Three-dimensional nonlinear modeling of tokamak plasmas with applied Magnetic Perturbations

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ELM control during H-mode operation is crucial for future tokamak fusion devices, such as ITER, as uncontrolled Edge Localized Modes (ELMs) can cause significant damage to plasma-facing components. One of the most promising approaches for controlling type-I ELM is the application of Resonant Magnetic Perturbations (RMPs). In parallel, the concept of magnetic perturbations generated by toroidally non-axisymmetric currents in the Scrape-Off Layer (SOL), induced by biased divertor plates, has been proposed both theoretically and experimentally. To fully understand the mechanisms of ELM control via applied magnetic perturbations, Three-dimensional (3D) nonlinear modeling of tokamak plasmas is essential, particularly the calculation of 3D equilibrium.

In this study, an integrated 3D model of ELM dynamics was conducted using plasma parameters from shot #31128 on the ASDEX Upgrade tokamak. The 3D equilibrium was calculated using HINT [1], with plasma response given by MARS-F [2]. The coupling dynamics of the ballooning mode with $n=2$ RMPs were simulated using MIPS [3]. The results show good agreement with experimental observations, validating the numerical tools for three-dimensional nonlinear modeling of tokamak plasmas.

Recently, a biased target system was designed for the HL-3 tokamak to investigate the effects of divertor-induced SOL currents on plasma behavior. In this study, the potential of the divertor biasing system for ELM control in HL-3 was simulated using a combined approach with the HINT and MIPS codes. The impact of SOL current configuration on MHD instabilities was analyzed for a designed 1.6 MA H-mode discharge. The field line tracing method was used to calculate the SOL current filaments induced by the divertor biasing system, and the magnetic field perturbation was calculated using Biot-Savart's law. Fig. 1 (a) and (b) show the changes in pressure distribution and magnetic topology in the 3D equilibrium when 0.2 kA and 0.4 kA SOL currents are superimposed on the $n=2$ configuration, respectively. The pressure change shows a positive correlation with the SOL current amplitude, but not in a strictly proportional manner, as seen when comparing Fig. 1 (a) and (b). This correlation leads to a modified pressure gradient in the pedestal, which directly impacts edge MHD instabilities. Fig. 1 (c) presents the time evolution of the kinetic energy of MHD instabilities from MIPS simulations, comparing cases with and without the $n=2$ SOL helical current. As the SOL current increases, the growth rate of the MHD instabilities decreases. These results clearly demonstrate the feasibility of ELM control via the divertor biasing system in HL-3, offering a promising approach for managing edge plasma dynamics and heat flux during H-mode operation.

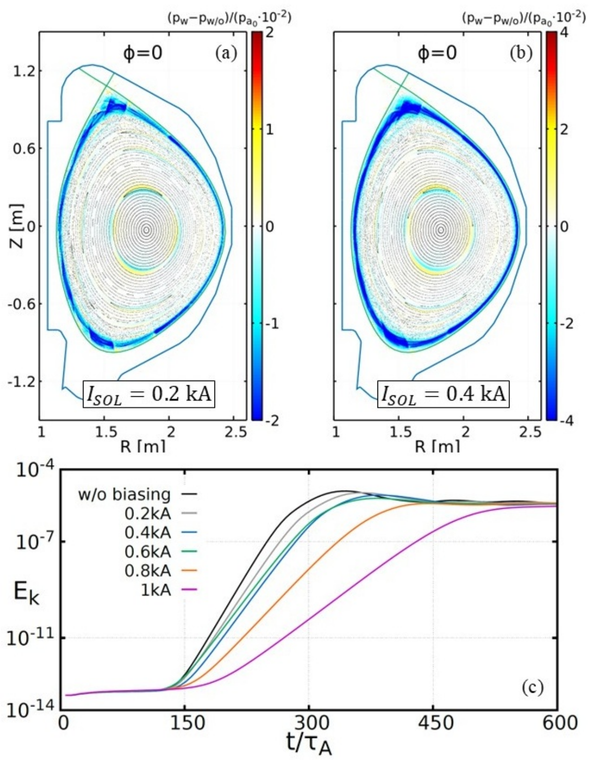

Figure 1 (a) and (b) Pressure change and Poincaré plot in 3D equilibrium with SOL currents of 0.2 kA and 0.4 kA, respectively (the colorbar follows a twofold relationship). (c) Time evolution of instability kinetic energy.

References

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