Feedback-Assisted Extension of the Tokamak Operating Space to Low Safety Factor

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Recent DIII-D experiments have demonstrated stable operation at very low edge safety factor, $q_{95} \lesssim 2$ through the use of magnetic feedback to control the $n = 1$ resistive wall mode (RWM) instability. The performance of tokamak fusion devices may benefit from increased plasma current, and thus, decreased $q$. However, disruptive stability limits are commonly encountered in experiments at $q_{\text{edge}} \approx 2$ (limited plasmas) and $q_{95} \approx 2$ (diverted plasmas), limiting exploration of low $q$ regimes. In the recent DIII-D experiments, the impact and control of key disruptive instabilities was studied. Locked $n = 1$ modes with exponential growth times on the order of the wall eddy current decay timescale $\tau_w$ preceded disruptions at $q_{95} = 2$. The instabilities have a poloidal structure that is consistent with VALEN simulations of the RWM mode structure at $q_{95} = 2$. Applying proportional gain magnetic feedback control of the $n = 1$ mode resulted in stabilized operation with $q_{95}$ reaching 1.9, and an extension of the discharge lifetime for $> 100 \tau_w$. Loss of feedback control was accompanied by power supply saturation, followed by a rapidly growing $n = 1$ mode and disruption. Comparisons of the feedback dynamics with VALEN simulations will be presented. The DIII-D results complement and will be discussed alongside recent RFX-MOD demonstrations of RWM control using magnetic feedback in limited tokamak discharges with $q_{\text{edge}} < 2$ [1]. These results call attention to the utility of magnetic feedback in significantly extending the tokamak operational space and potentially opening a new route to economical fusion power production.


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