Peeling-limited and high-pedestal ELM-free H-mode periods in MAST Upgrade spherical tokamak

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In H-modes, the core confinement of a tokamak plasma can be substantially improved by the establishment of a pedestal with steep radial pressure gradient near the edge region. It is therefore desirable to operate a tokamak with as high a pedestal as possible. However, too steep a pedestal pressure gradient (α) results in large and detrimental Type-I edge localized modes (ELMs), which can eject a substantial fraction of the stored thermal energy from the pedestal region. It is therefore imperative that we find advanced H-mode scenarios that can avoid large ELMs while still maintaining the high core confinement, which will be compatible with the objectives of future fusion pilot plants.

One such alternative high confinement scenario is called the quiescent H (QH)-mode, in which the Type-I ELMs are suppressed by optimizing the peeling-ballooning stability of the pedestal region, and the radial transport is regulated by edge harmonic oscillation. A prerequisite to a QH mode is to keep the pedestal closer to the peeling limit, by increasing the peak pedestal plasma current density (J) for given α. This is achieved by maintaining a low pedestal collisionality, with high pedestal top temperature while minimizing pedestal density accumulation. Since it is anticipated that compact fusion pilot power plants, such as STEP, will utilize ELM-free H-mode scenarios such as QH-modes, it is vital to demonstrate the feasibility of QH modes and other alternative high confinement scenarios on existing compact spherical tokamaks.

This paper reports on recent experimental results from MAST Upgrade (MAST-U) spherical tokamak on pedestal stability optimization. While the typical H-mode scenario of MAST-U is peeling-ballooning-limited with Type-I ELMs, a number of H-mode discharges with notably higher pedestal top temperatures have been observed with characteristically long ELM-free periods. According to the peeling-ballooning stability analysis using ELITE code of typical ELMy cases, there is weakened coupling between the peeling and ideal ballooning branches of the stability boundary, which is in part due to the strongly shaped plasma with high elongation and squareness [1]. On the other hand, during the long ELM-free periods with high pedestal top temperature, there is significantly more decoupling between the peeling and ballooning branches of the stability boundary, and the pedestals are found to the closer to the peeling limit with lower collisionality compared to the typical ELMy H-mode cases [2]. Our analysis and planned experiments in the 2024/5 campaign will enable us to gain deeper understanding of the underlying physics, with application to the development of QH mode and other ELM-free H-mode scenarios in STEP and other spherical tokamaks.

[1] Imada et al, Nucl. Fusion 64, 086002 (2024)

[2] Imada et al, Plasma Phys. Control. Fusion (submitted)