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Controlling Marginally Detached Divertor Plasmas

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A new control system at DIII-D has stabilized the detached divertor plasma state in close proximity to the threshold for reattachment, thus demonstrating ability to maintain detachment with minimum gas puffing. When the same control system was instead ordered to hold the plasma at the threshold, the resulting T_e profiles separated into two groups with one group consistent with marginal detachment, and the other with marginal re-attachment. This shows that a physical bifurcation is taking place, and the plasma dithers between the attached and detached states when the control system attempts to hold to the threshold. The control system is upgraded from the one described by Kolemen, et al. [1] and it handles ELMing plasmas by using real time D_alpha measurements to remove during-ELM slices from real time T_e measurements derived from Thomson scattering. The difference between measured and requested inter-ELM T_e is passed to a PID controller to determine gas puff commands. While some degree of detachment is essential for the health of ITER's divertor, more detached plasmas come at higher density with more radiation and excessive loss in confinement, making it desirable to limit detachment to the minimum level needed to protect the strike point [1]. However, the observed bifurcation in plasma conditions at the outer strike point with ion B × nabla B into the divertor makes this a significant challenge. The ideal solution without local impurity puffing lies within a narrow (3%) range in upstream density with a steep penalty for going out of bounds; if the divertor plasma were to reattach, there could be a long (depending on delays in the gas puff system) window of high heat flux before detachment could be re-established. Thus, good understanding of detachment behavior near the threshold for re-attachment is required to properly tune an active control system to maintain ideal divertor performance without reattaching. The top-of-pedestal electron densities during dithering across the bifurcation and during stable marginally detached operation are the same within uncertainty, showing the need for local real-time measurements of the divertor conditions.

[1] E. Kolemen, et al., J. Nucl. Mater. 463, 1186 (2014), DOI:10.1016/j.jnucmat.2014.11.099

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