CHARACTERISTICS OF THE H-MODE PEDESTAL AND EXTRAPOLATION TO ITER*

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Although the H-mode transport barrier typically occupies less than 5 % of the minor radius, the characteristics of this region have a strong impact on the expected performance of an H-mode based Tokamak reactor. Stiff temperature profile, turbulent transport models [1,2] predict core temperatures, and hence energy confinement and fusion power production efficiency, to be highly dependent on the value of the temperature at the top of the H–mode pedestal. Additionally, the low transport in the H-mode barrier generally results in the edge pressure building to a stability limit. This pressure rise triggers an ELM event that can transfer up to 15% of the H-mode pedestal energy to the divertor in less than 1 ms. Power fluxes of this level to the divertor plates would not be tolerable in a reactor scale device and it is thus important to understand the ELM energy loss mechanism and to explore small ELM or ELM free regimes. This paper discusses progress in these areas through inter-machine comparison under the venue of the International Tokamak Physics Activity, ITPA.

Transport is typically so low in the H-mode transport barrier region that the time averaged H-mode pedestal pressure is largely controlled by ELM stability. The critical pressure gradient for the instability sets the maximum pressure gradient at the edge, the size of the ELM energy loss sets the minimum pressure, and the edge pressure change largely determines the ELM energy to the divertor. Several features of the Type I ELM onset conditions are consistent with the ideal peeling-ballooning mode [3]: 1) the pressure gradient before the ELM increases strongly with triangularity consistent with stability calculations (Fig. 1) [4], 2) rapidly growing lower n modes are observed as ELM precursors, 3) the reduction in pressure gradient and increase in n number of the modes with increased edge collisionality at high density is consistent with reduced edge bootstrap current resulting in a lower critical pressure gradient. The critical pressure gradient for peeling-ballooning modes decreases with increasing width of the steep gradient region. This is supported by experiment and indicates a coupling between stability physics and H-mode transport barrier physics. Detailed inter-machine stability comparisons will be presented.

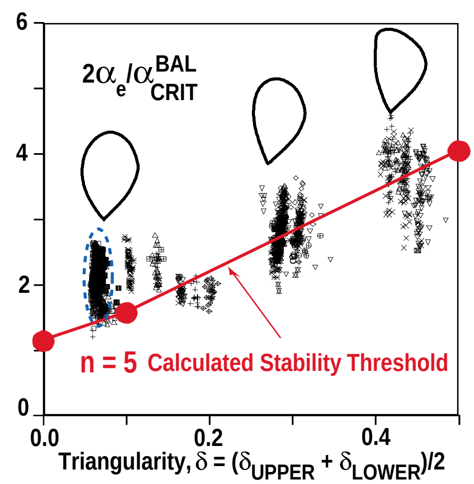

Figure 1: Variation of pressure gradient before Type I ELM with triangularity is in agreement with peeling-ballooning mode theory.[4]

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Type I ELM energy loss is found to be proportional to the energy in the H-mode pedestal across machines. Scaling from discharges without additional gas puff to the pedestal pressures required for good performance in a reactor scale Tokamak, and assuming a similar time scale for the loss, gives an ELM heat flux which would quickly erode the divertor. However, at high density ELM energy loss is reduced to levels that may be tolerable. This reduction is associated with a decrease in the edge temperature drop at the ELM, suggesting a reduction in the conductive loss channel. An increase in ELM precursor n number and a reduction in the radial extent of the effected region are also observed with increased density. This suggests that a reduction in the radial extent of the peeling-ballooning instability expected at higher n may also play a role. A shift to higher n is expected with reduced edge current density (bootstrap current) at high density and indicates a coupling between stability and ELM energy loss physics.

The other important factor in determining the edge pressure in H-mode is the transport barrier width. A variety of scaling laws have been proposed but it is difficult to separate them on the basis of fits to the ITPA database. The width is found to scale either as function of edge pressure or temperature, e.g. $\Delta \propto (\beta_{pol}^{PED})^{1/2}$ or $\Delta \propto (\rho_{POL}^{PED})^{2/3}$, and is therefore coupled to the stability and ELM physics. By adding plasma shape terms to a ballooning mode scaling in a fit to the critical pressure gradient before a type I ELM as suggested by the strong shape dependence of peeling-ballooning modes, a good fit is obtained to the pedestal pressure across machines, $p_{ped} = 10^4 (\frac{M}{n_{ped}})^{1/3} (\frac{a}{B_{pol}})^{2/3} ((\frac{dp}{dr})_0)^{4/3} (1+\delta)^{3.41} \kappa^{3.81} A^{-3.43} (\frac{P}{P_{LH}})^{0.144}$, where $P_{LH} = 2.84 M^{-1} B^{0.82} \overline{n}_e R a^{0.81}$ (Fig. 2)[5]. Current inter-machine comparison experiments will address whether Kadomtsev scaling constraints can be applied to the edge region and results of these experiments will be presented.

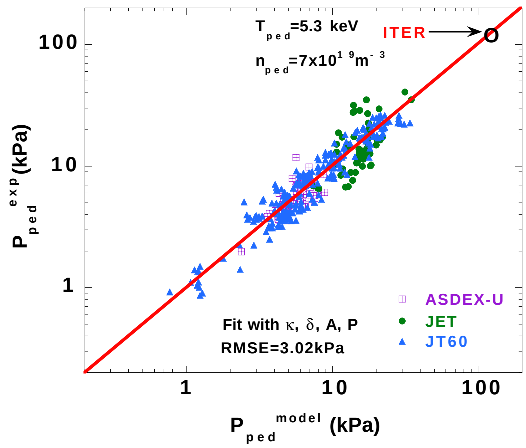

Figure 2: Fit of pedestal pressure to model that takes p' as the ballooning mode scaling modified with shape terms and ρ_{POL} scaling for width.[5]

Some small ELM or ELM free regimes, e.g. the "grassy" ELM regime in JT60-U [6], Type II ELM regime on ASDEX-Upgrade [7] or the ELM free QH-mode regime in DIII-D, have good energy confinement and resolve the problem of ELM divertor heat flux. In the steady state ELM free regimes, large or small scale-modes may limit edge pressure. We will present the results of inter-machine comparison of small ELM regimes.

[1] M. Kotschenreuter, et al., Proc. 16th Inter. Conf. on Fusion 1996, Montreal V 2, p. 371.
[2] R.E. Waltz, et al., Proc. 16th Inter. Conf. on Fusion 1996, Montreal V 2, p. 386.
[3] P.B. Snyder, et al. "Edge Localized Modes and Pedestal: A Model Based on Peeling-Ballooning Modes", accepted for publication, Phys. Plasmas, May 2002.
[4] J.R. Ferron, et al., Phys. Plasmas **7**, 1976 (2000).
[5] M. Sugihara, et al., "H-mode Edge Pedestal in ITER", 57th Annual Meeting of the Phys. Soc. of Japan.
[6] Y. Kamada, et al., Plasma Phys. Control. Fusion 42 (2000) A247.
[7] J. Stober, et al., Nucl. Fusion **41**, 1123 (2002).