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Integrated ELM Control: Project Overview, Results and Plans

R. Shousha[1], F.M. Laggner[2], D. Eldon[3], A. O. Nelson[2], S.H. Hahn[4], J. -K. Park[2], S. M. Yang[2], C. Paz-Soldan[3], T. E. Evans[3], M.E. Fenstermacher[5], B. A. Grierson[2], Q. Hu[2], D. A. Humphreys[3], A. W. Hyatt[3], R. Nazikian[2], O. Meneghini[3], P. B. Snyder[3], E. A. Unterberg[6], K. G. Erickson[2], E. Kolemen[1,2], The DIII-D Team and The KSTAR Team
[1] Department of Mechanical and Aerospace Engineering, Princeton University, [2] Princeton Plasma Physics Lab, [3] General Atomics, [4] National Fusion Research Institute, Daejeon, Republic of Korea, [5] Lawrence Livermore National Lab, [6] Oak Ridge National Lab
e-mail (speaker): rshousha@princeton.edu

Operating tokamaks in the H-mode regime offers attractive potential for fusion energy. However, the edge transport barrier that is developed in this regime is typically associated with ELMs, which expel particles and energy toward the divertor and first wall. The expected energy impulses from ELMs in ITER will exceed material limits. Some form of ELM control is thus required for safe operation. Non-axisymmetric 3D magnetic fields applied by in-vessel magnetic perturbation (3DMP) coils are a promising candidate to enable active ELM suppression. 3DMP-based ELM suppression has been achieved in various devices including DIII-D, KSTAR, EAST and AUG. Further, ITER will be equipped with a set of 3DMP coils dedicated to ELM control. However, 3DMP-based ELM suppression can lead to a reduction in pedestal density, which is also linked to a degradation of plasma confinement. This indicates the need for an ELM controller that not only maintains ELM suppression, but also maximizes plasma performance. The Integrated ELM Controller consists of two integrated control schemes: an ELM Controller which automatically suppresses ELMs via application of specific 3D perturbations and a density controller that controls pedestal density via 3DMP coil currents and gas fluxes. The fully envisaged system uses sensors that measure both 3DMP coil currents and monitor ELMs, and incorporates real-time equilibria supplemented by density and radiation measurements. The vacuum response is calculated using the RT-SURFMN algorithm and is used to compute the plasma response matrix. For a given coil set, RT-SURFMN calculates the applied vacuum edge pitch-resonant and kink-resonant harmonics of the applied 3DMP. The relationship between the vacuum and the plasma responses for specific plasma regimes can be approximated via off-line IPEC calculations and loaded into the plasma control system. The control scheme will eventually be able to then adjust the relative phase between each row of the 3DMP coil sets as the plasma boundary and safety factor (q) profile evolve. This enables optimization of the 3DMP field penetration based on theoretical predictions for ELM suppression. Simultaneously, the ELM controller tracks the ELM behavior and finds the 3DMP coil current amplitude and phase that will lead to ELM suppression while the integrated density controller calculates the 3D field or gas flux required to maintain density control. So far, versions of this ELM controller have been implemented (partially) and tested in DIII-D and KSTAR. At DIII-D, full ELM suppression has been achieved, demonstrating the potential to exploit the observed suppression hysteresis effect. During an experiment, it was observed after achieving complete ELM suppression, a smaller perturbation amplitude is sufficient to sustain it. The importance of minimized perturbation amplitude is demonstrated by showing that confinement and normalized pressure do not fully recover after initiation of the perturbations, and the reduction is greater for higher perturbation amplitudes (Fig 1.). At KSTAR, the ELM controller has been implemented and tested successfully, enabling strong ELM mitigation in regimes with small ELM suppression windows. The pedestal density controller which as of yet only uses gas puff ,has been implemented and tested in DIII-D, and demonstrated—in its current state of development--that this scheme can be utilized to partially compensate the density ‘pump-out’.

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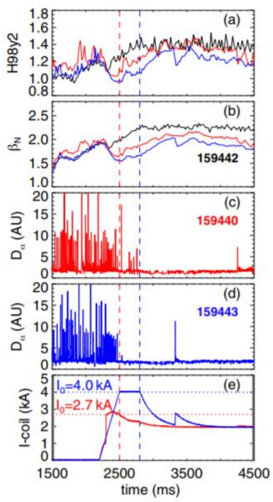

Fig. 1. : ELM suppression is achieved, however, lower confinement is observed throughout the remaining discharge, when a higher initial MP coil current is applied [2].

References

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