Advanced Control Techniques and High Performance Discharges on DIII-D*

A.G. Kellman for the DIII-D Team

General Atomics, P.O. Box 85608, San Diego, California 92186-5608
e-mail: Kellman@fusion.gat.com

The goal of the DIII-D advanced tokamak program is to provide the scientific basis for the optimization of the tokamak approach to fusion energy. A critical element in achieving that goal is the development of new control techniques for regulation of current and pressure profiles and suppression of plasma instabilities that enable plasma performance to be improved over the conventional tokamak. The DIII-D program has made significant progress in developing and implementing these advanced control techniques and has successfully achieved enhanced operating modes that have a strong impact on the technology for future fusion devices.

We continue to expand our electron cyclotron heating (ECH) and current drive (ECCD) system and now have a 4 MW, 5 gyrotron system with fully steerable launchers. We have developed advanced real-time control algorithms to locate and align ECCD deposition with magnetic islands to suppress both the 3/2 and 2/1 neoclassical tearing modes. Real-time calculation of the internal magnetic flux surfaces has allowed the ECCD/island alignment and mode suppression to be maintained while the plasma energy is further increased. The addition of a 12-element internal non-axisymmetric control coil system, the I-coil, has expanded our ability to stabilize the resistive wall mode (RWM), an instability that limits plasma performance at high plasma pressure. In a unique application of the I-coil coupled with the previous six-element external coil, an edge ergodic field has been produced that significantly reduces the occurrence of the large edge localized modes (ELMs) and their resultant high pulsed heat loads. Recent upgrades to our digital plasma control system speed enable more extensive implementation of advanced control algorithms including real-time calculation of the safety factor profile, q(r), that is needed for current profile control.

Using these and other control techniques, we have produced a variety of high performance discharges that represent significant progress toward successful realization of advanced tokamaks. Improved stabilization of the RWM has permitted robust operation up to β_N ~3.8, well above the conventional tokamak no-wall beta limit. By combining ECCD, neutral beam injection and high bootstrap current, we have demonstrated 100% noninductive current drive in discharges above the no-wall beta limit (β_N ~ 3.5). Using more conventional control techniques, we have achieved a hybrid mode of operation applicable to ITER that would enable operation at β_N ~3 at q_{95}=4.4 and Q=10 for a duration of 4500 s.

The DIII-D program is planning an aggressive set of system upgrades in 2005–06 that will further enhance our capabilities to investigate advanced tokamaks: expansion of the EC system to 6 MW, 10 s will permit improved current profile control; a new lower divertor baffle will permit pumping and more efficient current drive in highly triangular double-null discharges; and reversal of a neutral beamline will permit investigation of the ELM-free H–mode regime and RWM stabilization in low rotation discharges.

*This work was supported by the US Department of Energy under Cooperative Agreement DE-FC02-04ER54698.