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ABSTRACT
The ITER ICRF antenna will operate at a considerable plasma-wall distance. In these circumstances it is expected that the ICH&CD system will routinely deliver power near its maximum voltage in the Main Transmission Lines (MTL). On the other hand during ICRF heating of JET plasmas the distance between the plasma separatrix and the ICRH antenna is usually kept to a minimum in order to maximise the power coupled to the plasma. This is necessary in order to compensate for the drastic reduction of the coupling resistance R_c that occurs when the plasma goes into H-mode, due to the depletion of the density in the Scrape-Off Layer in front of the antenna. As a consequence of this the maximum voltage in the MTL line also increases, leaving less headroom to cope with fast transients like ELMs. However it has also been shown [1] that the proximity of the midplane plasma separatrix to the outer wall (RF antenna) increases the power necessary for the transition to H-mode.

1. INTRODUCTION
In order to access the H-mode regime a certain number of physical conditions must be fulfilled, which empirically translate into a threshold in the power needed, P_{LH}. For a given machine such threshold power is at first order dependent on global plasma parameters like density n_e, magnetic field B_T. Thus typically for JET $P_{LH} \propto n_e B_T$, although with variations due to the different types of Pumped Divertor used through the years [1]. It is however also clear that access conditions to the H-mode depend on the physical properties of the plasma edge and the Scrape-Off Layer (SOL). Thus, it is observed that a minimum distance between the midplane plasma separatrix and the outer wall limiters exists below which the power needed for the H-mode transition increases sharply, independently of the heating method used. This may be due to the fact that the nearer to the outer wall, the more the plasma resembles a limiter configuration, for which no H-modes can be obtained on JET (the X-point configuration may be stabilising microturbulences in the plasma edge, see e.g. [2]). The dependence of P_{LH} on the outer gap rout has been consistently seen on JET from the first H-modes. When Ion Cyclotron Resonance Frequency (ICRF) is used to heat the plasma, due to the nature of the fast magnetosonic wave the outer gap r_{out} should be minimised to allow the RF wave to tunnel through the edge evanescent layer. This translates in higher coupling resistance R_c and therefore lower voltage in the transmission lines, which also allows ICRF to cope better with fast transients like ELMs. In the present paper the conflicting requirements between ICRF coupling and access to the H-mode are analysed, and a solution that allows to maximise Rc without increasing P_{LH} is presented.

2. OUTER GAP AND ICRF PERFORMANCE
With similar edge conditions, a smaller outer gap rout in general corresponds to a higher coupling resistance R_c and therefore a lower maximum Main Transmission Line (MTL) voltage Vmax, which in turn allows more RF power to be coupled to the plasma. The situation is best described in Fig.1, where the average coupling resistance $\langle R_c \rangle$ is plotted against rout for a series of discharges from

the MkIIa experimental campaign (1996/97) used to study the transition to H-mode. A standard target plasma at 1.8MA/1.8T and densities of the order of 1-2×10^{19} m^{-3} is used. The heating scheme is second harmonic hydrogen resonance heating ($\omega = 2\omega_{cH}$ = 52MHz) with constant dipole ($\phi = 0\pi 0\pi$) phasing of the antenna current straps. Unless explicitly stated otherwise, all antenna quantities (like R_c and V_{max}) have been averaged over the current straps and refer to one antenna only, namely Module A. As shown in Fig.1, on average in L-mode and dithering H-mode conditions (i.e. just before and after the L-H transition) to a 1cm reduction of rout corresponds 0.9Ohms increase in R_c, leading to a reduction in Vmax (not shown in the figure) from 12.5kV to 6kV and therefore to about 50% more headroom to increase power, i.e. $\Delta P \cong$ 400kW more per antenna (in the same conditions). Figure1 also shows that there is a substantial reduction in R_c during the L-H transition and then to H-mode. The situation is best illustrated in Fig.2, where the time evolution one of the discharges of Fig.1 is shown. At constant RF power (0.75MW for Module A) and r_{out} = 1.6cm R_c decreases from 3.3 Ohms before the L-H transition to 2.8 Ohms by the end of the dithering phase, when the plasma has stabilised, while during the ELMy H-mode R_c = 2.2Ohms. Correspondingly, V_{max} increases from 12.1kV to 14kV to 16kV. The change in V_{max} corresponds to an overall equivalent power of 100 kW per antenna (in the same coupling conditions). If the plasma goes in ELM- free H-mode, the drop in Rc is even greater: for Pulse No: 41703 (a 1.8MA/1.8T ICRF heated 50:50 DT plasma with r_{out} = 1 cm) from the initial L-mode phase to the end of a 1.4s long ELM-free period R_c dropped from 5 to 1.9 Ohms and Vmax increased by about 7.5kV, corresponding to about 370kW of power per antenna that are not available for heating but are needed only to compensate for ΔR_c

3. OUTER GAP AND L-H TRANSITION

The threshold power P_{LH} is largely insensitive of the value that the outer gap assumes if r_{out}>3 4cm. Below this value however P_{LH} increases sharply, as illustrated in Fig.3 for series of shots obtained in different experimental periods. The phenomenon is independent of the heating method used, since H-modes heated with both ICRF and NBI are affected. A first analysis of this important dependence of the threshold power with rout has been reported elsewhere (cfr. [1]) and will therefore not be dealt with here. Suffice here to say that for the particular case of the discharges of Fig.1 (a subset of those labelled “MkIIa” in Fig.3) and r_{out}<3cm, then Δr_{out}=1cm (from say 2.5cm to 1.5cm) corresponds to an increase of PLH by about 1MW for typical plasma parameters (for instance B_T = 1.8T, n_e = 2×10^{19} m^{-3}), that is an increase by about 50% in the power needed to obtain the H-mode.

4. BALANCING TWO CONFLICTING NEEDS

From the previous analysis it is clear that while efficient ICRF heating would benefit from the smallest possible rout, this may be incompatible with access conditions to the H-mode. The example of Pulse No: 39912 can be useful to illustrate the problem further. In order to compensate for ΔR_c (and keep R_c = 2.8 Ohms constant) it would be sufficient to bring the plasma nearer to the antenna by 0.5cm to gain about 520kW for four antennas in the same coupling (L-mode) conditions. At the same time however P_{LH} increases by about 500kW and the extra power gained by decreasing rout is needed to overcome the higher P_{LH}. In the cases illustrated above rout was already very small (and P_{LH} higher!) and ICRF could cope well with the both the R_c reductions associated with the H-mode and with ELMs. However when maximum RF power is required the system runs near the maximum allowed Vmax value (typically around 30-33kV for well conditioned antennas). In these circumstances fast transient loads and R_c reductions can result in trips of the protection system and shutdown of the generators in the most severe cases. If the maximum available power is needed without increasing P_{LH} the following scenario, illustrated in Fig.4 for Mod.A, is a viable solution. In this case the H-mode transition has been obtained at low power and r_{out} = 3.7cm, corresponding to R_c =2.8Ohms, V_{max} = 19.2kV and P_{RF} =1.6MW. Subsequently the plasma has been brought nearer to the antennas (r_{out} =2.5cm), and R_c = 2.7Ohms, V_{max}=28.3kV and P_{RF} = 3MW were obtained without loss of the H-mode. With Δr_{out}=1.2 cm AFTER the L-H transition 0.7 Ohms have thus been gained by the time RF is at full power. Without this change Rc would have dropped below 2 Ohms and 3MW would have required $V_{max} \cong$ 37kV.

SUMMARY AND CONCLUSIONS

The often conflicting needs of maximising the RF coupled power and minimising the power required for the transition to H-mode have been analysed. It has been shown that in L-mode conditions Rc and P_{LH} (below r_{out} = 3-4cm) increase roughly linearly with decreasing r_{out}. The balance of these two opposing tendencies shows that in general the RF power gained by reducing rout in L-mode is lost by the extra power needed to access the H-mode. A viable solution is to obtain the H-mode at low power and r_{out} >3cm and then decrease rout if extra headroom in V_{max} is needed. In this paper no effort has been made to evaluate the influence on either the L-H transition or P_{RF} of the other plasma-wall gaps, which no doubt play as important a role as rout especially with changing first wall geometry and plasma shaping.

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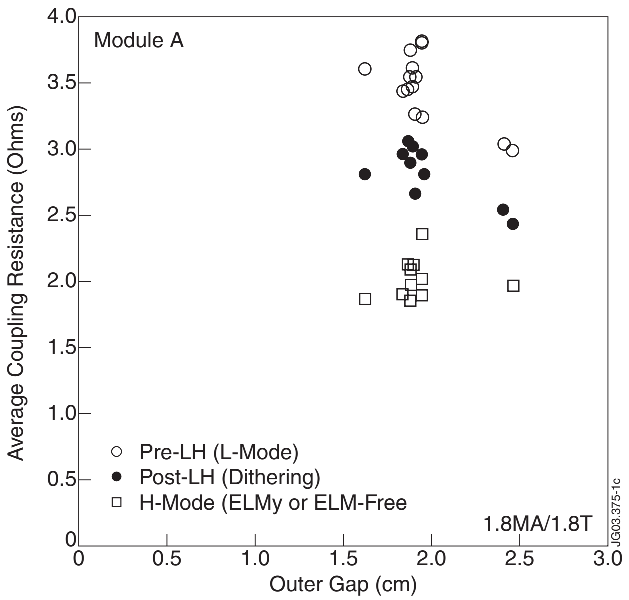

Figure 1: R_c as a function of r_{out} for L-mode, dithering H-mode and full H-mode phases of ICRF heated discharges (1.8MA/1.8T).

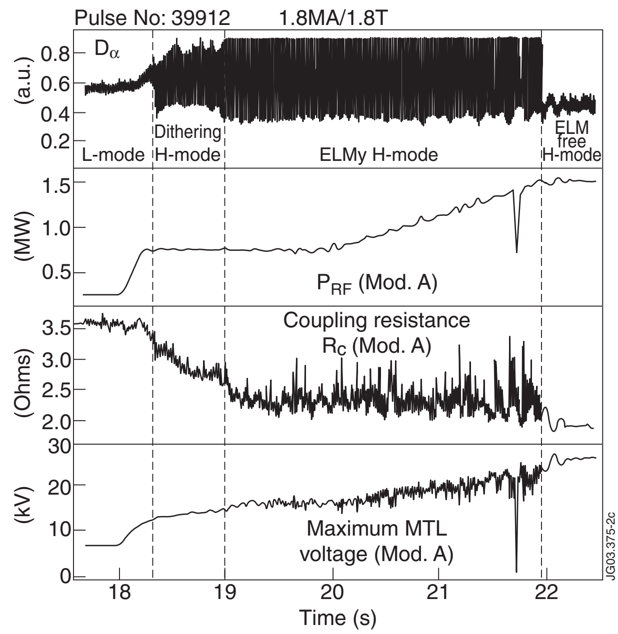

Figure 2: Time evolution of R_c and V_{max} during a typical H-mode.

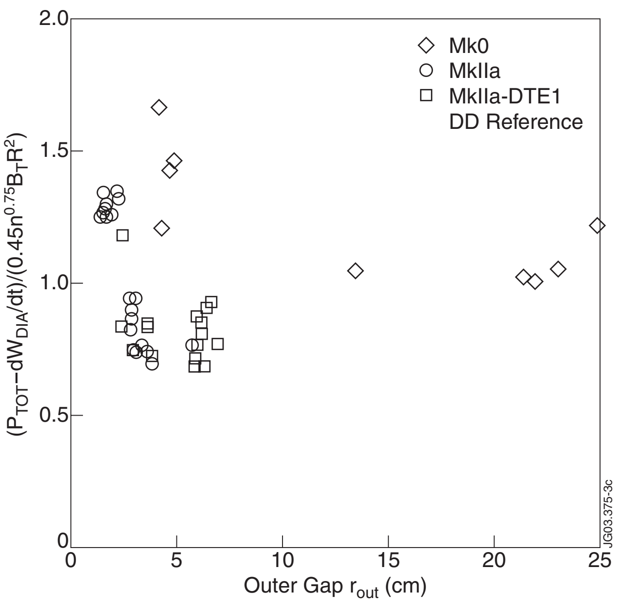

Figure 3: Threshold power normalised to the multi-machine scaling expression from [3] as a function of the outer gap r_{out}. Both ICRF and NBI heated discharges from Mk0 (1990-92) and MkIIa (1996-97) have been used.

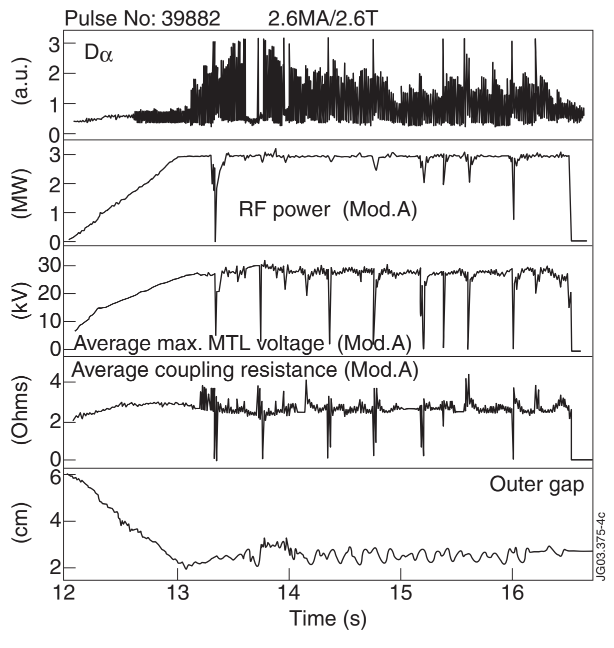

Figure 4: A viable scenario to avoid increased P_{LH} and maximise the RF power