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# Optimization of H-mode pedestal by adaptive ELM control using 3D fields

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We report a new adaptive real-time approach to control edge-localized modes with resonant magnetic perturbations (RMP) in a way that optimizes both the pedestal stability and confinement by exploiting the hysteresis in RMP ELM suppression [1]. Such adaptive control is essential to maximize the plasma performance while also maintaining an ELM-stable edge. We recover up to 60% of the original confinement ($H_{98}$) degradation and 45% of the fusion gain factor ($G=H_{98}\beta_N/q_{95}^2$) by using our adaptive method.

The adaptive ELM controller is implemented to KSTAR-PCS, which uses the real-time Dα-based ELM detector and adjusts the RMP accordingly. It iteratively increases and decreases the $n$=1 RMP amplitude during ELMy and ELM free phase, respectively, until it converges to a stable operating point that optimizes both ELM-free and confinement. As shown in Fig.1, such change in RMP amplitude results in recovered pedestal height with ELM suppressed.

In general, adaptive control is not trivial because the threshold characteristics of the bifurcation in and out of ELM suppression can lead to control system oscillations. Our approach has overcome these limitations by the outcome of ion-scale turbulence. We find that RMP-induced turbulence during ELM free phase widens the ion pedestal and improves ideal peeling-ballooning stability [2], allowing a higher pedestal and amplified field penetration [3]. This lowers the RMP threshold ($I_{RMP,IN}$) for recovering ELM-free, weakening the control oscillation. Figure.1(a) shows decreasing $I_{RMP,IN}$ due to these effects. The reduction of $I_{RMP,IN}$ leads to the smaller oscillation and faster convergence of RMP control, minimizing the ELMy period.

Such a favorable effect is difficult to be utilized as turbulence quickly disappears with ELMs. However, the adaptive method fully exploits it by re-increasing RMP amplitude immediately after the reduction of turbulence and the ELM returns, which is the key to control convergence.

Lastly, we will introduce the concept of improved ELM-free optimization based on other real-time indicators, such as changes in the turbulent amplitude, to minimize the return of ELM. This work was supported by US DOE Contract DE-SC0020372 and R&D Program of "KSTAR Experimental Collaboration and Fusion Plasma Research(EN2021-12)" through the Korea Institute of Fusion Energy(KFE), funded by the Government funds.

References

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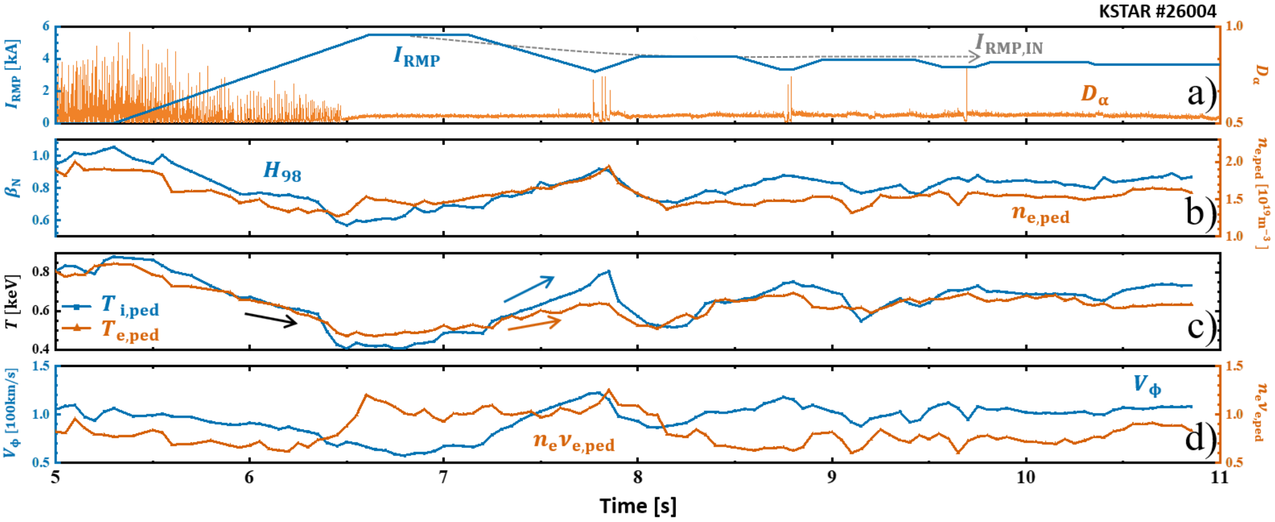

**Figure 1.** Time traces of discharge #26004 in KSTAR with adaptive ELM control using $n = 1$ RMP. (a) RMP coil current $I_{RMP}$ (blue) and $D_\alpha$ emission near the outer strike point (orange). (b) Normalized $H_{98}$ (blue) and density pedestal height $n_{e,ped}$ (orange). (c) Pedestal height of ion $T_{i,ped}$ (blue) and electron $T_{e,ped}$ (orange). (d) Toroidal carbon velocity at pedestal $V_\Phi$ (blue) in co-Ip direction and energy exchange coefficient $n_e v_{e,ped}$ on pedestal(orange). Gray dashed line in (a) denotes the change of $I_{RMP,IN}$.