Plasma Shape and Safety Factor Optimization for Steady-State Tokamak Development in DIII-D*

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Recent steady–state scenario development studies on DIII-D have focused on the optimization of plasma shape and safety factor profile. Steady-state tokamak operation requires all the plasma current be driven noninductively. The bulk of this must be provided by bootstrap current with the remainder provided by external sources such as electron cyclotron and neutral beam current drive. The bootstrap current fraction (f_{BS}) scales as $q\beta_N$, where q is the safety factor and β_N is the normalized pressure. The work discussed here uses a high triangularity double-null (DN) magnetic divertor shape with q_{min}>1.5. The shape is chosen to maximize the ideal-wall external kink stability and therefore the achievable β_N. Elevated q_{min} is chosen because ideal MHD stability modelling suggests high q_{min} scenarios can have a high wall-stabilized β_N-limit, and higher q_{min} is expected to generate higher f_{BS}. Systematic scans show that the baseline DN shape has a significant performance dependence on the shape parameter squareness (ζ), which may be adjusted without affecting divertor coupling. Within the range of ζ explored, the achievable β_N varied by ~30%, the energy confinement time (τ_E) at fixed $\beta_N \approx 2.4$ varied by ~30%, and τ_E at peak sustainable β_N varied by ~70%. These variations are attributable to greater pedestal pressure and external kink stability and lower core thermal transport at the lower end of the ζ range. A small imbalance of the DN divertor optimizes the control of the line-averaged density through pumping with reductions up to 30%. Using these shape optimizations, the q_{min}>1.5 scenario has achieved a noninductive fraction ($f_{NI} \equiv I_{NI}/I_P$) near unity for over 1 second with $3.5<\beta_N<3.9$, f_{BS} >65%, and good confinement. Similar optimization of the q-profile is underway. In some cases as q_{min} is increased, τ_E and maximum β_N are observed to decrease, so maximum f_{BS} may not correspond to the highest q_{min}.

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