Design Parameters for DIII-D Steady-State Scenario Discharges*

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In recent DIII-D experiments, we have systematically studied the physics that affects the choices of parameters for a discharge where the goal is 100% noninductively driven current ($f_{NI} = 1$) at high plasma pressure ($\beta_N \geq 4$). The self-consistent response of the temperature (T), density (n), and bootstrap current density (J_{BS}) profiles was measured in a scan of the q profile, varying q_{min} and q_{95} independently at $\beta_N \approx 3.5$. The focus was on weak shear discharges without large, local pressure gradients that would reduce the stable β_N. Both the bootstrap current fraction (f_{BS}) and f_{NI} increased with q_{95}, with $q_{95}>6$ required for $f_{BS}>0.5$. With sufficiently high β_N, the J_{BS} profiles are relatively uniform in the region between the axis and the H-mode pedestal so that the current density $J>>J_{BS}$ over the inner half of the discharge. This leads to a requirement for external current drive that is centrally peaked. Adjustment of the toroidal field strength (B_T) was found to be a tool to obtain a balance between the required current drive and heating powers when all external power sources provide both heating and current drive. At fixed β_N and q_{95}, the externally driven current fraction increases with B_T allowing f_{NI} to be adjusted to a target value which, ideally, is 1. Typically H_{98}=1.5, but as n decreases during the high β_N phase of the discharge as the wall particle source is depleted, a trend toward decreasing τ_E is observed. This places constraints on the ability to reduce n in order to maximize the total externally driven current. To obtain f_{NI}=1, f_{BS}>0.5 with q_{95} reduced to 5 for increased fusion gain, the focus now is on q_{min}>2 at increased β_N. High q_{min} minimizes the external current drive requirements near the axis by reducing J and, for a given pressure gradient, increasing J_{BS} in that region. An increase in β_N through pressure profile broadening is the route to higher f_{BS}. Off axis neutral beam injection is a key tool to broaden the fast ion pressure profile (and thus the total pressure), to avoid excess J_{NBCD} near the axis, and to drive current off axis where it is needed at reduced q_{95}. Off axis ECCD drives current and provides electron heating to increase both J_{BS} and J_{NBCD}.

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