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Ideal MHD Kink-Peeling Modes and Their Relation to ELMs

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The H-mode regime of improved energy confinement in tokamaks has always been accompanied in steady-state by a relaxation oscillation that regulates the pressure gradient at the plasma edge. Because of reduced thermal conductivity at the edge, the pressure gradient grows until an Edge Localized Mode (ELM) instability occurs. Since their discovery in ASDEX, the cause of ELMs has remained something of a mystery. In 1985 we conjectured that these could be ideal MHD edge-peeling modes driven by the finite edge pressure gradient and the associated Pfirsch-Schluter current. Only with recent improvements in the accuracy of equilibrium reconstruction has it been possible to make a comparison between MHD stability theory of intermediate n ideal kink mode stability and the observed onset of ELMS.

Equilibrium reconstruction of plasmas in DIII-D now uses the Motional Stark Effect (MSE) diagnostic with correction for the radial electric field to measure field line pitch, and improved fitting of the edge pressure gradient and current density. Large local changes in the edge pressure gradient near the edge are now accurately calculated in the EFIT equilibrium reconstruction code, with the edge current density constrained to match the bootstrap current. Without this constraint, the stability calculations predict gross violations of ballooning stability. The stability calculations also require accurate reproduction of the plasma shape, including up-down asymmetry and the presence of a divertor and of a nearby conducting wall.

Using these new procedures, calculations for an ELMing discharge immediately before an ELM show instability for $n \geq 3$ modes with the strong edge localization one expects for an ELM. The n=2 mode is marginally stable and the n=1 mode is stable. During the prior ELM-free period no instability is found for any $n < 6$. The calculated unstable n=3 mode is shown in Fig. 1. The mode is very strongly localized near the edge as expected for a peeling mode. This discharge is in the transition regime near the edge and so is not limited by ballooning mode instability.

While the peeling mode conjecture is substantially correct, as usual the real situation is more complex. The computed unstable modes appear to be driven by a combination of the pressure gradient and associated bootstrap current near the edge, in addition to the Pfirsch-Schluter current. Stability to ballooning modes can also play an important role: the discharges are found to have open access to the transition regime near the edge which allows the buildup of the edge pressure gradient to the point where the intermediate n modes can be destabilized. In turn, the edge bootstrap current facilitates access to the transition regime. The analysis shows a strong similarity to calculations for the so-called X-event, which terminates the high performance VH-mode and H-mode NCS plasmas. The major difference is that for the present case, the lowest unstable mode has higher n and is more strongly localized at the edge, consistent with the more localized steep edge pressure gradient in H Mode compared to the VH-mode. This is also consistent with the observation that, while the X-event irreversibly terminates the high performance, the ELM in standard H-mode causes only a temporary reduction in confinement. Our increased understanding of ELMs should lead to better control of both ELM characteristics and of high performance termination by, for example, controlling access to the transition regime through cross section shaping or edge collisionality.

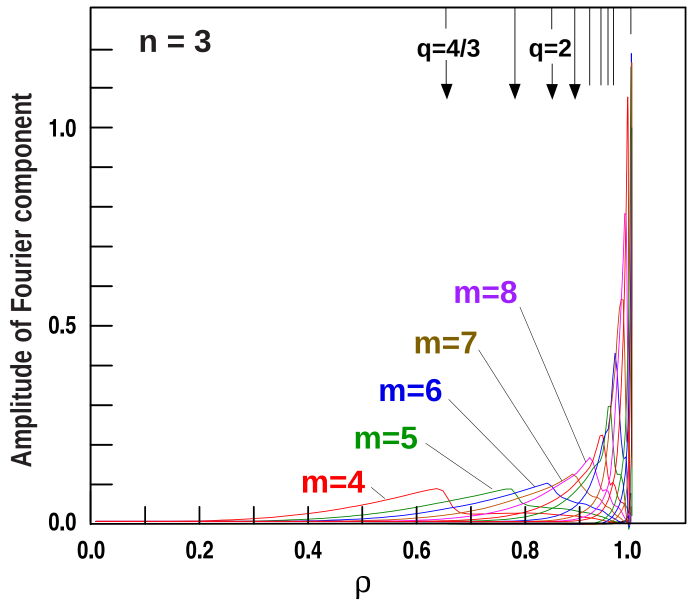

Fig. 1. *Radial structure of poloidal Fourier components of the unstable ideal n=3 mode, just before an ELM. Plotted is $\xi \cdot \nabla \psi$, where ξ is the plasma displacement and ψ is the equilibrium poloidal flux.*

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