Progress Toward Sustained High-Performance Advanced Tokamak Discharges in DIII-D*

J.R. Ferron,[1] D.P. Brennen,[2] T.A. Casper,[3] A.M. Garofalo,[4] C.M. Greenfield,[1] A.W. Hyatt,[1] R. Jayakumar,[3] L.C. Johnson,[5] J.E. Kinsey,[6] R.J. LaHaye,[1] L.L. Lao,[1] E.A. Lazarus,[7] J. Lohr,[1] T.C. Luce,[1] M. Murakami,[7] M. Okabayashi,[5] C.C. Petty,[1] P.A. Politzer,[1] R. Prater,[1] E.J. Strait,[1] A.D. Turnbull,[1] J.G. Watkins,[8] M.R. Wade,[7] and W.P. West[1]

[1]*General Atomics, P.O. Box 85608, San Diego, California 92186-5608 USA*
[2]*Oak Ridge Institute for Science Education, Oak Ridge, Tennessee 37831 USA*
[3]*Lawrence Livermore National Laboratory, P.O. Box 808, Livermore, California 94551 USA*
[4]*Columbia University, New York, New York 10027 USA*
[5]*Princeton Plasma Physics Laboratory, Princeton, New Jersey 08543*
[6]*Lehigh University, Bethlehem, Pennsylvania 18015 USA*
[7]*Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831 USA*
[8]*Sandia National Laboratories, P.O. Box 5800, Albuquerque, New Mexico 87185 USA*

Key elements of a sustained advanced tokamak discharge in DIII-D are large fraction of the total current from bootstrap current (f_{BS}) and parameters that optimize the capability to use electron cyclotron current drive (ECCD) at $\rho \approx 0.5$ to maintain the desired current profile. Increased f_{BS} results from increasing both the normalized beta (β_N) and the minimum value of the safety factor (q_{min}). Off-axis ECCD is, for the available gyrotron power, optimized at high β_N, high T_e and low n_e. In DIII-D, discharges have been produced with many of these characteristics, $\beta_N \approx 4$, $H_{89} \approx 3$ (ratio of τ_E to L–mode scaling), and $q_{min} > 1.5$ with $\beta_N H_{89} > 10$ sustained for about 0.6 s ($\approx 5\ \tau_E$). Here f_{BS} is about 65% and β_N reaches $6\ \ell_i$, close to the predicted limit for the ideal n = 1 kink mode with an ideal wall at the DIII-D vessel. The ideal no-wall β_N limit is about $4\ \ell_i$. Achievement of sustained β_N values well above the no-wall limit is aided by improved correction of intrinsic error fields, allowing toroidal plasma rotation above the level required to stabilize the n=1 resistive wall mode.

The achievable β_N in these discharges has been found empirically to depend on the edge safety factor, q_{95}. In the discharge shape designed to make use of divertor-region pumping, by increasing q_{95} from 4.0 to 4.8 (by increasing B_T at fixed I_p), reproducible β_N increased from 3.4 to 4. This observation contrasts with predictions from ideal MHD modeling from which a reduction in the β_N limit to the n=1 mode is predicted at higher q_{95}. The improved β_N values in the experiment appear to result primarily from improved ability to operate close to the ideal wall β_N limit.

The value of q_{min} in the high β_N phase of the discharge is presently set by resistive relaxation of the current profile. This high performance phase is normally terminated by the onset of a tearing mode as q_{min} decreases to about 1.5. Recently the ability to reach the high β_N phase with $q_{min} > 2$ was demonstrated by inducing H–mode early in the plasma current ramp to increase T_e.

The goal is to maintain a stable high performance equilibrium by sustaining the current profile using ECCD. Modeling based on parameters from a discharge with $q_{min} \approx 1.5$ has shown that this is possible using the available gyrotron power. The required elements for efficient off-axis ECCD have been separately demonstrated: density control at high β_N with $n_e \leq 5\times10^{19}\ m^{-3}$ using divertor-region pumping, stability at high β, and ECCD at the theoretically predicted efficiency. Challenges remaining are to integrate these elements and to increase T_e to increase the driven current.

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