Impact of 3-D fields on divertor detachment in NSTX and DIII-D

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Increasing input power and plasma current in present and future tokamaks naturally leads to more serious divertor and first wall heat flux problem. This is true for both the steady state and the transient ELM heat deposition. Therefore, ELM control using the 3-D fields and peak heat flux reduction with the divertor detachment must be compatible. Partial divertor detachment both on the inboard and outboard sides has been demonstrated in the high performance H-mode plasmas in NSTX [1]. Results from NSTX have shown that partially detached divertor plasma can be re-attached by applying 3-D fields (n=3). However, this can be avoided when the detachment is enhanced by puffing sufficient gas into the divertor region [2].

A large amount of deuterium (D_2) gas is puffed into the lower divertor area through the 'CHI gap' between the inner and outer divertor plates in NSTX, for naturally ELMy H-mode plasmas, to produce partially detached divertor condition, *i.e.* detachment only occurs near the strike point. A small amount of pre-discharge lithium, well below that needed for full ELM suppression, was used to condition the PFC surfaces. 0.2kA n=3 error field correction was applied as a baseline, followed by super-position of the n=3 perturbation field for the 2nd half of the gas puff period. The amplitude of 3-D coil current ($I_{3\text{-}D}$ = −0.5 kA) was below the ELM triggering threshold that was confirmed from the ELM triggering experiment in the lithium enhanced ELM-free plasma. Plots in figure 1 are the calculated heat flux profile onto the divertor surface during the inter-ELM period, based on the dual band IR camera data [3]. Two divertor gas puff rates were tested. Plot 1(a) is for the low gas puff (~$7\text{x}10^{21}$ D/sec) and 1(b) is for the high gas puff (~$1.1\text{x}10^{22}$ D/sec). The heat flux profiles in red are before the gas puff and are peaked near the strike point at R~38 cm in both cases, which indicates that the divertor plasma is attached. The blue profiles are obtained after the detachment onset (by gas puff) but before the 3-D field application. The peak heat flux is reduced by ~70 % compared to those in the attached regime before the gas puff. It is also seen that the heat flux profile after the detachment onset is slightly higher for the low gas puff, which is interpreted as a "weaker" degree of detachment compared to the high

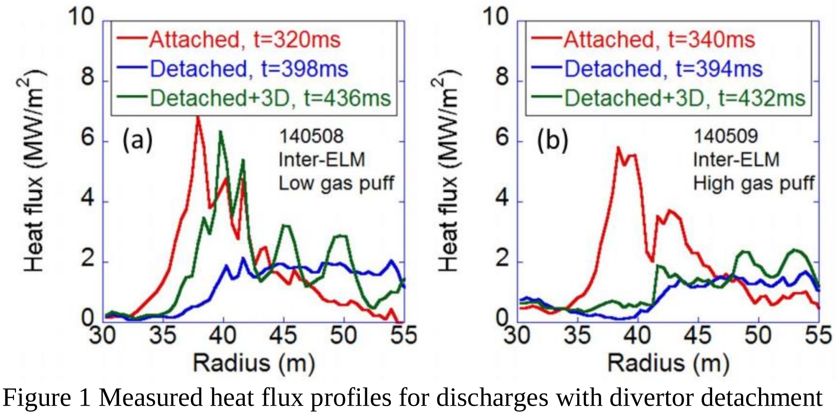

Figure 1 Measured heat flux profiles for discharges with divertor detachment in NSTX by (a) low and (b) high divertor gas puff (D_2) [2]. Each profile is color coded; red is before gas puff, blue is after gas puff, green is after gas puff plus 3-D field application.

gas puff. The green profiles are after the 3-D field was applied to the detachment. It is clearly seen that the heat flux profile becomes peaked again in the low gas puff case, i.e. the divertor plasma re-attaches. However, it remains flat in the high gas puff case (~50% increase of gas puff rate), which indicates that the plasma remains detached. Therefore, the 3-D fields can re-attach weakly detached plasma but this can be avoided by enhancing detachment with higher gas puff.

A similar experiment was carried out at DIII-D to investigate the impact of n=3 3-D fields by I-coils on divertor detachment, which was established by upstream D_2 gas puffs. 4 kA coil current, with both even and odd parities, was applied to high density ($\bar{n}_e$>7x10^{19} m^{-3} and $v_e^* > 1$) H-mode discharges. It was found that the plasma did not respond to the applied 3-D fields, *i.e.* there was no striation observed either in the heat or particle flux profile, although the pedestal collisionality was high enough compared to the value reported necessary ($v_e^* > 0.5$) to achieve heat flux striations in a previous study [4]. Figure 2 shows contour plots of connection lengths (L_c) calculated by the TRIP3D-MAFOT field line tracing code for an n=3 even parity case for a discharge that had no striation induced by 3-D fields.

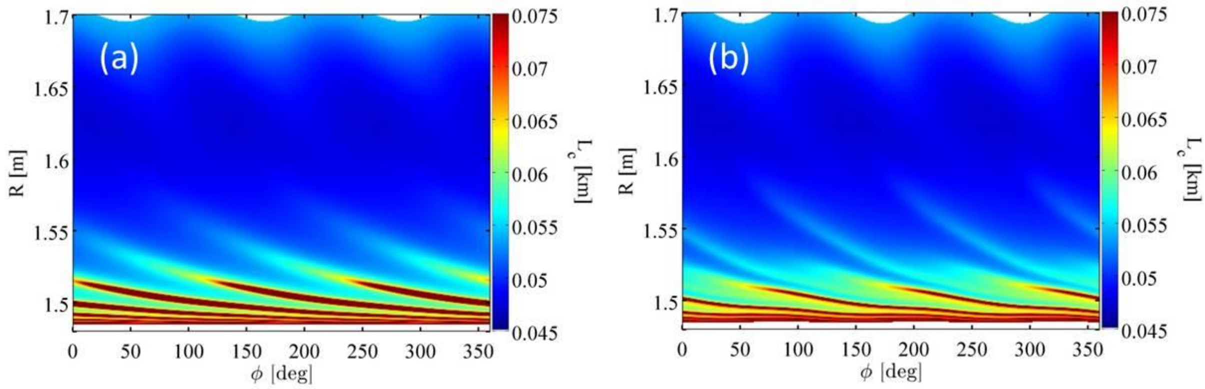

Figure 2 Calculated connection lengths (L_c) at the outer divertor surface from a field line tracing by TRIP3D-MAFOT for an n=3 even parity I-coil application at DIII-D. Plot (a) is without and (b) is with plasma response (from a two-fluid, linear M3D-C^1 calculation) included in the field line tracing.

While the vacuum approximation, figure 2(a), predicts a clear striation pattern, inclusion of linear, resistive plasma response from M3D-C^1 in the field line tracing shows reduction of striation, see figure 2(b). Although this result does not fully explain why there was no striation observed experimentally for these discharges, it shows that plasma response can play an important role in setting up strike point splitting and therefore in the effect of 3-D fields on detachment. Work is in progress to model nonlinear, resistive plasma response to be included in the field line tracing as well as to be used in 3-D edge transport calculation by EMC3-Eirene. This will allow for a quantitative comparison with experimentally measured striation patterns and their impact on detached divertor plasmas. Characterization of 3-D fields spectra and shape parameters regarding their impact on detachment conditions, along with comparison of results from NSTX and DIII-D, will be presented.

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