CONFINEMENT OF HIGH β_{POL} PLASMAS IN JET

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INTRODUCTION

Experiments aimed at examining the confinement characteristics of plasmas with high values of poloidal beta (β_{pol}) have been performed over a wide range of plasma parameters in JET. In previous JET campaigns high β_{pol} plasmas were achieved in conditions of very high confinement ($\tau_E/\tau_{ITER89L\text{-}P} \approx 3.7$) [1,2]. In these ELM free H-mode plasmas the high confinement phase collapsed after an uncontrolled rise of the plasma density. In the JET pumped divertor campaign the aim of the experiments was to achieve high β_{pol} in quasi steady state conditions to study the confinement. The results of these studies are presented.

EXPERIMENTAL BACKGROUND

ELMy H-mode plasmas form the basis of these experiments in which the stored energy and density typically achieve quasi stationary conditions early in the heating phase (Fig. 1).

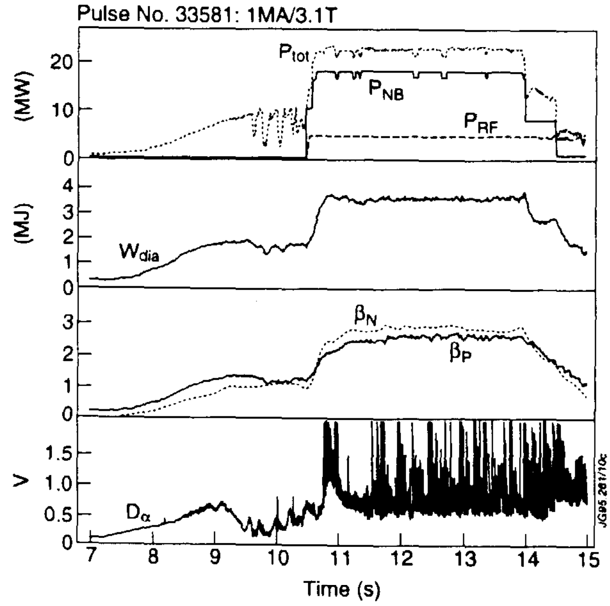

Figure 1: A high beta poloidal discharge

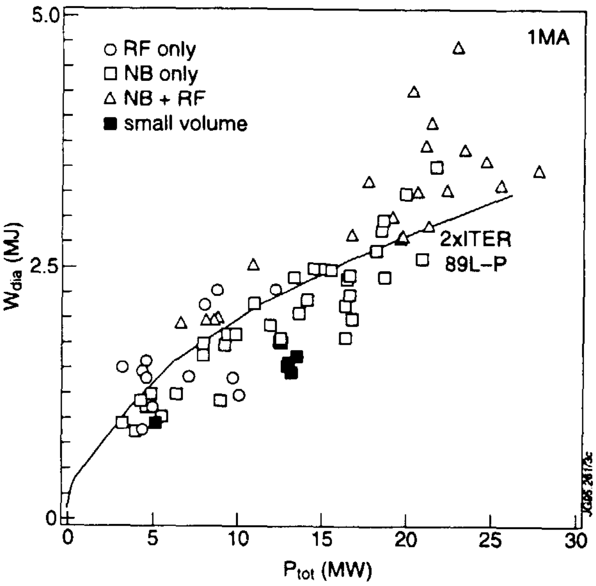

Figure 2: Stored energy vs. input power.

High combined heating powers are used (maximum: 28 MW, for several seconds) mainly at 1 MA with a variation of the toroidal field from 1.0 to 3.4 Tesla. Carbon tiles were installed in the JET divertor and the divertor cryo-pump was used extensively.

CONFINEMENT

In previous JET campaigns, ELM free H-mode were obtained at 1 MA/3.1 Tesla with only 7 MW of ICRH power in double null X-point discharges. High β_{pol} was achieved by virtue of the very high confinement ($\tau_E/\tau_{ITER89L\text{-}P} \approx 3.7$) achieved in these conditions. However, the high confinement regime was only transient.

In the JET pumped divertor campaign the aim of the experiments was to achieve high β_{pol} in quasi steady state conditions to study the confinement. Compared with previous campaigns the pumped divertor geometry offers better power handling and the divertor cryo-pump can be used to control the density. However, the experiments are at reduced volume and are single null X-point plasmas.

It was found that H-modes in the JET pumped divertor configuration are naturally ELMy, allowing quasi steady state operation at high poloidal beta. In these conditions the stored energy (W_{dia}) reaches typically twice the prediction of the ITER89L-P scaling expression up to the maximum additional heating power of 28 MW (Fig. 2). The confinement is independent of the additional heating method. In the high combined heated discharges a beta limit has not yet been reached [4].

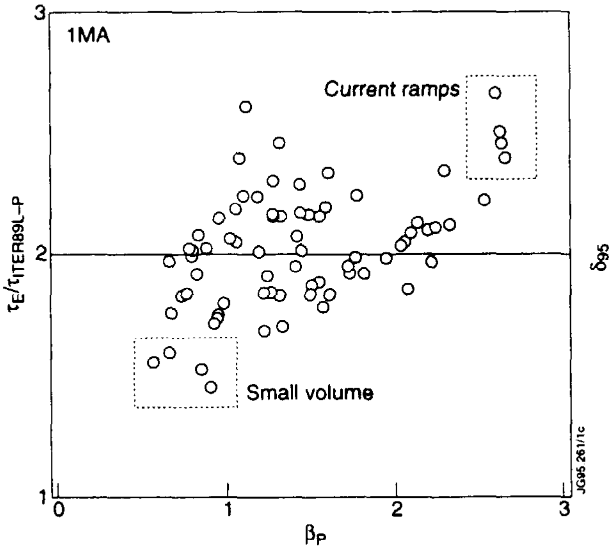

Figure 3: H-factor (ITER89L-P) vs. beta poloidal

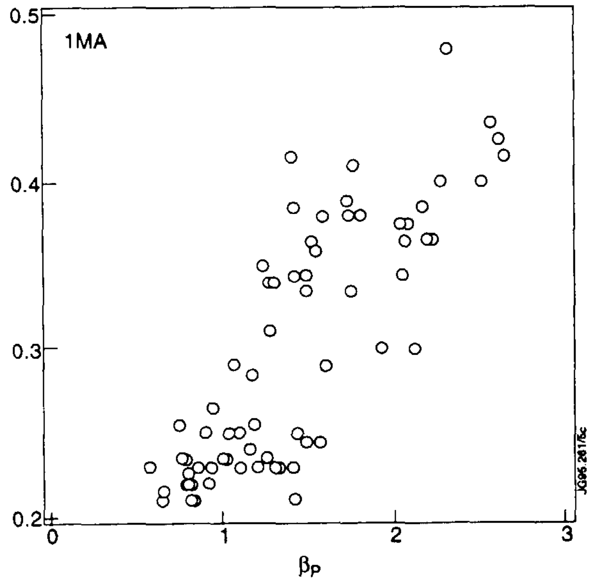

Figure 4: Triangularity (δ_{95}) vs. beta poloidal.

From these results it can be concluded that there is no apparent increase in confinement over H-mode scaling with β_{pol} (Fig. 3). High β_{pol} plasmas become naturally triangular (δ_{95}), despite this increased triangularity the confinement in these ELMy H-modes does not improve (Fig. 4).

SMALL VOLUME PLASMAS

The data presented in the previous section also contain a variation of the aspect ratio. Dedicated experiments have been performed in 'small volume' plasmas in JET in which the volume has been reduced from 85 m^3 to 55 m^3. The confinement in these small volume plasma is not much different from the large volume plasmas. However, at 1 MA the confinement of the small volume plasmas is slightly below the H-mode scaling (Fig 3). When included in the data a possible increase in the H-factor (ITER89L-P) with plasma volume in JET is found. But, a comparison of discharges on the same day at 1.5MA shows no difference between large and small volume plasmas [3]. The reduction in the H-factor compared to the rest of the 1 MA data may then be due to the fact that the divertor cryo-pump was not used and the discharges were heavily gas fuelled to prevent neutral beam shinethrough, both of which might lead to a higher ELM frequency.

TRANSIENT ELEVATED CONFINEMENT

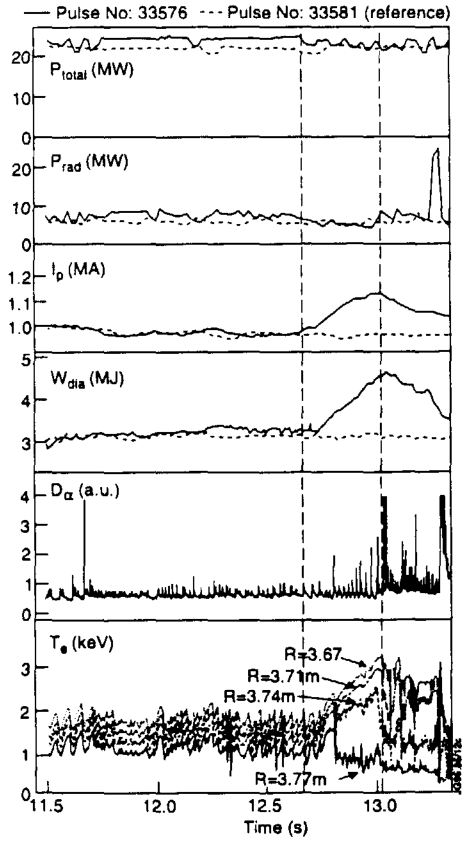

Figure 5: High beta poloidal with current ramp.

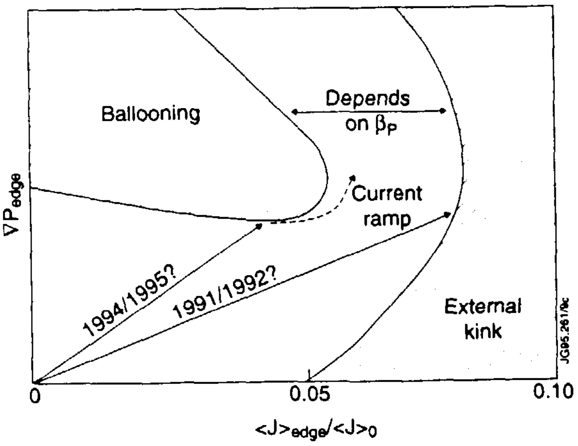

Figure 6: Stability diagram [5].

In some high β_{pol} discharges it is observed that the stored energy can suddenly increase at constant input power, correlated with oscillations in the plasma current at high β_{pol}. This was exploited by pre-programmed ramps of the plasma current (ramp up). The edge temperature increases just after the current ramp but the ELMs do not cease, i.e. not a transition to ELM-free H-mode (Fig. 5).

A speculative explanation is offered as follows: In the JET pumped divertor configuration the edge pressure is limited by the first stability ballooning limit. Access to 2nd stable regime exists in the plasma periphery at high β_{pol} and will allow an improved confinement regime during the heating. However, the ratio of $j_{edge}/\nabla P_{edge}$ is not large enough, due to reduced edge collisionality, despite the divertor cryo-pump which helps to keep the edge density low. The plasma needs a modest increase in j_{edge}. With a current ramp in the high β_{pol} phase, the link between ∇P_{edge} and j_{edge} will be broken and the edge current density is increased (Fig. 6).

The current ramps may be used to extend the high β_{pol} regime to give improved confinement at higher currents by starting at 1 MA level and high β_{pol} and using the current ramp to 'kick' the plasma into the VH mode regime. After the current ramp, the improved confinement of the VH mode regime may be stable due to a larger bootstrap current at the edge generated by increased pressure gradients. However, such a plasma may destabilise external kinks modes due to the high edge current density.

CONCLUSIONS

There is no apparent increase in confinement over H-mode scaling at high β_{pol} in quasi steady state ELMy H-mode conditions (β_{pol} up to 2.7). In this regime the confinement is also insensitive to the heating method, toroidal field and plasma shape, although at 1 MA the small volume plasmas exhibit confinement parameters at the lower end of the spectrum.

Transient improved levels of confinement can be induced with plasma current ramps (up!) with the plasma already at high beta poloidal. A possible explanation is that, with a current ramp during the high β_{pol} phase, the link between ∇P_{edge} and j_{edge} is broken and the current density is increased in conditions where access to second stability exists (VH mode). Current ramps could be used to achieve high β_{pol} and high fusion performance at $I_p \geq 2$ MA.

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