Introduction

Definition of KSTAR Hybrid scenario
- Stationary discharges with $\beta_{\text{N}} \geq 2.4$ and $H_{\text{N}} \geq 2.0$ at $q_{95} < 6.5$ without or very mild sawtooth (ST) activities
- A representative long pulse hybrid scenario for the 2020 KSTAR campaign which sustained $\beta_{\text{N}} \leq 2.5$, $H_{\text{N}} \leq 2.3$ during the main heating phase

Experimental approach to establish hybrid scenario
- Being widely used to obtain hybrid scenario in various tokamak devices [1-4]
- Delaying the current diffusion so as to avoid ST activity
- Applying the full heating in the current flattop phase to obtain stable performance enhancement

Current overshoot approach
- Based on ITG theory [5], core confinement enhanced by favorable magnetic shear configuration – Vanished after current diffusion
- ELM frequency increases – line average density decreases – fast particle content increases – MHD mode transition (ST $\rightarrow$ FB)

Double null configuration approach
- Peeling mode stabilized by ‘active’ X-point [6] – more frequent ELMs by the edge PBM stability theory [7]
- Core temperature increase via core stiffness due to reduced density
- MHD mode transition (ST $\rightarrow$ FB) with reduced electron density and increased fast ion confinement

Early heating approach
- Stationary discharges with $\beta_{\text{N}} > 2.4$ and $H_{\text{N}} > 2.0$ at $q_{95} < 6.5$ without or very mild sawtooth activities in KSTAR
- Long pulse operation has been established up to ~30 s but showing some performance degradation
- Hybrid scenarios have been established by early heating, late heating, plasma current overshoot, and DN configuration approach
- The reasons for confinement enhancement are studied for a representative discharge of KSTAR hybrid scenarios in this transition period. A comprehensive confinement enhancement mechanism has been proposed by considering the core-edge interplay.


- Increase of $H_{\text{N}}$ without $H_{\text{N}}$ increase (4.3-5.0 s)
- Thermal confinement enhancement (5.0-5.3 s)

Performance analysis

- Linear gyro-kinetic analysis
  - The stability boundary is expanded and the diamagnetic effect boosts the pedestal growth.
  - The pedestal is improved due to increase of $\beta_p$ and subsequent Shafranov shift.
  - The EPED model [10] could reproduce the height of the pedestal if experimental II is used.

Kinetic profile analysis

- The EM effect is important where the finite $\beta$ stabilisation effect plays a role together with the fast particle stabilisation effect around the core region $\rho_{\text{c}} = 0.35$.
- $w_{\text{fa}}$ can reduce the linear growth rate of ITG in the off-axis region, $p_{\text{fa}} = 0.5$ and 0.7.
- The alpha stabilisation effect is also found at $\rho_{\text{c}} = 1.5$.
- ETG is estimated to appear at $\rho_{\text{c}} = 0.5$ and 0.7 from linear $g$KPS [9].

Hypothesis of confinement enhancement in hybrid scenarios

Conclusion

- The hybrid scenario is defined as a stationary discharge of with $\beta_{\text{N}} \geq 2.4$ and $H_{\text{N}} \geq 2.0$ at $q_{95} < 6.5$ without or with very mild sawtooth activities in KSTAR
- Hybrid scenarios have been established by early heating, late heating, plasma current overshoot, and DN configuration approach
- The reasons for confinement enhancement are studied for a representative discharge of KSTAR hybrid scenarios in this transition period. A comprehensive confinement enhancement mechanism has been proposed by considering the core-edge interplay.

References