Growth of Ideal MHD Modes Driven Slowly Through Their Instability Threshold: Application to Disruption Precursors

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The growth of an ideal magnetohydrodynamic (MHD) instability in a high temperature plasma is calculated in the case where the plasma β is driven slowly through its instability threshold. The MHD perturbation grows faster than exponentially, approximately as $\exp[(t/\tau)^{3/2}]$. Its characteristic growth time $\tau \sim (3/2)^{2/3}\hat{\gamma}_{\mathrm{MHD}}^{-2/3}\gamma_{\mathrm{h}}^{-1/3}$ is a hybrid of the ideal MHD incremental growth rate $\hat{\gamma}_{\mathrm{MHD}}$ and the heating rate γ_{h}. This simple model agrees well with the observed growth of disruption precursors in high β DIII–D discharges having strongly peaked pressure profiles, where the observed growth times of $\geq 10^{-4}$ s are significantly slower than the typical ideal MHD time scale of $\leq 10^{-5}$ s.

Disruptions are of great concern [1] in tokamak plasmas and not well understood [2]. Here, by disruptions we mean rapid decreases in plasma confinement, plasma pressure collapses, etc. While the instability boundaries for global ideal magnetohydrodynamic (MHD) modes apparently demarcate [3] the limits of the achievable volume-average pressure $\langle P \rangle$ or $\beta \equiv \langle P \rangle / (B^2/2\mu_0)$ in tokamak plasmas, the origin of the precursors to β limiting disruptions is not clear, although models have been advanced for some precursors [4–6].

The growing oscillations observed [6] to precede major disruptions in DIII–D L–mode negative central magnetic shear (NCS) plasmas occur in well diagnosed plasmas and are of particular interest. The growth times of these precursors ($\sim 100-500\ \mu$s) are much slower than the few μs growth times typical of ideal MHD instabilities. Thus, slower growing resistive modes [7] were proposed [6] as contributing to at least the early development of the disruption precursors. These modes were essentially resistive double tearing modes coupled externally to the ideal external kink and modified by the presence of sheared plasma rotation and finite pressure effects, especially at the inner rational surface where the resistive instability criterion ($D_{\mathrm{R}} > 0$) was satisfied.

Although these modes had many of the features expected for the observed precursors, questions remain concerning the growth rates of these modes; specifically, the typical growth rate is slow ($\gamma_{\mathrm{R}}^{-1} > 1$ ms) and very sensitive to details of the rotation and pressure profiles.