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Advances in tokamak control: from multi-actuator MHD control to model-based current profile tailoring[1]

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Recent experiments on TCV have demonstrated integrated control of the sawtooth and Neoclassical Tearing Mode (NTM) instabilities in a combined preemption-suppression strategy. This strategy is enabled by new sawtooth control methods (sawtooth pacing) in which modulation of sawtooth-stabilizing electron cyclotron power during the sawtooth cycle stimulates the advent of the crash. Rather than controlling the average sawtooth period, the precise timing of each individual crash can now be prescribed. Using this knowledge, efficient preemptive stabilization of NTMs becomes possible by applying power on the rational surface only at the instant of the crash-generating seed island. TCV experiments demonstrate that this approach, reinforced by NTM stabilization as a backup strategy, is effectively failsafe. This opens the road to inductive H-mode scenarios with long sawteeth providing longer inter-crash periods of high density and temperature. Also Edge Localized Modes are susceptible to EC modulation and it is shown that individual ELM events can be controlled using similar techniques. For advanced tokamak scenarios, MHD control is to be combined with optimization and control of the plasma kinetic and magnetic profile evolution in time. Real-time simulation of a physical model (RAPTOR) of current transport, including bootstrap current, neoclassical conductivity and auxiliary current drive, yields complete knowledge of the relevant profiles at any given time. The pilot implementation on TCV shows that these calculations can indeed be done in real-time and the resulting profiles have been included in feedback control schemes. Integration of this model with time-varying equilibria and internal current profile diagnostics provides a new framework for real-time interpretation of diagnostic data for plasma prediction, scenario monitoring, disruption prevention and feedback control.

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