MF-OV12

Recent Experimental and Modeling Advances in QH-mode Research

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The transient heat flux from large Type I Edge Localized Modes (ELMs) cannot be tolerated in a burning plasma device, due to the impact on the lifetime of plasma facing components. Therefore, stationary regimes that have the high energy confinement of H-mode, and are naturally free of large ELMs are of great interest and may be required. The regime of "quiescent H-mode" (QH-mode) operates without ELMs at ITER's values of collisionality and beta, and provides excellent energy confinement (better than standard H-mode) even at the very low plasma rotation expected in ITER, with adequate impurity transport provided by the edge harmonic oscillation (EHO). QH-mode was originally discovered on DIII-D and was subsequently observed on ASDEX-Upgrade, JT-60U, and JET. More recently, DIII-D experiments have achieved stationary QH-mode operation in an ITER similar shape for many energy confinement times at simultaneous ITER relevant values of beta, normalized confinement, and safety factor. The operating space has also been extended to densities exceeding 80% of the Greenwald limit, consistent with peeling-ballooning theory of QH-mode density thresholds. At these higher densities, the coherent EHO is often replaced by broadband MHD oscillations with similar frequencies, but different rotation characteristics. High density operation in the QH-mode regime has opened a path to a previously predicted region of parameter space, named "Super H-mode", that can have pedestal pressure more than a factor of two above the stability limit for similar H-mode discharges at the same density, and that could be beneficial in helping ITER achieve its Q=10 mission. In double-null shaped plasmas, the QH-mode regime has been found to bifurcate into a new state at low torque, characterized by increased pedestal height and width. In parallel, extensive non-linear MHD simulations of the pedestal show saturation and coupling of low-n kink-peeling modes, reproducing many EHO characteristics, including a larger particle transport relative to the thermal transport. Through this coordinated work of modeling and DIII-D experiments, significant progress has been made in advancing the QH-mode operating space and physics basis, increasing confidence that QH-mode will enable high confinement, ELM-stable operation on ITER.

This work is supported by the US Department of Energy under DE-FC02-04ER54698.