type I ELMs. It is not at all clear why these configurations are prone to this whilst the standard configuration and the configuration with the outer strike on the horizontal target were not. This experiment will be repeated once the septum is removed, and compared with configurations with **both** strikes on the horizontal targets in front of the pump throats (as used on MKIIA).

CONCLUSIONS

It is possible to raise the density in ITB scenarios, by gas fuelling in the preheat phase, such as to permit acceptable ELM behaviour. Increasing the elongation, at low triangularity, increases the ITB performance whilst also maintaining acceptable ELM behaviour. However increasing the triangularity at low elongation favours the formation of a strong H-Mode pedestal with long intervals between Type I ELMs. Fortunately it is still possible to form and sustain an ITB following reverse type I to type III transitions. At the highest elongation and triangularity, the ELM free pedestal is even stronger, but it has not proved possible, as yet, to avoid a VDE at the first type I ELM.

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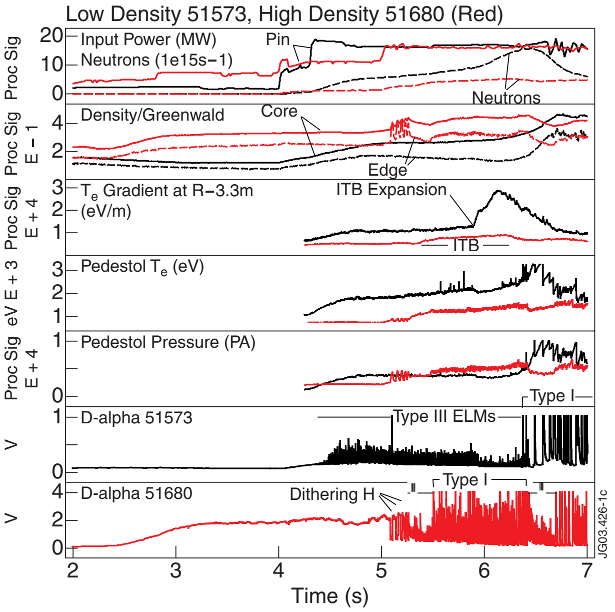

Figure 1: Various time traces for low target density 51573 and high target density 51680 (red). Both pulses have plasma current 2.2MA and toroidal field 2.6Tesla

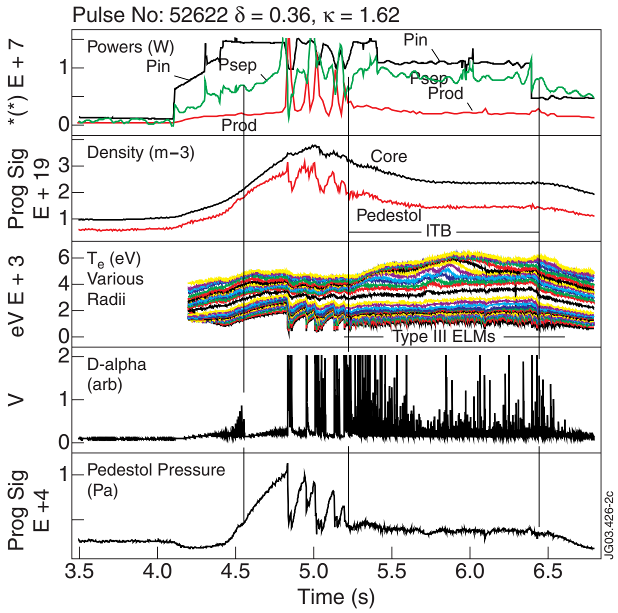

Figure 2: Various time traces for low elongation fairly high triangularity Pulse No: 52622. Vertical bars mark type III to ELM free transition and also duration of ITB.

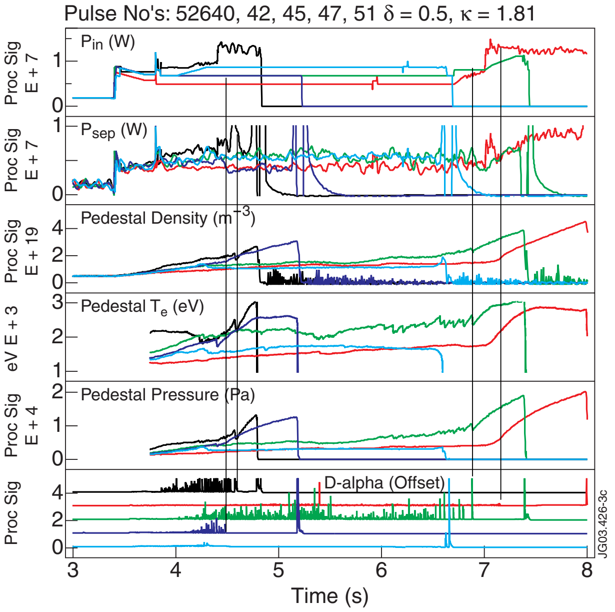

Figure 3: Various time traces for several pulses exploring the type III to ELM free transition (vertical bars) for ITER-LIKE shape. Pulse No: 52651 (cyan trace) used an argon bleed which restored L mode edge.