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ABSTRACT

- (i) Feedback control of energy confinement and radiated power fraction is achieved in high performance ELMy H-modes discharges with Ar seeding.
- (ii) A resulting significant reduction of mean and peak temperature of the divertor target plates is measured.
- (iii) The role of the septum for obtaining high density at low δ is assessed.

1. INTRODUCTION

The design value of ITER-FEAT is based on operation at $n/n_{GW} = 0.85$ and $H_{98y2} = H_{98}(y,2) = 1$ where n_{GW} is the empirical Greenwald density limit. These values have been routinely achieved on JET in Ar seeded ELMy H-mode discharges at low and high triangularities (δ) in presence of the MkIIGB divertor [1].

In low δ discharges the good conditions were obtained with the X-point lying on the septum – or dome – of the divertor and by using the technique of “puff” (P-phase with reduced confinement due to strong D_2 puffing assisted by simultaneous Ar seeding to raise the density close to n_{GW}) and “afterpuff” (AP-phase where good confinement is recovered and density maintained by carefully tailoring the D_2 and Ar refuelling). Finally AP-phases could be achieved with stationary high performances ($n/n_{GW} = 0.85$, $H_{98y2} \approx 1$, $\beta_n \approx 1.8$, $\gamma = p_{rad}/p_{tot} = 45\%$) up to the end of the heating phase with negligible Z_{eff} increase due to the Ar seeding. No measurement of the effect of Ar on the divertor target plates were made in this configuration.

In high δ discharges in vertical target configuration high performance ($\gamma = p_{rad}/p_{tot} = 70\%$, $H_{98}(y,2) = 0.9$ at $\beta_n = 2.1$ and $n/n_{GW} = 1.15$) could be achieved with Ar seeding and continuous D_2 fuelling throughout the discharge [1]. Z_{eff} rise was moderate and there is formation of a radiating belt. Furthermore, there are some indications of reduced heat load on divertor target plates.

First experiments with Ar seeding have been performed with the new divertor configuration where the septum is replaced by a plate (Septum Replacement Plate) in low and high δ configurations chosen to optimise the edge diagnostic possibilities. They allow to assess the importance of the septum to recover the performances at low δ and to perform meaningful IR measurements on the divertor plates. At the same time stationarity optimisation by feedback control has been developed.

2. ASSESSMENT OF THE EFFECT OF THE SEPTUM AT LOW TRIANGULARITY

Figure 1 compares in a H_{98y2} vs n/n_{GW} diagram the performances of a low δ discharge with the X-point on the septum (Pulse No: 53030) with a set of DOC-L (Diagnostic Optimised Configuration at Low δ) discharges with the new divertor. The P-AP (“puff-afterpuff”) technique is applied in both cases. For all discharges H_{98y2} drops in the P-phase while the density increases. In the AP-phase the confinement is recovered while the high $n/n_{GW}=0.95$ is only maintained for the septum discharge but not for the other discharges. Hence the importance of the septum in obtaining the high performances in low δ discharges. Physical reasons are not yet fully understood but are probably

linked to recycling effects on the septum. Fig.1 shows a large scatter in H_{98y2} during the AP-phase for a given n correlated to the D_2 refuelling: increasing the D_2 refuelling helps to slow down the decrease of n (although its effect saturates rapidly) but at the expense of a degradation of H_{98y2} . This sensitivity of the confinement to the D_2 refuelling rate leads us to make use of a feedback control system.

3. H_{98y2} FEEDBACK CONTROL BY ACTING ON THE DEUTERIUM REFUELLING RATE IN LOW δ DISCHARGES

The aim here is to maximise the D_2 refuelling in order to obtain the highest density that the DOC-L configuration can sustain for a given preset value of H_{98y2} . A simple feedback scheme is chosen to control the D_2 refuelling rate in the AP-phase $\Phi_{D2,AP}$: if $H_{98y2} \leq K1$ then $\Phi_{D2,AP} = 0$ whereas if $H_{98y2} > K1$ then $\Phi_{D2,AP} = 1$ where Φ_1 is a preset level. Fig.2(a) shows the main parameters of such a feedback controlled DOC-L discharge with $K1 = 1$. After the P-phase in which larger n/n_{GW} and γ are obtained thanks to the Ar seeding the feedback is applied maintaining the recovered H_{98y2} close to 1 during whole the AP-phase. This results in a constant reactivity and the highest $n/n_{GW} \cong 0.7$ compatible with the requested confinement for this configuration.

4. SIMULTANEOUS FEEDBACK CONTROL OF H_{98y2} AND $\delta = P_{rad}/P_{tot}$ IN LOW δ DISCHARGES

In order to simultaneously control the confinement and the radiated power fraction - γ - of Ar seeded discharges a similar feedback scheme is applied to the Ar refuelling “blips” $\Phi_{Ar,AP}$: if $\gamma \geq K2$ then $\Phi_{Ar,AP} = 0$ whereas if $\gamma < K2$ then $\Phi_{Ar,AP} = \Phi_2$ where Φ_2 is a preset level. The interval between the “blips” is chosen equal to the response time of γ to the Ar seeding pulse in order to achieve a stable feedback system. Fig.2(b) shows such a discharge. The amount of Ar seeded during each “blip” depends on the rate at which the fluctuations of γ exceed the level $K2 = 0.6$. The feedback control is acting up to 24s.

5. EFFECT OF AR SEEDING ON THE TEMPERATURE OF THE DIVERTOR TARGET PLATES

Figure 3(a) compares in the DOC-L configuration (optimized for IR measurement) a series of vertical temperature profiles on the inner and outer target plates “during” and “in between” ELMs for discharges with and without Ar seeding. This series consists of 15 consecutive ELMs extracted from IR measurements during the AP-phase (21-22s). A significant reduction of the target plates’ temperature excursion during ELMs is observed with Ar. Furthermore the target plates’ temperature value at the strike point between ELMs is lowered due to the increase of γ as shown in Fig.3(b). A first decrease of the base temperature of the outer target plates is observed in the P-phase (with degraded confinement) where γ is the highest. In the AP-phase the slope of the temperature rise on the outer tile is smaller with Ar seeding corresponding to a lower loaded energy on the tile. This

decrease of the base temperature of the target plates and of its excursion due to the ELMs with enhanced radiation should lead to a reduction of the target plates' erosion.

6. IMPROVEMENT OF $\gamma = P_{\text{rad}}/P_{\text{tot}}$ FEEDBACK CONTROL SCHEME IN HIGH δ DISCHARGES

First tests were made at high δ (in the so-called HT3 configuration) at reduced current ($I_p = 2\text{MA}$) in which an improved feedback control of γ has been developed. In high δ configurations large D_2 fuelling rates do not lead to strong confinement degradation and there is no need to use the P-AP technique. Hence the D_2 fuelling is applied continuously throughout the discharge. Instead of an on-off control in the Ar seeding pulses a continuous control of the Ar seeding rate has been used (see Fig.4). Correct smoothing of the γ signal is essential in this case. The derivative and integral gains of the PID, which ensures the stability of the feedback loop, are adjusted by replacing the plasma in the loop by a transfer function [3]. This function simulates the γ response to the Ar injection and is derived from test discharges with programmed Ar pulses. Fig.4 shows the resulting stabilisation of γ near 65%. Good performances are also achieved during the feedback phase: $n/n_{\text{GW}} \approx 0.85$, $H_{98y2} \approx 0.85$, $\beta_n = 1.5$ with constant neutron yield, formation of a radiating belt and similar reduction of target plate temperature as the one described above.

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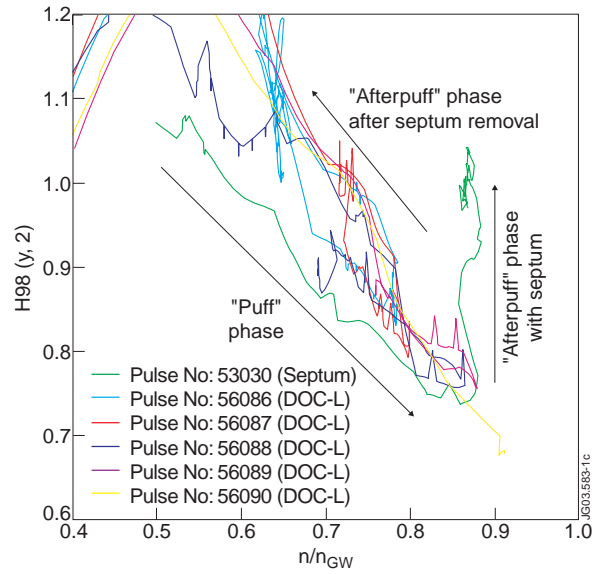


Figure 1: Trajectories of Ar seeded discharges in the space $(n/n_{GW}, H_{98y2})$ for a low δ discharge on the septum (Pulse No: 53030) and low δ discharges in the DOC-L configuration.

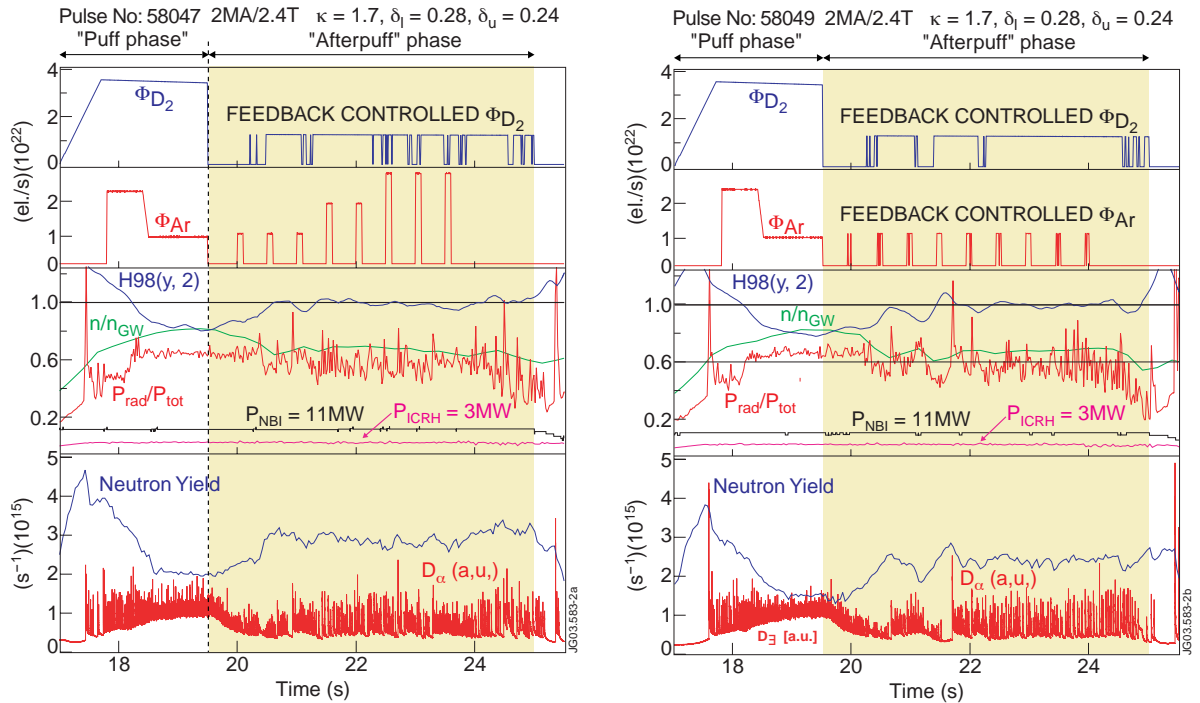


Figure 2: Time traces of global plasma parameters in discharges with (a) feedback control of H_{98y2} by acting on Φ_{D2} and (b) simultaneous feedback control of H_{98y2} by acting on Φ_{D2} and γ by acting on Φ_{Ar} . H_{98y2} is the measured signal used for the feedback control and is not corrected for fast particles.

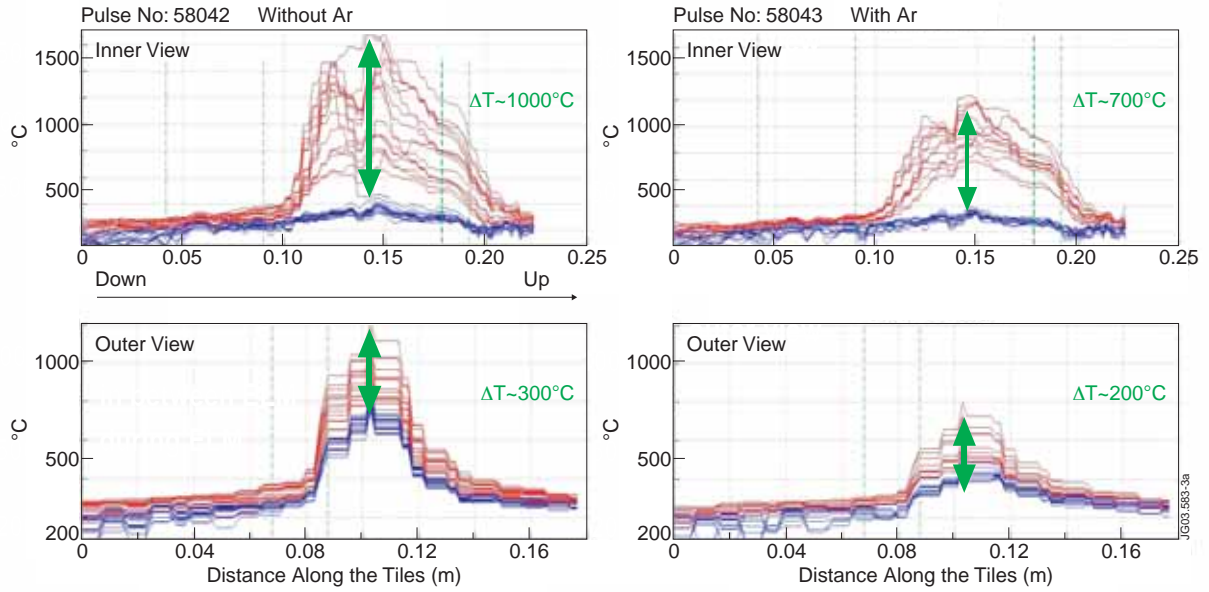


Figure 3(a): Vertical temperature profiles measured by IR thermography on inner (top) and outer (bottom) target plates in an unseeded reference discharge (Pulse No: 58042 – left) and an Ar seeded discharge (Pulse No: 58043 – right). Series of 15 consecutive ELMs during the AP-phase (21–22s).

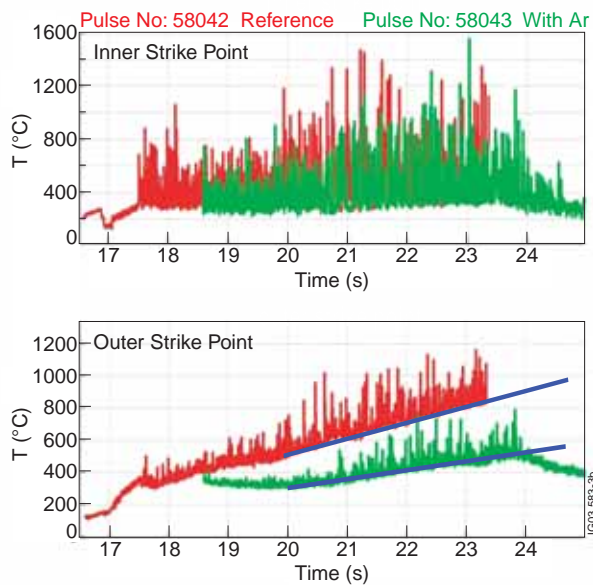


Figure 3(b): Temperature at inner strike point (top) and outer strike point (bottom) in an unseeded reference discharge (Pulse No: 58042) and in an Ar seeded discharge (Pulse No: 58043).

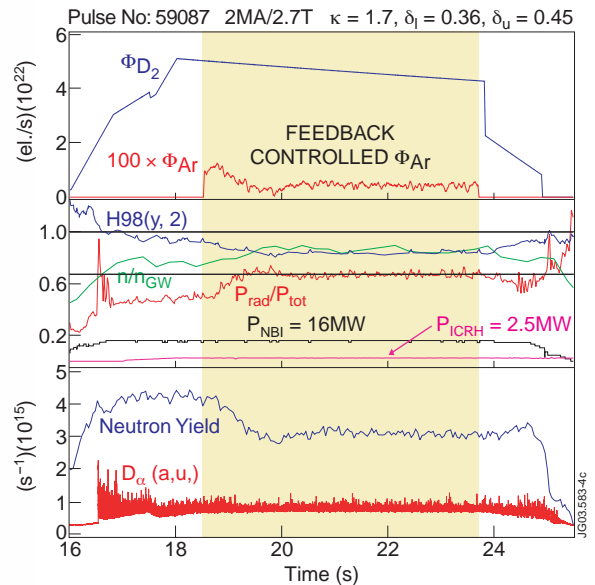


Figure 4: Time traces of global plasma parameters in a discharge with improved feedback control of γ by acting on Φ_{Ar} .