Trapped Energetic Particles Effect on Resistive Wall Mode and Excitation of Fishbone-Like External Mode in RFP plasma


1. ConsorzioFIN, Associazione ENEA sulla fusione, Corso Stati Uniti 4, Padova 35127, Italy
2. Euratom/CFE Fusion Association, Culham Science Center, Abingdon, Oxon OX14 3DB, UK
3. Princeton Plasma Physics Laboratory, Princeton, New Jersey 08543, USA

ABSTRACT
Investigation of the different features of RWM instabilities between RFP and tokamak can provide an in-depth understanding on the RWM physics and Energetic particle physics on RWM and FLEM.

- MARS-K code is applied on the recent studies, considering self-consistently the drift kinetic effects of thermal particles as well as isotropic/antisotropic energetic ions (EIS).
- Physics analyses & Comparison between RFP and Tokamak are focused on the following subjects:
  1. The energetic particle effects on RWMs.
  2. The characteristics of a non-equilibrium Fish-bone Like External kink Mode (FLEM) and its relation with the RWMs.

Fishebone-like external kink (FLEM) instability driven by EPs
- A non-equilibrium fishbone-like external kink mode (FLEM) in RFP plasma can be driven by the precessional drift resonance of trapped Eps over the ideal wall.
- FLEM satisfies the usual external ideal kink dispersion relation[6]

\[ \Omega_{RWM} = \Omega_{FLEM} \]

- Since \( \Delta \omega > 0 \) and \( \Delta \omega' > 0 \), under the approximation \( \gamma << \Omega_{RWM} \), it is valid for most parameter regimes.

\[ \\beta_{E}\gamma_{E} < 0 \]
- \( \gamma_{E} \) is mainly determined by Real (\( \beta_{E} \)), \( \gamma \) is mainly determined by \( \rho_{E} \).
- \( \Delta \omega' \) is largely influenced by \( \gamma_{E} \) and the ideal plasma.
- \( \Delta \omega' \) is mainly determined by \( \gamma_{E} \) and \( \beta_{E} \).

Condition of the FLEM excitation
- If the frequency \( \alpha \) (mainly determined by \( \Delta \omega' \)) falls inside the range satisfying the moment condition \( \gamma \) with the precession frequency of a given type of EPs.

\[ \frac{\beta_{E} \gamma_{E}}{\Omega_{RWM}} < 0 \]

The FLEM Instability can occur
- Thermal (passing) particles do the damping effects on FLEM by transit resonance, which is stronger in RFPs than in tokamaks.

FLEM Instabilities in RFP plasmas
- The instability of FLEM does not depend on the wall condition.
- The FLEM instability is far
- With the presence of EPs in the plasma, the FLEM and the RWM can cancel or couple to each other, depending on the plasma parameters.

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Equilibrium properties of fast ions
- The birth energy profile \( v_{b} \) of fast ions can be determined by specifying the fraction \( P_{b}P_{a} \) and \( N_{b}N_{a} \).
- We choose constant birth energy \( v_{b} \) and fraction \( P_{b}P_{a}(\gamma_{b}) \) in this work.

- The frequencies are distribution averaged over the particle velocity space \( \gamma_{T} \) and the poloidal angle \( \gamma_{P} \).

- For thermal particles, \( \beta_{T} \) is Maxwellian distribution. For Eps, \( \beta_{E} \) is Shearing down distribution.

- \( \gamma_{p} \) is the plasma frequency of fast ions, \( \gamma_{T} \) and \( \gamma_{E} \) are the beam and transit frequency of thermal particles.

- For \( \gamma_{p} > 100 \) and \( \gamma_{p} < 1 \), \( \gamma_{T} \) is comparable to \( \gamma_{p} \) and \( \gamma_{E} \) (or \( \gamma_{p} \)).

- The kinetic energy \( \beta_{E} \gamma_{E} < 0 \) satisfies the moment condition \( \gamma \) with the precession frequency of a given type of EPs.

- The instability of FLEM does not depend on the wall condition.
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Effects of energetic particles (Eps) on RWM
- Modeling of the equilibrium distribution function for energetic ions (Eps) Shering down + Gaussian model for the particle pitch angle distribution[41]:

\[ f_{E}(\theta) = a \left( 1 + e^{-b(\theta - \theta_0)^2} \right) \]

- The resonance condition for kinetic damping by the thermal particles in RFP (transit resonance):

\[ \omega_{RWM} = \Omega_{FLEM} \]

- By the energetic ions (Eps):

\[ \omega_{E} = \beta_{E} \gamma_{E} \]

- The kinetic effects modify the ideal wall \( \beta_{E} \), limit

FLEM vs. RWM (both are external kink modes)
- With the presence of EPs in the plasma, the FLEM and the RWM can cancel or couple to each other, depending on the plasma parameters.

Reference