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Stationary Small/No ELM H-mode Regimes for High-performance Steady-state Operations in EAST

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A stationary fully non-inductive H-mode regime with high heating power (6-8 MW), high plasma stored energy ($W_{MHD} > 200$ kJ), low pedestal collisionality ($\nu^*_e < 1$), high ELM frequency (>~ 1 kHz) and tiny ELM size (divertor target peak heat flux ~ 2 MW/m^2) have been achieved in the last experimental campaign in EAST. This regime was obtained at high edge safety factor ($q_{95} > 6$), high poloidal beta ($\beta_p > 1.6$), high triangularity ($\delta > 0.55$), and optimized high internal inductance ($l_i \sim 1.1$) , similar to the plasma parameter space of the Grassy ELM H-mode regime obtained previously in JT-60U [1]. Good density control can be achieved in this regime at a line-averaged density up to 60% of the Greenwald density (for even higher density, not test yet). Impurity concentration and core radiation are maintained at low level, suggesting that significant particle exhaust is driven by the high-frequency small ELMs.

This regime is a good candidate for achieving high-performance steady-state operations in EAST, ITER and beyond. The high β_p gives a high bootstrap current fraction and a high Shafranov shift. The high Shafranov shift is good for improving global energy confinement and core MHD stability [2]. Good global energy confinement with $H_{98,y2}$ up to 1.4 has been achieved in this regime. In addition, it is a suitable regime to achieve fully non-inductive operation (zero loop voltage), since it has relatively low plasma current and high bootstrap current fraction. The required power for external current drive is relatively low. In EAST the rest non-inductive current is provided by LHCD. In future fusion reactors, it can be provided by ECCD. And more important, operations with high q_{95} significantly reduce the disruption risk as well as the potential damages induced by major disruptions. This regime shows good reproducibility and robustness. Very stable operations with very few disruptions have been achieved with almost all heating power currently available on EAST.

Torque scan, density scan and plasma current scan have been performed. The torque scan was achieved by changing the co- and counter-NBI power. The results indicate that this regime is not sensitive to the change of toroidal torque, line-averaged density or plasma current in the parameter range that we have explored. It has a rather big parameter window. Although the ELM frequency and amplitude change with the parameters, these ELMs are still small and high-frequency ELMs. This regime has been achieved at low torque injection and low toroidal rotation, that is very promising, as future fusion reactors are anticipated to operate at low torque and low rotation due to the high plasma inertia and insufficient external torque injection.

Three stationary ELM-free H-mode regimes have been obtained in EAST. The first is an enhanced-recycling H-mode regime [3], appearing at relatively high pedestal collisionality ($\nu^*_e > 1$) with RF-dominated heating (mainly LHCD), characterized by an enhanced divertor Dα emission and a high-*n* electrostatic Edge Coherent Mode (ECM) driving significant particle and heat transport in the pedestal steep-gradient region [4]. The ECM and the regime disappear at high heating power and low pedestal collisionality ($\nu^*_e < 1$).

The second is a low-recycling H-mode regime, achieved with RF-dominated heating (mainly LHCD) and extensive lithium wall coating (30 g for each time, usually twice) or during lithium power injection. Additional power (> 0.5 MW) from co-NBI will usually bring ELMs back. Counter-NBI can facilitate the access to this regime. Access to this ELM-free regime exhibits a clear density threshold and the density threshold increases with plasma current i.e., $n_{el} \geq 3\times10^{19}$ m^{-3} at I_p = 450 kA and $n_{el} > 3.5\times10^{19}$ m^{-3}, at I_p = 500 kA, where n_{el} is the line-averaged density. The ECM usually still appears in this regime, but its frequency band becomes much broader, compared with that in the enhanced-recycling H-mode regime. The ECM tends to become much weaker during the lithium power injection but another mode in the pedestal region, a low-*n* (mostly $n = 1$) Magnetic Coherent Mode (MCM) [5], becomes stronger or more coherent. The MCM shows very weak density fluctuations but strong magnetic fluctuations as measured by fast Mirnov coils mounted on the wall.

The third ELM-free regime was obtained at high heating power and low pedestal collisionality ($\nu^*_e < 1$), with strong MCM but without ECM [5]. Dedicated experiments have been conducted in the last campaign to study the nature of MCM. Density ramp-up experiments exhibits a good linear scaling of the MCM frequency with the local Alfvén frequency and the frequency is near the local TAE frequency, suggesting the possibility of TAE modes. In addition, the MCM frequency was observed decreasing during I_p ramping down, i.e., q_{95} ramping up. This phenomenon can be interpreted as a continuous radially-inward shift of TAE gap up the pedestal density gradient. The role of MCM in ELM suppression is still under investigation.

References

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