Kinetic Equilibrium Reconstruction and Stability Analysis of KSTAR Plasmas Supporting Disruption Event Characterization and Forecasting

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Disruption prediction and avoidance research first requires accurate equilibrium and stability analyses

- Motivation: Disruption prediction and avoidance is
  - Required to sustain long pulse, high performance plasmas
  - Critical for ITER and next-step tokamakas

- Outline
  - Kinetic equilibrium reconstruction approach, results, implications
  - Kinetic equilibrium provides greater profile details than magnetics-only cases
  - MSE data indicates regions of weak / strong shear
  - Validation with CCD images, IRTV, and MHD activities
  - Reversal shear in center correlated with increased βp and MHD activity
  - Ideal and resistive stability analysis
  - Stability calculation shows sensitivities to pressure profile and q profile
  - Summary / next steps

Kinetic equilibrium reconstruction

Kinetic data supplements magnetic input for KSTAR kinetic equilibrium reconstructions

- Motional Stark Effect (MSE)
  - MSE (up to 25 channels) measuring plasma/magnetic field pitch angle
- Thomson scattering (TS)
  - TS 27 channels
  - Electron density & temperature (ne, Te)
- Change exchange spectroscopy (CES)
  - CES 32 channels
  - Ion Temperature (T_i)

“Partial kinetic” approach for total pressure allows greater flexibility in profile shape

- Electron Pressure P_e = 27 Thomson scattering (T_e, n_e) systematic error
- Ion Pressure P_i = 32 CES (T_i, n_i estimated from n_e and estimated Zeff)
- Fast particle pressure P_{pup} “based” on P_e with 100% error bar
- Total pressure P_t = P_e + P_i “with” large total error

Kinetic equilibrium with MSE produces greater detail in P and q profiles than Magnetics-only

Ideal and resistive stability analysis

Robust 8W evaluation with the reconstructed plasma based on kinetic equilibrium

- Present work examines the ability to produce reliable time evolution of stability calculations using experimental data.
- Calculation of poloidal and toroidal stability limits, such as for toroidal n = 1 kink modes and resistive wall modes (RWM), are needed for disruption characterization and prediction.
- Kinetic equilibria with MSE enable reliable calculation of the global mode stability (e.g. no-wall beta limit, β_p^no-wall), which depends strongly on the plasma pressure and q profiles.
- Ideal DCON stability calculation in plasma potential energy, 8W, can determine whether plasmas are above or below the ideal no-wall beta limit.

Ideal stability calculations are sensitive to the equilibrium quality and pressure profile

Resistive DCON result shows equilibrium model with lowest error produces similar Δ^2 evolution

- Too much freedom of the q profile near boundary due to the high polynomial order number will allow the solution of equilibria with negative shear in the model.
- When the qmin is larger than 2, there is no q = 2 surface.
- Computation of the resistive Δ^2 shows output variation of increasing variation when q approaches 2 flux surfaces.
- Trendslines (20 pt. average) are taken from the results with Q, to eliminate the influence from the numerical large variation.

Validation by CCD, IRTV and MHD activities

- Outboard radial gap to the 2nd X point (dips).
- CCD images show time evolution of visible light during this period. Bright curve light shows the outer strike point on the divertors.
- Computed drsae consistent with configuration change from USN to DN, and LSN by CCD images.
- Subsequent IRTV photos illustrate inner strike points on the center stack moving down first, and then moving up. Bright points in the pictures show higher temperatures on lower side view of the KSTAR machine, including divertor and the center stack bottom.
- Computed vertical position of the inner strike point shows the same change within 3 cm during 100 ms.

Reverse shear in plasma center found to correlate with high βp and MHD activity for KSTAR discharge

- Lower gradient in pitch angle (square) goes across the 0 deg axis and produces reversed shear in the plasma center.
- The kinetic equilibrium shows the reverse shear in plasma center at several time windows (yellow line).
- High βp ≥ 1 and n = 2 MHD activities with 20-30 KHz frequency are detected during reverse shear window.

Ideal and resistive stability analyses are improved for disruption prediction and avoidance research

- Kinetic equilibrium reconstruction with MSE
  - Polymial and spline basis functions for toroidal current density are studies with KSTAR high performance plasmas.
  - Reversed shear in plasma center correlated with high βp and MHD activity is needed further work.

- Ideal, and resistive stability analyses
  - Ideal 8W and linear Δ^2 are evaluated with low noise by using present kinetic equilibrium.
  - Improved equilibria with best convergence error level enables ideal and resistive stability analysis with a determination of result sensitivity.

- Key input for disruption prediction and avoidance research
  - Provides reliable and physics validated equilibrium and stability input for DECAF analysis.