Numerical investigation of energetic particle driven interchange mode in LHD

M. Idoukass, Y. Todo, H. Wang, J. Wang
National Institute for Fusion Science
Fusion Theory and Fusion Research Division
idoukass.malik@nifs.ac.jp

Abstract
• Energetic particle driven Interchange mode (EIC) recently observed in LHD, causing energetic ion losses
• Mode investigated with hybrid code MEGA,
• An \( m/n=2/1 \) is observed, inducing a strong energetic particle perpendicular pressure redistribution,
• Frequency chirping is observed at mode saturation.

Context
• Energetic particle driven Interchange mode (EIC) recently observed in LHD [1] with perpendicular NBI active
• \( m/n=1/1 \) mode with a frequency consistent with helical precession frequency, and observation of frequency chirping.
• Significant losses of energetic ions observed through the drop in neutron emission in deuterium experiment.

Numerical simulation code
• Numerical code used: hybrid code MEGA [4]
  • Thermal plasma described with MHD equations:
    \[
    \frac{\partial \rho}{\partial t} = -\nabla \cdot (\rho \mathbf{v}) + \nu_h \Delta (\rho - \rho_0)
    \]
    \[
    \frac{\partial \rho \mathbf{v}}{\partial t} = -\rho \mathbf{v} \cdot \nabla \mathbf{v} - \nabla p
    \]
    \[
    + (\mathbf{j} - \mathbf{j}_0) \times \mathbf{B} + \frac{4}{3} \nabla (\nu p \mathbf{v} \cdot \mathbf{v}) - \nabla \times (\nu p \omega)
    \]
    \[
    \frac{\partial p}{\partial t} = -\nabla \cdot (\rho \mathbf{v}) - (\gamma - 1) \rho \nabla \cdot \mathbf{v}
    \]
    \[
    + (\gamma - 1) \left[ \nu p \omega^2 + \frac{4}{3} \nu p (\nabla \mathbf{v} \cdot \mathbf{v})^2 + \nu j \cdot (\mathbf{j} - \mathbf{j}_0) \right]
    \]
    \[
    + \chi \Delta (\rho - \rho_0)
    \]
    \[
    \frac{\partial \mathbf{j}}{\partial t} = -\nabla \times \mathbf{E} - \frac{1}{\rho_0} \nabla \times \mathbf{B}, \quad \mathbf{E} = -\mathbf{v} \times \mathbf{B} + \eta (\mathbf{j} - \mathbf{j}_0)
    \quad \omega = \nabla \times \mathbf{v}
    \]
• Energetic particles described by the drift kinetic equations, and their contribution to the MHD equations enters in \( \mathbf{j}_h \)

Results
• Observation of a \( m/n=2/1 \) mode
  • Saturation at \( \sim 0.5 \) ms, with \( \nu_p/v_A \sim 10^{-3} \), with \( \beta_L = 1\% \)
  • Mode frequency \( f \sim 9.3 \) kHz, and frequency chirping from 0.44 ms to 0.5 ms, going to a negative frequency for a short time
  • Strong perpendicular pressure redistribution at saturation, with decrease of central pressure
  • Change of the radial velocity profile in the nonlinear phase associated with the inversion of mode frequency

Conclusion
• A numerical investigation of the EIC mode in LHD is attempted using the code MEGA
• An energetic particle driven \( m/n=2/1 \) mode is found in the core plasma, showing:
  • a strong perpendicular pressure redistribution,
  • a rapid frequency chirping
• Further investigation is required in order to find an energetic particle driven \( m/n=1/1 \) interchange mode located at the plasma edge.

REFERENCES