MHD and Semikinetic Modeling of Error Field Amplification and Resistive Wall Mode Stabilization by Flow and Active Feedback

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We study the physics of resistive wall modes (RWM) numerically using full, single-fluid MHD in toroidal geometry, extended with a kinetic model to account for ion Landau damping.

In advanced tokamaks, the plasma pressure is often limited by ideal external kink modes. These ideal kinks can be stabilized by a close-fitting, ideally conducting wall. However, the finite conductivity of the wall only suppresses the growth rates of the ideal modes to the time scale of the wall eddy current decay time. The slowly growing resistive wall modes have to be stabilized completely, in order to achieve a steady state operation.

Using the toroidal linear MHD stability code MARS, we study two mechanisms for RWM stabilization, namely toroidal plasma rotation and active magnetic feedback. The new development, which is the key step for the feedback studies, is to construct a model for the plasma response. The corresponding transfer functions can then be used for controller design and optimization. We construct the plasma response models from the computed results by MARS, using low order rational function approximations (Padé approximations) [1]. The response models are represented in terms of frequency-dependent transfer functions [2,3] from the feedback current or voltage to the (magnetic) sensor signals. Such low order representations have been shown to be good approximations of true transfer functions obtained as expansions in a complete set of stable and unstable RWM in the absence of feedback coils [4,5].

We have established that the RWM in tokamaks can be controlled with good performance, using a set of active coils with one coil in the poloidal direction. The sensors should detect the poloidal field and be located at the outboard mid-plane inside the first wall. Such a system works well with simple control logic [2-5]. Moreover, robust control of the RWM can be achieved with respect to the plasma pressure, total current and toroidal rotation [4]. We have carried out calculations for an advanced scenario in ITER with non-conformal double wall [6].

A key issue in modeling the influence of plasma rotation on RWM stability, as well as on the error field amplification, is the model for energy dissipation. In a new development of the MARS code, we add a semikinetic model for the dissipation into the MHD equations. This model is derived from the drift-kinetic [7] calculations in a large aspect ratio approximation including particle trapping [8]. The dissipation mechanism is the ion-Landau damping from the motion along the field lines, driven by the toroidal coupling from equilibrium curvature and field gradients. Recent numerical calculations indicate that this new model is in good agreement with the DIII-D experiments, concerning both the threshold rotation for stability of the RWM and the error field amplification.

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