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Ohmic H-mode Accessibility in Shaped TCV Plasmas

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INTRODUCTION

Future fusion reactors like ITER are planned to operate in the ELMy H-mode regime. The H-mode is desired because of its high confinement properties and ELMs are necessary to control the plasma density and plasma impurities. ELMs, however, represent a threat to the divertor plates because of the deposited heat flux if the delay between ELMs becomes too large. Therefore, the identification of the plasma parameters which can control the ELM frequency is necessary. The strong shaping capabilities of TCV can be used to investigate the effect of plasma shape and position with plasma parameters on the ELM activity. On TCV, additional heating can not, as in other machines [1, 2 and references therein], be used to access a desired ELMing regime. Thus, other machine or plasma parameters must be found.

H-mode have already been obtained in ohmic TCV discharges with a large variety of plasma shapes, currents and densities. A large number of these discharges had an ELM free H-mode phase while some, seemingly similar discharges, exhibited ELMs. The goal of this study was to determine the conditions necessary for the production of a stable ELMy H-mode. These discharges could subsequently be used to study the plasma behaviour and ELM dynamics in an ELMing regime.

In this initial investigation, the plasma current, density, elongation, triangularity and plasma to wall gaps were scanned whilst keeping the toroidal magnetic field at its nominal value of 1.4T. A single null divertor with the ion grad B drift directed away from the X point was chosen for these experiments. This configuration has been extensively used in previous experiments and led to most of the ELMy discharges previously observed on TCV. An ELM free H-mode period on TCV results in the plasma density increasing until the discharge terminates by a high density disruption. Since many such discharges had already been obtained, plasma parameters leading to this regime could be avoided. In the same way, discharges in this configuration which remained in L-mode were also avoided. From database studies of TCV discharges, ELMs were expected for plasma parameters between these limits.

It was found that an ELMy regime could be obtained by passing through a small but well defined region of the operational domain. Surprisingly, large changes in the machine conditioning, (including a boronisation) did not significantly affect the position of this “gateway” which was used to reliably access an ELMy TCV regime (see next section). Once in the ELMy regime, the plasma was found to be relatively robust to changes in the current, shape and density. It was thus possible to access a wider range of plasma parameters whilst remaining in an ELMy regime. A subsequent section describes the operational boundaries of the established ELMy regime and the limiting operational parameters.

THE "GATEWAY" TO THE OHMIC ELMING REGIME

This section first presents how the boundaries of the ELMy "gateway" were determined. The plasma discharges in this study were tagged with one of the labels: ELMY for stationary ELMy discharges, LMODE for discharges remaining in L-mode, ELMFREE for discharges which transited to an ELM free phase, ELMYL and ELMYELMFREE were attributed to discharges alternating between the two modes and ELMY-FAIL was attributed to discharges disrupting shortly after the transition, for which the mode was unknown. Example discharges for these labels are shown in Fig. 1. The non stationary ELMing discharges were classified in two categories: discharges which ceased to be ELMy soon after the L-H transition and discharges whose ELM frequency became irregular as a result of programmed changes in some of the plasma parameters (Fig 2).

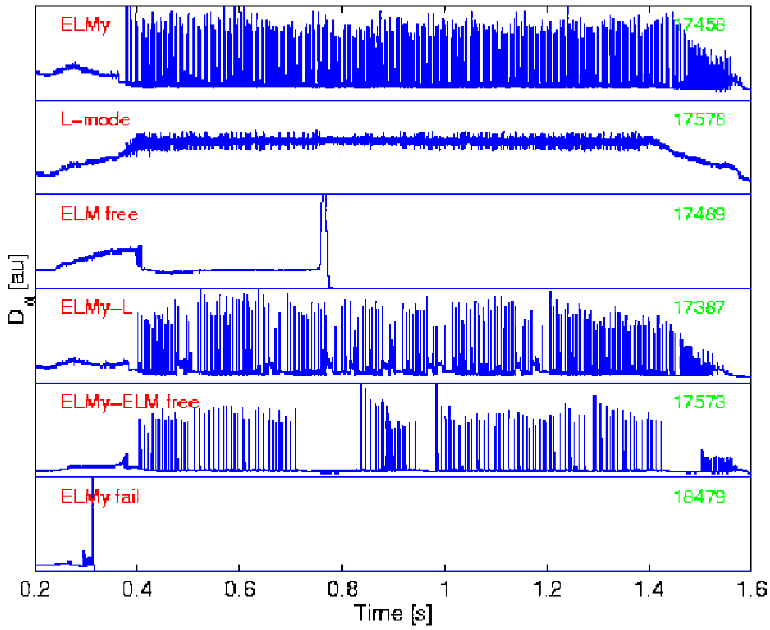

***Figure 1**: Time evolution of the D_α emission from different type of discharges as indicated on the left.*

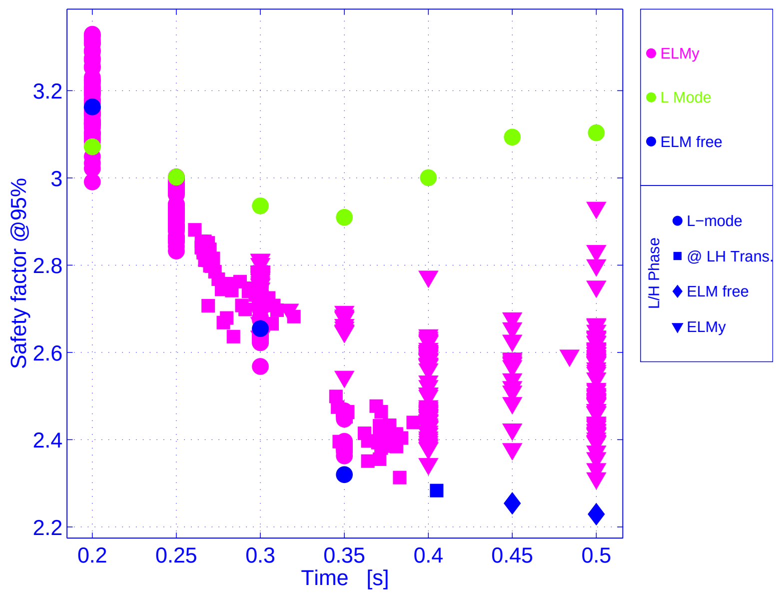

***Figure 2**: Time evolution of the safety factor for ELMy L-mode and ELM free shots indicating the available range in q_{95} for accessing the ELMy regime.*

To pass the "gateway" to the ELMy regime, three parameters must simultaneously exceed a threshold value to obtain an H-mode: a) the plasma current has to be greater than 350kA or equivalently q_{95} must be lower than 3.0 with κ=1.6-1.7 and δ=0.5-0.6 as shown in Fig. 2; b) the plasma line average density must exceed $4.5 10^{19} m^{-3}$; c) the distance between the plasma and the tiles must be greater than 1cm. The inter-dependencies between these limits were small. With the same plasma shape parameters, the plasma current must not exceed 430kA (or q_{95}<2.3) otherwise the transition leads to an ELM free phase. A high density (> $6.10^{19}m^{-3}$) at the transition also led to an ELM free phase.

LH transitions were also provoked at higher plasma elongation (in the range 1.7 to 2.1) by retarding the formation of the SND configuration. In otherwise similarly shaped plasmas with similar densities, the L-H transition was obtained at higher q_{95}, with roughly equal values of I_p. However, these transitions led to ELM free H-modes. A reduction in the plasma density at the L-H transition time resulted in L-mode discharges. Minor changes in the plasma shape at higher q_{95} sometimes resulted in ELMs but with low frequency and high amplitude. The resulting perturbation in the control system was sufficient to lose vertical plasma position control and a disruption (VDE) ended the discharge. Changes in the control observers are being developed to improve this situation [3] which, for this paper, limited the maximum plasma elongation.

In summary, the "gateway" to the ohmic ELMy is bounded by the following limits in the operational parameters :

	I_p [MA]	$n_e[10^{19}m^{-3}]$	κ	δ	$gap_{pl-w}[m]$
Min	0.35	4.5	1.6	0.5	0.01
Max	0.43	6.0	1.7	0.6	0.03

THE OPERATIONAL DOMAIN OF THE OHMIC ELMY REGIME

Once in the ELMy regime, it was then possible to modify certain plasma parameters while preserving the ELMs. The plasma elongation was increased to κ=2.1, with q_{95} approximately constant, as shown in Fig. 3a. Changes in q_{95} during the elongation ramp resulted in vertical stability problems. Decreases in q_{95} lowered the ELM frequency, as mentioned above, whereas increases in q_{95} made the plasma less vertically stable. Moreover, the plasma current must

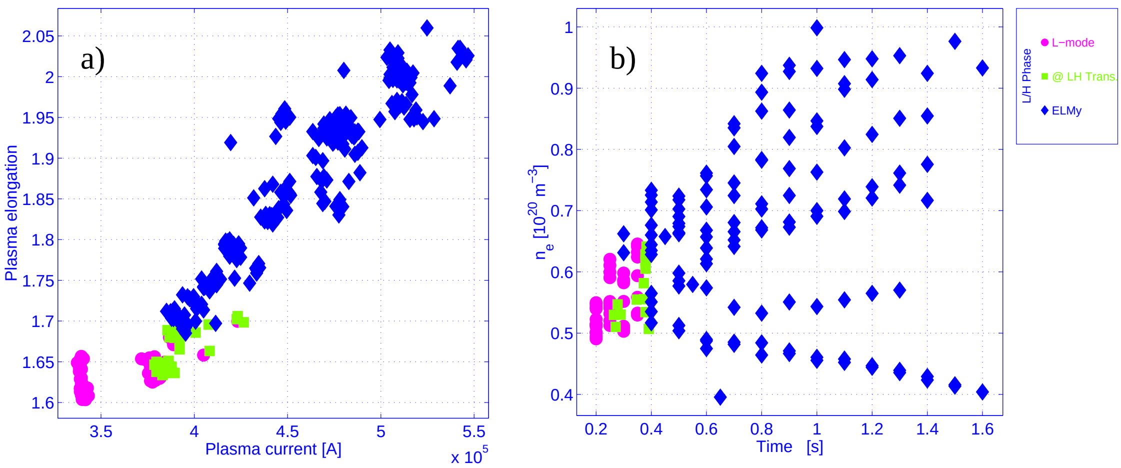

***Figure 3**: a) Accessible plasma current and elongation for the ELMy H-mode. b) Accessible plasma density for the ELMy H-mode. In both cases these parameters may only be obtained after passage through the ELMy "gateway".*

be ramped sufficiently slowly, or the discharge showed spontaneous H-L-H transitions regime or even returned to L-mode for higher values of dI_p/dt.

Once in ELMy H-mode, the plasma density could be decreased or increased in the range between $4\text{-}10.10^{19} m^{-3}$. A strong gas puff led to alternating ELM free and ELMy phases and reducing the density finally led to a return to L-mode.

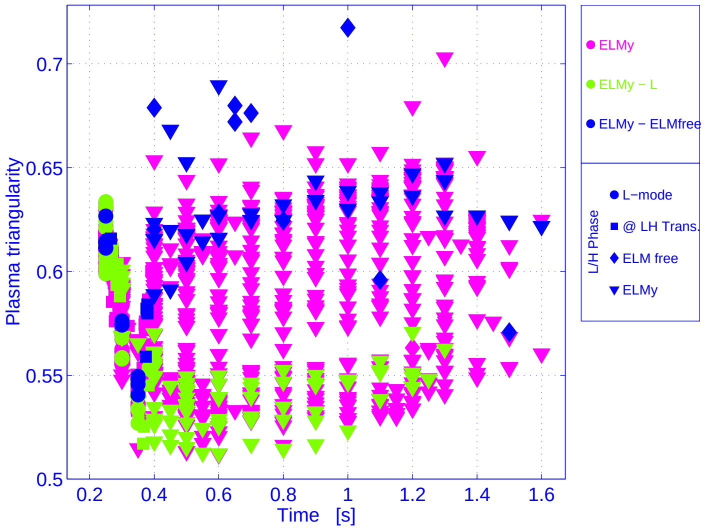

Figure 4*: Time evolution of the triangularity for different discharges. It shows that low triangularity may lead to ELMy-L oscillations, whilst increasing the triangularity led to ELM free H-mode.*

Finally, small modifications of the plasma triangularity led to changes in the ELM accessibility (Fig 4). A relatively small increase in the plasma triangularity led to alternating ELMy and ELM free phases whereas a slight reduction in the triangularity resulted in stable discharges with frequent transitions to L-mode.

CONCLUSION

A reliable ELMy H-mode regime was successfully obtained in TCV. Access to ELMy discharges was only possible for a small region of the operational domain. Once this “gateway” is traversed, the ELMing state is stable to changes in the operational parameters. Plasma elongations from 1.6 -> 2.1, and densities from 4 -> 10 $10^{19} m^{-3}$ were successfully attained by passing the L-H transition with the “gateway” parameters and then programming plasma control changes. Although the ELM frequency was modified for these discharges, the ELMy regime characteristics were conserved. The triangularity was limited between 0.5 and 0.6 with the discharge transiting to an ELM free phase for higher triangularity and to ELMy-L regime for lower triangularity. It may be possible to extend this range by compensating these effects with changes in other plasma parameters.
The reliable access to the ELMy regime on TCV opens the way for the study of ELM dynamics and plasma confinement in this regime, both with and without ECH as a function of the plasma shape.

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