Tearing Mode Suppression as Part of a Comprehensive Real-Time Disruption Avoidance and Mitigation System

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The amount of free energy available in a full performance ITER discharge is about 1 GJ. If this energy is transferred rapidly to the material structure of the tokamak (a "disruption"), there is significant risk of damage to the structure through thermal and electromagnetic stresses. In contrast, the fusion power output and the bootstrap current needed for steady-state operation increase with the thermal energy. Therefore, maximizing the fusion output or potential for steady-state operation also increases the energy that could be released in a disruption. Disruptions are known to occur under certain conditions, such as when the control hardware or software fails or when mechanical failure introduces a solid object into the plasma. Disruptions can also come about when probing plasma physics limits such as extreme shaping, high plasma current, high density, or high pressure. Control or mechanical failures are characterized by frequencies of occurrence, but are unpredictable. On the other hand, the physics limits are either predicted by theory or characterized by empirical studies, but only to limited accuracy. A comprehensive disruption safety system would allow optimization of the tokamak performance, while dissipating the free energy safely in the event of any disruption, independent of its origin.

The emphasis in this paper will be on the demonstration of avoidance of disruptions in DIII-D that occur when a pressure limit is reached. In the context of the ITER baseline scenario, the manifestation of the pressure limit will likely be the onset of an m=2/n=1 tearing mode. In DIII-D, the onset of the mode is detected in real time by analog combinations of the fluctuating magnetic fields of the mode. Above preset limits on the mode amplitude and duration, the plasma control system (PCS) switches to new operational instructions. Two types of response have been used in DIII-D — a safe-shutdown response and a mode suppression response using ECCD. For mode suppression, localization of the ECCD on the instability is essential for effective suppression. Two real-time algorithms for optimizing the ECCD location have been demonstrated successfully. Real-time determination of the mode rational surface has also been demonstrated. This allows optimum aiming of the EC system prior to mode onset and opens the possibility of pre-emptive application of ECCD for operation at higher performance. In addition to the work on ECCD, the pellets and gas jets have been explored as a means to mitigate the effects of a disruption in the event it cannot be avoided.

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