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Optimised Shear Discharges in the Gasbox Divertor in JET

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1. Introduction

Regimes with Internal Transport Barriers (ITB's) provide a route for enhanced performance in Tokamak experiments. In the past few years, research has concentrated on heating during the current rise phase of the discharge in conditions of weak or reversed magnetic shear in the centre. In JET, experiments on internal transport barriers were started during the Mark IIa divertor campaign (1996/1998) [1,2]. This paper gives an overview of some key points of the experiments performed in discharges with ITB's in the Mark II Gas Box divertor (Mark II GB, 1998/1999), a more closed divertor compared to Mark IIa.

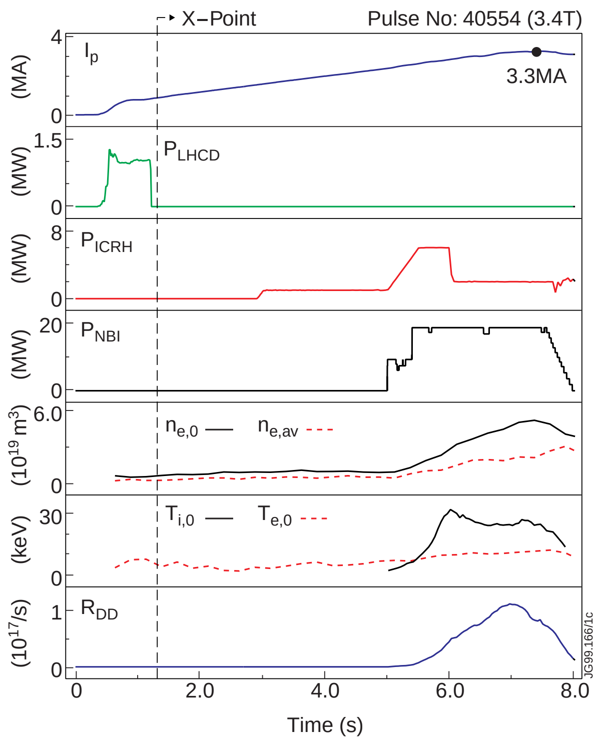

Fig. 1: Breakdown and initial current rise with early heating. The X-point is formed at 1.3 seconds.

2. Scenario for the Mark II GB divertor

The optimum condition for the formation of internal barriers in JET, is a target with low shear in the centre and q_{ax} values close to 2 [3]. This can be obtained with a current rise (0.4 MA/s) in X-point at low density (Figure 1). LHCD can be used as breakdown assist (optional), low power (≈1 MW) ICRF with the H-minority heating in the centre is used as preheating. High power is applied at low target density ($0.6{\bullet}10^{19}\,m^{-3}$) using a combination of neutral beam injection and ICRH. The current ramp is continued to a flat top with an edge safety factor q_{95}=3.2. Experiments at 2.5MA/2.5T in Mark II GB confirmed the importance of the q=2 surface for the formation of the internal transport barrier (Figure 2). When the power required to form the internal transport barrier is maintained the discharges generally disrupt (pressure peaking). However, the edge makes a transition to ELMy H-mode with small amplitude ELMs; this in contrast to Mark IIa where discharges generally kept an L-mode edge. In order to improve the performance and duration of discharges with internal transport barriers, experiments in Mark II GB concentrated on (i) input power control to avoid MHD modes and disruptions, (ii) study of the effect of plasma configuration on the edge behaviour and (iii) the use of gas dosing (mainly Argon and Krypton) to keep the edge conditions constant.

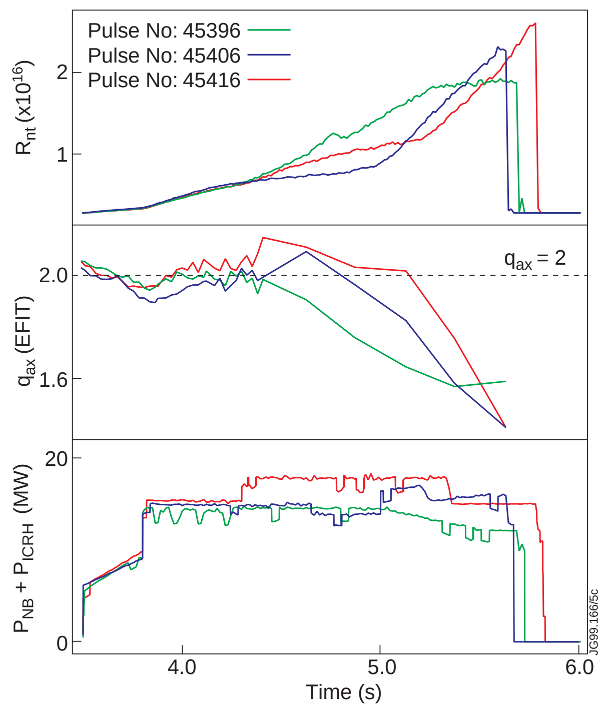

Fig. 2: Internal transport barrier formation at 2.5MA/2.5T, in the Mark II Gasbox divertor.

3. Input power control to avoid MHD modes and disruptions

The formation of an ELMy H-mode in Mark II GB helps to broaden the pressure profile, which was important in improving the performance in Mark IIa. However, early formation of an ELMy H-mode changes the evolution of the discharge dramatically. In experiments at 3.5MA/3.45T (Figure 3), a narrow ITB is formed starting the heating when q_{ax} is close to 2 (# 46664). But this discharge disrupts, despite a power step down. This power step down also reduces the H-mode pedestal giving a stronger peaking of the total pressure. Delaying the heating (# 46464) gives a wider ITB, but requires more power up to a limit where the power is not sufficient to keep the ITB. In order to reach high β_N a control of the pressure profile is essential [4] (Figure 4). For Mark IIa discharges with an L-mode edge, input power control was sufficient, with an ELMy H-mode, the edge of the plasma needs to be controlled as well.

4. Study the effect of plasma configuration on the edge behaviour

Control of the edge plasma from L-mode to ELMy H-mode has been attempted by varying the plasma configuration. The standard configuration in Mark II GB has low triangularity (δ^{upper}=0.1, δ^{lower}=0.25) and the strike points close to divertor cryopump. This gives the lowest edge pedestal at high input power, but no L-mode edge (Figure 5). When the strike point

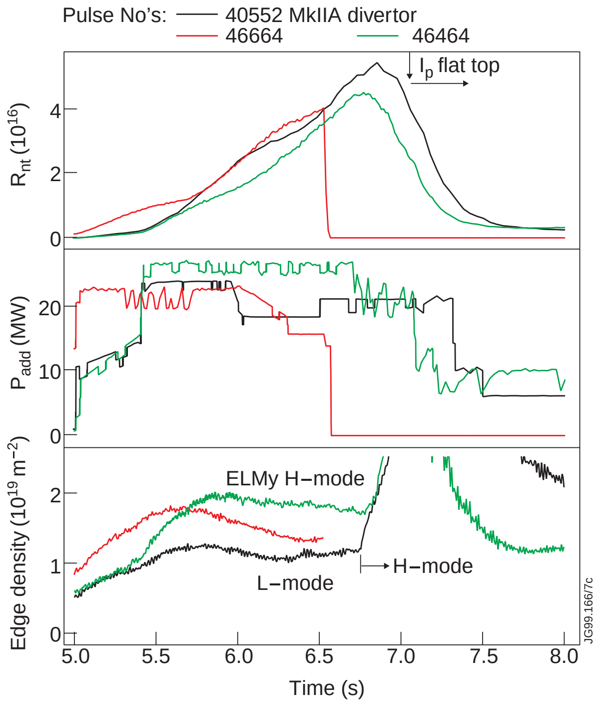

Fig. 3: Early heating (# 46664) disrupts, while delaying the heating (# 46464, wider ITB) requires more input power. Compared to Mark IIa (# 40552).

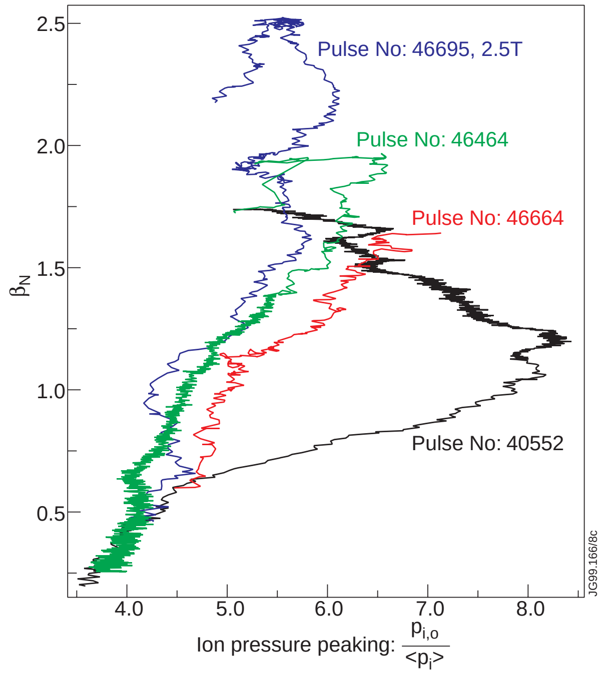

Fig. 4: The stability of discharges with internal transport barriers is related to the peaking of the pressure profile (only ion pressure is displayed here).

positions are changed the edge density rises rapidly, deteriorating the ITB or preventing the formation of an ITB. An increase in triangularity leads to a higher density and type I ELM activity, again undermining the ITB. Only a top X-point (open divertor) with gradB away from the target plates has an L-mode edge, but is limited to Ip=2.2 MA and a maximum energy input of 25 MJ before a Carbon bloom. In contrast, experiments with reversed Ip/Bt have nearly the same edge behaviour as discharges with normal Ip/Bt direction in the Gasbox divertor.

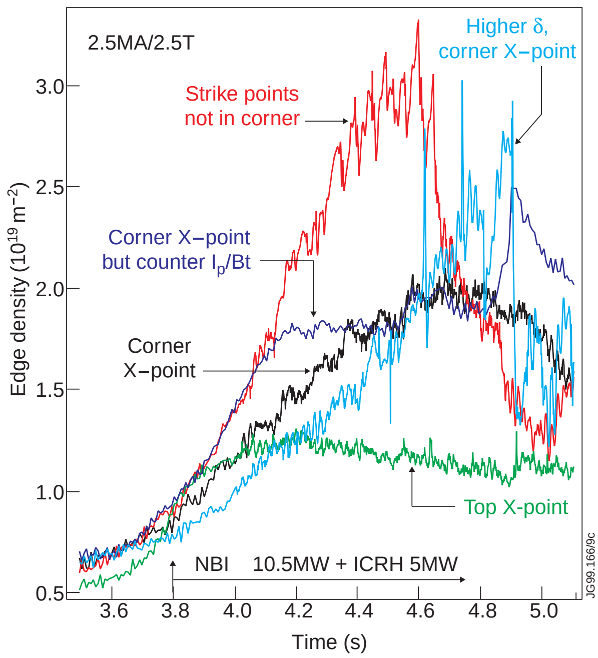

Fig. 5: Edge density evolution during the main heating phase for various plasma configurations.

5. Impurity and Deuterium gas dosing

When Argon dosing is used just after the high power heating step, the ITB duration is significantly prolonged (Figure 6). The Argon dosing increases the radiation fraction of the discharge to 40% (10% from the core and 90% from the edge). This is sufficient to control the edge to small ELMs or L-mode.

The control of the edge pedestal gives some control over the q-profile evolution, the dynamics of the transport barrier and peaking of the pressure profile. The maximum performance obtained at 2.5MA achieves β_N =2.5 (Figure 4) and H_{89} = 2.9 [5]. Krypton gas dosing has also been used successfully. However, Krypton accumulates in the vessel walls, giving difficulties to maintain the experimental conditions. Attempts to raise the density in discharges with an ITB by deuterium gas dosing have so far been unsuccessful. With or without additional Argon dosing, deuterium fuelling leads to a rapid rise of the edge density and a subsequent loss of the ITB (Figure 7), despite only a 5% reduction in central power deposition by neutral beams.

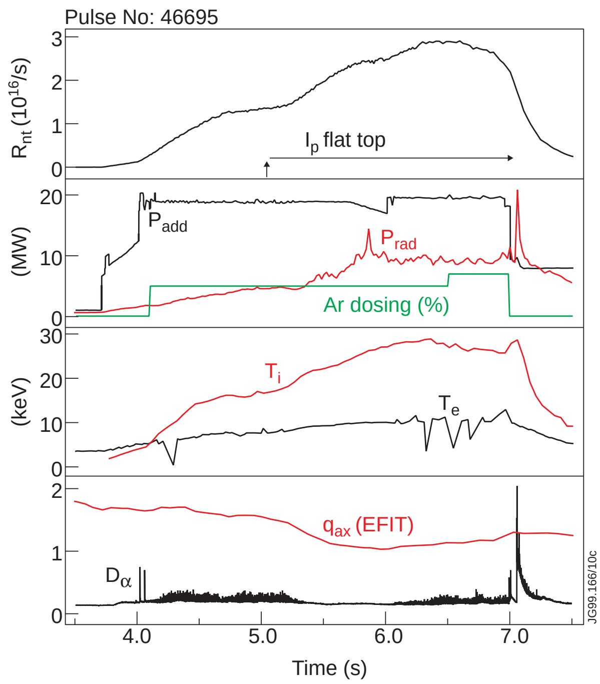

Fig. 6: Argon dosing during the high power phase helps to sustain the ITB (compare to Figure 2).

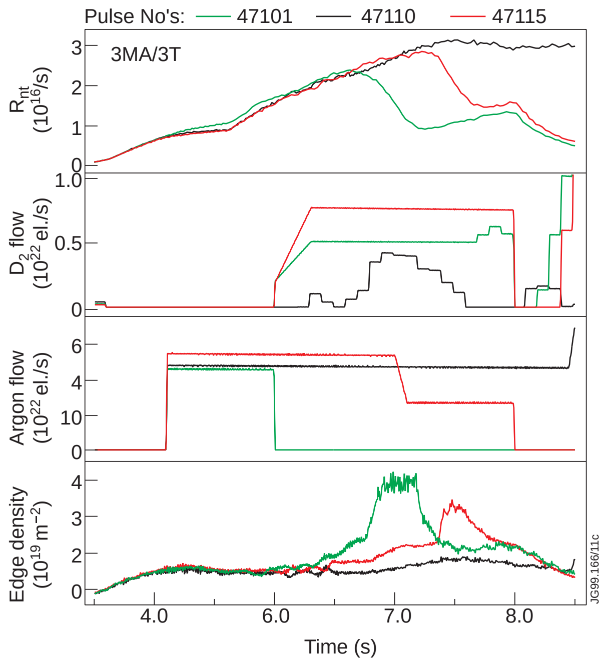

Fig. 7: Deuterium gas dosing during the high power phase triggers collapse of ITB.

6. Conclusions

The duration and β_N of optimised shear discharges have been improved in Mark II GB by timing of the applied power compared to the evolution of the central q, by using a low triangularity configuration with strike points close to the divertor cryopump and impurity gas dosing (Argon in particular) to control the evolution of the edge current density and pressure.

References

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