Active Control of Toroidal Alfvén Eigenmodes Using the Electron Cyclotron Waves in KSTAR High-Performance Discharges

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1. Introduction

1.1. Previous study: AE suppression by co-ECCD scan in high β, long-pulse discharges enhances the plasma performance

- Optimization of W-factors (AE) in high-performance discharges lead to
  1. Redistribution of core fast-ion pressure
  2. Improvement of fusion yield
- Need of AEs mitigation to avoid performance degradation in the KSTAR advanced scenarios.

2. Experimental Observations:

- Experimental observations on the TAE mitigations have shown the attention to significant enhancement of performance in the advanced operation scenarios (high β).
- Off-axis co-ECCD applications in the high qₜ₀ for qₜ₀ scenarios show TAE mitigation for several tens of qₜ₀, resulting in better confinement enhancement.
- Primary mechanism of AE mitigation is based on increased continuum damping.
- ECCD scan is one of promising techniques to control the TAEs.

1.2. Previous study: AE suppression by co-ECCD scan in high β, long-pulse discharges enhances the plasma performance

- ECH-off period: ∆(1.8 T, 0.5 MA), qₜ₀ = 1.5 @ flat-top, t = 0.75 – 0.85
- Heating: NB1-A & B (~ 50 keV, 2.9 MW), co-ECCD (~ 800 GHz, 0.7 MW, qₜ₀ \approx 0.75)(25846) tor: \(Z_{EC} = +30 \) cm (during 5.0 – 5.5 s)

- As, approaches, \(λ_{AE} \)
- Alfvén stability is disrupted and the overall performance increases.

- Stabilization in the enhanced β scenario.

2. Experimental Setup (Investigations on Co- & Counter-ECCD applicability)

- Experimental condition:
  \([β, \lambda] \approx (1.8 T, 0.5 MA), qₜ₀ = 1.5@flat-top, t = 0.75 \approx 0.85\)

- Heating: NB1-A & B (~ 50 keV, 2.9 MW), co-ECCD (~ 800 GHz, 0.7 MW, qₜ₀ \approx 0.75)(25846) tor: \(Z_{EC} = +30 \) cm (during 5.0 – 5.5 s)

- Two EC-wave launchers: 1 central ECH (fixed) & 1 co- and counter-ECCD (scanning)

3.1. Experimental Results

- Both co- & counter-ECCD cases can mitigate or suppress the TAEs in elevated qₜ₀ scenarios.
- Primary control mechanism: Increase in continuum damping by blowing core q-profile shape.
- Overall plasma β increases. → Benefit to TAE stabilization (same in high β scenario).
- Co-ECCD is superior than counter-ECCD to control TAEs for over tens of qₜ₀.
- Counter-ECCD has the possibility of TAE control under the elevated qₜ₀ scenario.

- Measured amplitudes of n = 1 EFM in co-ECCD-assisted mitigation stage presents the enhancement of the plasma performance (including core fast-ion pressure).

3.2. Profiles (safety factor, fast-ion / total pressure, shear, ...)

- Co-ECCD (shot #25846) suppresses TAEs in the mitigated beam-power (PEC = 4.3 MW). However, the control was lost due to tearing mode excitation.
- Fast-ion pressure increases as the AEs are mitigated.
- TRANSP calculated \(D_{fast}\) for the co-ECCD-assisted TAE mitigation case is close to the classical transport.

DISCUSSIONS

- High qₜ₀ (1.5) and \(q_{AE} \) drop (~0.5) by mild off-axis ECCD provided good testbed for driving & controlling the AEs.
- Co-ECCD, directional ECCD (0.75MW) mitigates AEs successfully in the high β, qₜ₀ scenarios of KSTAR: Performance enhancement, but the on-axis co-ECCD is not so effective.
- Excessive core total pressure gradient is a candidate cause.
- Need to investigate the TAE control without large-amplitude tearing modes.