High Internal Inductance for High $\beta_N$ Steady-State Tokamak Operation\textsuperscript{1}

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An attractive scenario for steady-state tokamak operation at relatively high values of the internal inductance, $l_i > 1$, has been demonstrated at DIII-D. The more peaked current density profile leads to reduced core energy transport and higher ideal stability limits that could eliminate the need for $n \geq 1$ active stabilization coils at $\beta_N \approx 4$, or enable $\beta_N \approx 5$ with wall stabilization. The scenario’s potential is shown by discharges at $l_i \approx 1.3$ with high bootstrap current fraction $f_{BS} \approx 0.8$, high plasma pressure $\beta_N \approx 5$ and excellent confinement $H_{98(y,2)} \approx 1.8$. This very high $\beta_N$ discharge with $q_{95} = 7.5$ has noninductive current fraction $f_{NI} > 1$ and too much bootstrap current in the H-mode pedestal, so $l_i$ decreases with time.

To achieve a stationary current profile, the key is to maximize $\beta_N$ and $f_{BS}$ while maintaining $l_i$ high enough for stability through choice of $q_{95}$ or by reduced pedestal current. DIII-D modeling shows that with $q_{95}$ reduced to lower $f_{BS}$ to $\approx 0.5$, a self-consistent equilibrium has $l_i \approx 1.07$ and $\beta_N \approx 4$ (below the $n=1$ no-wall limit) with $q_{95} \approx 6$. The remainder of the current can be externally-driven near the axis where the efficiency is high. Discharge tests with similar $l_i$ in the ITER shape at $q_{95}=4.8$ have reached $f_{NI}=0.7$, $f_{BS}=0.4$ at $\beta_N \approx 3.5$ with performance appropriate for the ITER $Q=5$ mission, $H_{98\beta_N/q_{95}}^2 \approx 0.3$. The $l_i$ was shown to increase further above 1, to enable higher self-consistent $f_{BS}$ and $\beta_N$, by reducing pedestal pressure and bootstrap current density through application of $n = 3$ resonant magnetic fields. With similar fields for ELM mitigation, and neutral beam and electron cyclotron current drive sources for near-axis current drive, the high $l_i$ scenario is a potential option for ITER. The increased core confinement can help mitigate the effect of reduced pedestal pressure.

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