Studies of Halo and Relativistic Electron Currents

White Paper on Integrated Simulations in topical area: Disruption prevention, avoidance, and mitigation

Allen H. Boozer
Department of Applied Physics and Applied Mathematics, Columbia University, New York, NY 10027
ahb17@columbia.edu

Of the topics on which ITER requires guidance from theory and computation, none is more important that those related to disruptions. A single disruption in ITER could produce unacceptable damage to the machine itself through 10MA of highly relativistic electrons striking the wall or a toroidally rotating halo current having an oscillatory resonance with the toroidal field coils. The strategy required for avoiding such catastrophes cannot be validated on ITER— the danger to the machine is too great. Basic physical processes can be studied in experiments, but ITER is in a fundamentally different parameter for the production of large currents of runaway electrons than any existing tokamak. The present strategy for mitigating halo currents appears to be what one would do produce strong currents of relativistic electrons. The issue is urgent because the disruption mitigation system is supposed to undergo design review in 2016 for construction by the United States.

Strong halo currents arise when the plasma becomes so unstable that the conducting structures surrounding the plasma cannot slow the growth of the instability below the rate determined by the Alfvén speed. A common occurrence is when a vertical plasma displacement causes a sufficiently rapid loss of the edge plasma that the edge safety factor drops to about two. When a halo current arises, it flows in the edge halo plasma along open magnetic field lines for part of its path and through the surrounding wall and conducting structures for the rest of its path. It slows the growth of the instability to the resistive time of the halo just as current in the wall can slow the growth of a resistive wall mode to the resistive time scale of the wall. The study of halo current effects is greatly simplified by physics constraints: (1) The current in the halo plasma must be essentially force free, so $j_{||}/B$ must be constant along the field lines. (2) For a kink-driven halo current, the minimum radial width of the current channel is set by the amplitude of the kink, for otherwise the energy required to establish the halo current is too great to be balanced by the energy released by the instability. (3) The rotation of the halo current requires an asymmetry in the toroidal direction of the plasma response, which may be due to the EXB flow associated with quasineutrality in the halo region causing an asymmetric sonic plasma flow to the walls parallel and anti-parallel to the magnetic field lines. The physics of halo currents is discussed in Section 6.3 of Nuclear Fusion **55,** 025001 (2015).

The conversion of the net plasma current into a current of highly relativistic electrons can arise in ITER when the current is changed on a time scale short compared to tens of seconds. The number of relativistic electrons exponentiates each time the poloidal flux changes by roughly 2V·s, and ITER has approximately 100V·s of poloidal flux, which places it in a fundamentally different physics regime from any existing tokamak. The critical parameters for the conversion of the plasma current into a relativistic electron current, the important times scales, and possible mitigation strategies are discussed in Physics of Plasmas **22**, 032504 (2015).

The importance of halo current and relativistic electron issues to the survivability of ITER as a device coupled with the clear steps that could be taken now to greatly enhance the assessment of the dangers and mitigation strategies make the low level of theoretical and computational work in the world fusion program difficult to comprehend.