Characterization and Modification of Edge-Driven Instabilities in the DIII–D Tokamak*

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H–mode and VH–mode discharges are unstable to MHD instabilities driven by large values of the pressure gradient and current density near the discharge edge. These modes appear as the relatively large, global, instability that terminates the high confinement, ELM-free phase in both VH–mode and NCS-type discharges, and as the rapidly reoccurring, more edge localized mode commonly called an ELM. These modes cause energy and momentum loss over a broad enough region to destroy, or prevent formation of, the type of internal transport barrier that characterizes VH and NCS-type improved confinement discharges.

The large amplitude, low toroidal mode number ($n \leq 9$) instabilities that terminate the high confinement phase are observed in DIII–D discharges with moderate squareness where there is access to the infinite-n ballooning mode 2nd stability regime in as much as 20% of the discharge edge flux. The edge pressure gradient (P') is observed to exceed the value that would be allowed by the ballooning mode 1st stability regime by a factor of 2 or more. Similar values of P' are also observed during type I ELMs. The most unstable edge modes, driven by both pressure gradient and the self-consistent bootstrap current density, are predicted by n = 1–3 stability analysis to be kink-like with relatively low poloidal mode number and thus relatively broad radial extent. For broad pressure profiles n = 3 modes are predicted more unstable than n = 1 and the predicted radial width of the unstable mode increases with the width of the region of large pressure gradient at the edge.

Ballooning stability analysis predicts that at sufficiently high discharge squareness (rectangular-shaped discharges) or low squareness (triangle-shaped) there is no ballooning mode 2nd regime access in the edge region with the amount of bootstrap current produced at the low, 1st regime limited value of the pressure gradient. With no 2nd regime access, and the resulting lower edge pressure gradient and current density values, the edge localized low-n kink-like modes are less likely to be unstable. Rather, the most unstable edge modes would be expected to be closer to the ideal infinite-n ballooning mode, with high toroidal and poloidal mode numbers, reduced radial extent of the modes, and reduced effect on a core transport barrier.

In the experiment a clear correspondence between the instability character and the discharge squareness is observed. Beginning with a discharge with moderate squareness, as the discharge squareness is increased, the ELM frequency increases by up to a factor of 100 and the ELM amplitude decreases. Similar changes in ELM character are observed in low squareness discharges. At the lowest and highest squareness there is a significant change in ELM character, requiring only a small shape change to produce, that appears to be coupled to complete loss of 2nd stable regime access. The perturbation to T_e by an ELM is below the measurement threshold of the ECE diagnostic. Simultaneously, the edge pressure gradient decreases to the value predicted for the 1st regime limit. The ballooning stability code indicates that there is no edge 2nd stable access in these discharges. With these small perturbations resulting from the ELMs, a core transport barrier has been maintained. Theoretical studies show that a high order local perturbation of the plasma shape in the outboard bad curvature region can be another approach to removing edge 2nd regime access.

These results suggest that both high-n ballooning modes and low-n current and pressure gradient driven modes interact and play a key role in the observed edge instabilities and that the relative role of the instabilities can be modified through changes in the discharge shape. Further experiments are planned to explore modification of edge instabilities through pellet and impurity gas injection and localized electron heating with ECH, and local shape perturbation.

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