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Toward an Emerging Understanding of ELM Dynamics and Energy Loss Scaling & Advanced Divertor Analysis of HL-2M

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A

We report on the latest BOUT++ studies in the past 2 years which: (1) illustrate the consistent collisionality scaling of ELM energy losses with ITPA multi-tokamak database; (2) a new nonlinear criterion for predicting the onset of ELMs. We show that for an ELM crash to occur, the coherence time of the relative phase between potential and pressure perturbations must be long enough to allow growth to large amplitude. This phase coherence time is determined by both linear and nonlinear dynamics. (3) a new mechanism for the electron ELM conductive energy loss dominant over the convective energy loss due to Landau wave-particle resonances with electromagnetic turbulence caused by the ELM perturbation. A series of BOUT++ simulations are conducted to investigate the scaling characteristics of the ELM energy losses vs collisionality via a density scan, while keeping the plasma cross-sectional shape, total stored energy, total plasma current, pressure profiles fixed. The neoclassical collisionality at peak gradient position increases by a factor of 3262 from 0.0019 to 6.197. As the edge density decreases, the unstable mode spectrum shifts to lower n, both initial bursts and the turbulent spreading increase in both radial and poloidal extent and in intensity. This leads to larger relative pedestal energy loss during ELM crash evolution for several thousand Alfven times. The Landau-Fluid simulations further show that the electron pedestal temperature height plays a major role in determining the electron conductive energy loss in nonlinear phase, even though the characteristics of linear P-B modes are the same for a density scan with fixed pressure profile, pedestal density width, and density and temperature at the peak gradient position. The increasing electron pedestal temperature height leads to (1) an increasing radial turbulence correlation length and large turbulence spreading; (2) larger electron conductive energy loss. We demonstrate that ELMs can be mitigated by reducing the phase coherence time without changing linear instability. As an example, we show that the large RF-induced poloidal flow shear near the separatrix tears apart P-B filaments, increases mode-mode energy coupling, decreases the mode cross-phase coherence time, and generates a broad turbulence fluctuations, avoiding large ELMs.

B

Standard divertor and exact snowflake, snowflake-plus and snowflake-minus divertor configurations of HL-2M are designed. The potential properties of these divertors are analyzed and presented: low poloidal field area around X-point, connection length from outside mid-plane to the primary X-point, target plate design and magnetic field shear. The results show that the snowflake configurations not only can reduce the heat load at divertor target plates, but also may improve the magneto-hydrodynamic stability by stronger magnetic shear at the edge. According to the vacuum vessel geometry of HL-2M, a divertor target geometry which is suitable for HL-2M divertor configurations (standard divertor, snowflake divertor and tripod divertor configurations) has been designed to reduce the peak heat load on the target to an acceptable level. The heat load on divertor targets with different core plasma parameters and divertor configurations are investigated by SOLPS5.0. The linear characteristics of peeling–ballooning (P–B) modes, transient heat flux bursts up due to ELMs and the distribution and evolution of the heat load on targets of HL-2M tokamak for the different divertor configuration will be presented using BOUT++.

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