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Nonlinear modeling of ELM mitigation with RMP on HL-2A

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Resonant magnetic perturbation (RMP) has been proven as an effective approach for edge localized mode (ELM) control. We report recent progress of ELM control with RMP on the HL-2A and HL-3 tokamaks, including both experiments and simulations.

Experiments- The type-I ELMs were mitigated by application of the n=1 (n is the toroidal mode number) RMP at 4.9 kAt coil current on HL-2A (Figure 1) [1]. Detailed analysis of the experimental data shows that an edge-coherent oscillation (ECO) with a bursting feature exists in the steep-gradient pedestal region of H-mode plasmas in the HL-2A tokamak, where the oscillation drives a significant outflow of particles as directly measured by probes, thus providing a channel for nearly continuous extra particle transport across the pedestal during ELM mitigation. Bi-spectral analyses from Beam Emission Spectroscopy and Doppler reflectometry suggest that this burst is populated through three-wave coupling of turbulence, which is in turn enhanced by the application of RMP. This whole physics mechanism provides a pathway for a more continuous particle transport in tokamak H-mode plasmas. Active mitigation and suppression of ELM with RMP were recently observed for the first time on the newly built tokamak HL-3, where the n=1 RMP with odd parity was applied.

Modeling- Nonlinear modeling of ELM mitigation with RMP is performed for the HL-2A tokamak, utilizing the three-dimensional (3D) magnetohydrodynamic (MHD) code JOREK [2]. Detailed examination of the simulation results shows persistent resonant field screening even during the ELM mitigation phase. Finite plasma resistivity however does enable partial penetration of the resonant field thus modifying the edge magnetic topology and characteristics of the edge transport. Plasma radial profiles undergo pronounced changes around the pedestal region, when the magnetic energy of the most unstable toroidal mode reaches the maximum value. Nonlinear simulations also show strong mode coupling among toroidal Fourier harmonics, allowing redistribution of the magnetic energy such that the most unstable toroidal mode saturates at a lower level. This magnetic energy cascade offers explanation of the RMP-induced ELM mitigation achieved in HL-2A. Systematic scans of the applied RMP coil current with the JOREK simulations find a threshold value of around 4.5 kAt required for achieving the ELM mitigation on HL-2A (Figure 2). The linear [3] and non-linear modeling [4] results of ELM control with RMP on HL-3 will be introduced at the meeting.

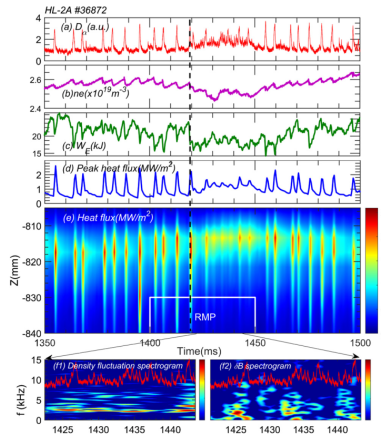

Figure 1 Time evolution of (a) the divertor D_ α -signal, (b) the line-averaged electron density, (c) the plasma stored energy, (d) the peak heat flux measured by infrared thermography, (e) the heat flux profile during the ELM crash and mitigation phases, and (f) the power spectrum of electron density fluctuation during mitigation from the Beam Emission Spectroscopy (BES) measurement at ρ =0.9 (f1) together with magnetic fluctuation (f2).

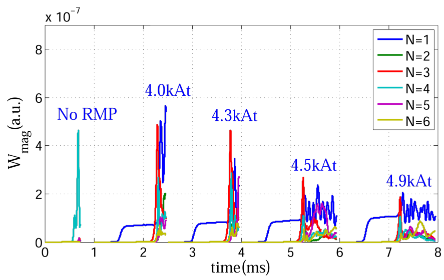

Figure 2 Time evolutions of the simulated magnetic energies for the n=1-6 toroidal modes, assuming different levels of the RMP coil current. The case with no RMP corresponds to zero coil current. For better visualization, the start time is horizontally shifted for different cases.

References

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