Demonstration of actively controlled detachment in high performance scenarios on DIII-D and EAST

D. Eldon*, H.Q. Wang, L. Wang[a], J. Barr, S. Ding, A. Garofalo, X.Z. Gong[a], H. Y. Guo, A. E. Järvinen[b], J. McClenaghan, A. G. McLean[b], J. G. Watkins[c], D. Weisberg, Q.P. Yuan[a], K. D. Li[a]

General Atomics, 3550 General Atomics Ct., San Diego, CA 92121, USA
[a] Institute of Plasma Physics, Chinese Academy of Sciences, Hefei 230031, China
[b] Lawrence Livermore National Laboratory, Livermore, CA 94550, USA
[c] Sandia National Laboratories, Albuquerque, New Mexico 87185, USA

*E-mail: eldond@fusion.gat.com

Active control systems using fuel or impurity gas injection for managing divertor detachment via the active feedback of electron temperature (T_e) and ion saturation current density (J_{sat}, as a proxy for degree of detachment or DoD) have been jointly demonstrated in DIII-D and EAST with Te $\leq$ 5 eV and DoD > 3 across the divertor target plate, while excellent core plasma performance ($H_{98y2} \approx 1.5$, $\beta_N \approx 3$) was maintained during detachment. Partial detachment is required for reactor-grade devices to control heat flux, target erosion, and melting. Accomplishing partial detachment without significant degradation of the pedestal and core has proven to be challenging, and hence, the active control of detachment is of great importance in keeping the scenario closer to optimum.

In DIII-D, $T_{e,div}$ is measured by divertor Thomson scattering (DTS), 2 cm above the floor, while J_{sat} is measured by target-embedded Langmuir probes (LPs). The plasma boundary is positioned close to DTS to obtain T_e as close to the strike point as possible, while the LP closest to the strike point is selected from an array of available probes. In EAST, both quantities are measured by the divertor triple LPs near the strike point. J_{sat} is normalized to its peak value before the roll-over into detachment, J_{roll}, which the control system identifies automatically. Errors between T_e and J_{sat}/J_{roll} and pre-programmed targets are used as input to a PID (proportional-integral-derivative) controller, which outputs commands for the gas injectors. The controls are robust to differences in wall composition (DIII-D's graphite vs. EAST's ITER-like tungsten wall), auxiliary heating system type (neutral beam injection on DIII-D vs. radio frequency heating on EAST), and core plasma scenario/performance level.

In DIII-D, we chose a high β_p scenario with a large radius internal transport barrier (ITB), which is relevant to ITER steady-state operations. This scenario has been proven to be sensitive to excess gas puffing and can lose confinement quality as a result thereof. The J_{sat}-based detachment control system has minimized impurity (N_2 or Ne) gas puffing to only the required level, which allowed the ITB to maintain stability and retain internal pressure even as the pedestal is somewhat degraded ($p_{e,ped}$ decreases by ≈30%) during detachment, allowing for confinement remaining at $H_{98y2} \approx 1.5$ while keeping $T_{e,div} \leq 5$ eV as measured by LPs across the divertor plate. In EAST, similar discharges employing a $T_{e,div}$-based detachment control system have demonstrated stable control of $T_{e,div}$ at 10 eV, 8 eV and 5 eV using impurity seeding (Ne or Ar), with $H_{98y2} > 1$. The J_{sat} detachment control system can also achieve $T_{e,div} \leq 5$ eV successfully in EAST. This work was supported by the Department of Energy under Award Number(s) DE-FC02-04ER54698.

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