Inter-ELM power losses and their dependence on pedestal parameters in JET C- and ITER-like wall H-mode plasmas

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Empirically based, power-balance calculations of the inter-ELM, separatrix loss power P_{sep}^{iELM} are presented for JET pulses with both the carbon- (JET-C) and ITER-like (JET-ILW) walls, to facilitate comparisons with results of on-going, non-linear gyro-kinetic calculations of pedestal heat transport, e.g. as reported in [1]. These might be able to explain the generally lower pedestal temperatures found in otherwise similar JET-ILW and JET-C H-mode pulses.

To determine P_{sep}^{iELM} correctly, as well as the radiated power from the confined plasma P_{Rad}^{Pl}, it is also necessary to subtract the time-averaged ELM loss power $\langle P_{ELM} \rangle$, which is of comparable magnitude. Our calculations utilise estimates of the plasma stored energy W_{MHD} from fast EFIT reconstructions to determine $\langle P_{ELM} \rangle$ (which in quasi-steady conditions is equivalent to dW_{MHD}/dt during the inter-ELM periods), together with P_{Rad}^{Pl} from bolometric measurements to calculate $P_{sep}^{iELM}(= P_{in} - P_{Rad}^{Pl} - dW_{MHD}/dt$, averaged over the inter-ELM periods).

We concentrate mainly on a series of pulses from a scan of the input power P_{in}, at low plasma current (1.4 MA/1.7T) with a low rate of gas fuelling [2], for which the ELM frequency is low enough ($f_{ELM} \leq 40$ Hz) for the ELM energy losses ΔW_{ELM} to be determined from magnetics to within ± 20% of kinetic estimates ΔW_{kin} determined from pre- and post-ELM high-resolution TS profile data. For this series of pulses, radiation and ELMs each account for ~ 20% of the total power loss, with inter-ELM pedestal transport P_{sep}^{iELM} accounting for the remaining ~ 40%. As the input power P_{in} is increased from 4.5 to 16 MW, the loss powers in all three channels increase approximately proportionally, with P_{sep}^{iELM} rising from ~ 2 to 6 MW.

The dependence of P_{sep}^{iELM} on pedestal parameters is investigated by shifting the timing of HRTS profile data relative to that of the previous ELM. It is found, broadly consistently with results in [3], that, as P_{in} is increased (4.5→16 MW): at the pedestal top, $T_{e,ped}$ approximately doubles, while the $n_{e,ped}$ decreases by ~ 25%, with the gradients changing similarly, hence, doubling $\eta_e \equiv L_{n_e}/L_{T_e}$, which saturates at ~ 2; Also, during the ELM cycle, as P_{in} is increased, $dp_{e,ped}/dt$ is also increases, and the pre-ELM $p_{e,ped}$ saturates at a higher value (2→4 kPa).

A comparison of high-performance, high-current 3 MA JET-C (P_{in}=18 MW) and JET-ILW (P_{in}= 33 MW) pulses, with similar $\beta_N \sim 2.2$, $H_{98} \sim 1$, reveals that radiation accounts for a larger fraction of the power losses (~ 0.3 c.f. 0.2) in JET-ILW, in spite of the higher ELM frequency (~ 3×) and correspondingly lower ΔW_{ELM}, while the ELMs and inter-ELM losses contribute approximately equally in both cases. In the JET-ILW pulse, $P_{sep}^{iELM} \sim 11$ MW is about twice that in the JET-C pulse. Also, the pre-ELM pedestal $T_{e,ped} \sim 1.0$ keV is lower in the JET-ILW pulse than in the JET-C pulse (~ 1.5 keV), while $n_{e,ped} \sim 0.6\times10^{20}$ m^{-3} is higher (c.f. 0.4×10^{20} m^{-3} in JET-C), resulting in a comparable pre-ELM $p_{e,ped} \sim 10$ kPa in both cases.

In the 3 MA ILW pulse, bolometer tomography reveals that the radiation is predominantly from the 'mantle' region, ($\psi_N \sim 0.8$-1.0), adjacent to the pedestal top, with a poloidal distribution consistent with this being from tungsten ($W^{25\text{-}30+}$) impurities, which might somehow be a contributing factor to the low pedestal temperatures typical of ILW pulses.

[1] Hatch D.R. et al., Nucl. Fusion 57 (2017) 036020; [2] Challis C. D. et al., Nucl. Fusion 55 (2015) 053031;
[3] Maggi C. F. et al., Nucl. Fusion, 57 (2017) 11612.