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Burning Plasma Relevant Control Development: Advanced Magnetic Divertor Configurations, Divertor Detachment and Burn Control

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Novel control schemes have been implemented at DIII-D to test and optimize heat-handling capabilities and burn regulation for advanced tokamaks. The topological instability of the snowflake (SF) configuration, which has a second-order null-point, motivated implementation of a control system to sustain the SF. We implemented the world's first real-time SF detection and control system on DIII-D in order to stabilize this configuration. The algorithm calculates the position of the two null-points in real-time by locally expanding the Grad-Shafranov equation and controls shaping coil currents to achieve and stabilize various snowflake configuration. SF divertor experiments achieved a 2.5 times increase in the flux expansion and a 2.5 reduction in peak heat flux for many energy confinement times without any adverse effect to core plasma such as confinement in advanced tokamak scenario with $\beta N=3.0$ and $H98(y,2)\simeq 1.35$. Also, a new detachment and radiation control algorithm was implemented at DIII-D. The algorithm uses divertor temperature measurements from real-time Thomson diagnostics and a line ratio measurement to compute the detachment level, and a real-time bolometer diagnostic to determine core and divertor radiation. The new system was used to test the feasibility of the envisioned ITER partial-detachment operation using divertor Thomson measurements on DIII-D. A dedicated partial detachment control was implemented to control the detachment front location using divertor temperature measurements from real-time Thomson diagnostics while minimizing the effect of the detachment on the core by fixing the core density independent of the detachment control. The control stabilized the detachment front fixed at the user defined distance between the strike point and the X-point throughout the shot. Finally, in a new approach to burn control, it was demonstrated that the simulated fusion power could be controlled by the application of non-axisymmetric fields using in-vessel coils. In DIII-D experiments, alpha-heating excursions were simulated with transient increases in neutral beam power. The burn control algorithm compensated the increased heating power by increasing the I-coil current, which reduced the energy confinement time and kept the stored energy (proxy for fusion power) constant.

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