Feedback-assisted extension of the tokamak operating space to low safety factor

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Recent DIII-D and RFX-mod experiments have demonstrated stable tokamak operation at very low values of the edge safety factor $q(a)$ near and below 2. The onset of $n = 1$ resistive wall mode (RWM) kink instabilities leads to a disruptive stability limit, encountered at $q(a) = 2$ (limiter plasmas) and $q_{95} = 2$ (divertor plasmas). However, passively stable operation can be attained for $q(a)$ and q_{95} values as low as 2.2. RWM damping in the $q(a) = 2$ regime was measured using active MHD spectroscopy. Although consistent with theoretical predictions, the amplitude of the damped response does not increase significantly as the $q(a) = 2$ limit is approached, in contrast with damping measurements made approaching the pressure-driven RWM limit. Applying proportional gain magnetic feedback control of the $n = 1$ modes has resulted in stabilized operation with q_{95} values reaching as low as 1.9 in DIII-D and $q(a)$ reaching 1.55 in RFX-mod. In addition to being consistent with the $q(a) = 2$ external kink mode stability limit, the unstable modes have growth rates on the order of the characteristic wall eddy-current decay timescale in both devices, and a dominant $m = 2$ poloidal structure that is consistent with ideal MHD predictions. The experiments contribute to validating MHD stability theory and demonstrate that a key tokamak stability limit can be overcome with feedback.

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