Abstract

- A transition from an interchange mode to a non-resonant mode is found in the nonlinear MHD simulation for an LHD plasma with net toroidal current.
- This transition occurs when the magnetic shear is weak and the rotational transform is close to unity in the core region.
- In this transition, the mode number of the dominant Fourier component is reduced.
- In the case where the difference in the kinetic energy between the largest two components is small, the \((m,n)=(1,1)\) component can be dominant, which qualitatively agrees with the LHD experiment.

Background

- Observation of partial collapse in LHD experiments
  - The net toroidal current is increased and reaches a certain value, a partial collapse is observed.
  - The partial collapses are ALWAYS caused by \((m,n)=(1,1)\) mode.

Theory for pressure driven modes:
The linear growth rate is larger for higher mode numbers for pressure driven modes.

Numerical Method

- 3D equilibrium calculation: HINT code
  - The HINT code (Y. Suzuki et al., NF (2006)) calculates 3D equilibria without any assumption of the existence of nested flux surfaces by iterating 2 steps.

- 3D stability analysis: MIPS code
  - The MIPS code (Todo et al., PFR2010) solves the full MHD equations. The 4th order finite difference and 4th order Runge-Kutta method are employed.

- Simulation conditions
  - Magnetic configuration: LHD, \(\gamma_p = 1.1738\), \(R_{\text{pp}} = 3.6m\) (same as the above experiment)
  - Equilibrium pressure profile: \(P_0 = P_1(1 - 0.05s^2 - 0.32s^4)\)
  - Equilibrium parameters:
    - \(S = 5.0 \times 10^7\)
    - \(\gamma = 2.5 \times 10^5\)
    - Equilibria with 2 kinds of net current
  - Without net toroidal current case (reference):
    - \(l = 0\)
    - \(\beta_0 = 3.1\%\) (Higher than experiment)
  - With net toroidal current case
    - \(l = 0.5\%\) for \(B_0 = 3T\)

Dynamics of LHD plasma with net toroidal current

- Close dominant components case
  - (1st choice of initial random numbers) : a transition to \((1,1)\) mode
    - At \(t=450A\) (linear phase): The \(m=2\) and \(n=3\) components have the largest Ek. \(E(k=2) / E(k=3) = 1.12\) (very close)
    - At \(t=500A\) (early nonlinear phase): The \(3,3\) and \(2,2\) are localized at the resonant surface.
    - At \(t=700A\) (further nonlinear phase): The non-resonant \((1,1)\) becomes dominant at low shear region through the nonlinear coupling.

- Spaced dominant components case
  - (2nd choice of initial random numbers) : a transition to \((2,2)\) mode
    - At \(t=450A\) (linear phase): The \(n=3\) component is clearly dominant. In Ek, \(E(k=n3)/E(k=n2) = 1.82\) (spaced)
    - At \(t=500A\) (early nonlinear phase): The \(3,3\) is localized at the resonant surface.
    - At \(t=700A\) (further nonlinear phase): The non-resonant \((2,2)\) becomes dominant at low shear region.

Dynamics of LHD plasma without net toroidal current

- Monotonic rotational transform with high shear
  - At \(t=520A\) (early nonlinear phase): \((2,2)\) component is localized at the resonant surface.
  - At \(t=700A\) (further nonlinear phase): Many side bands appear and make the pressure structure complicated.

Concluding Remarks

- A transition from the interchange mode resonant the \(\pm 2m=1\) surface to a non-resonant mode in the nonlinear phase is obtained.
- This transition occurs in the equilibrium where the shear is weak and the rotational transform is close to unity.
- The mode number of the dominant component after the transition depends on the relation of the two dominant components in the linear phase.
- In the close dominant components case, the \((1,1)\) component becomes dominant, which is considered one of the candidates of the \((1,1)\) collapse observed in the experiments.
- In the spaced dominant components case, the \((2,2)\) component becomes dominant.
- It is necessary to introduce additional physics such as background global flow and kinetic ion effects for the investigation of the mechanism for the robust \((1,1)\) component observation in the LHD experiments.

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