§5. Nonlocal Energetic Particle Mode in a JT-60U Plasma

Todo, Y.
Shinohara, K., Takechi, M., Ishikawa, M. (JAERI)

Three types of frequency chirping instabilities, slow frequency sweeping (slow FS) mode, fast frequency sweeping (fast FS) mode, and abrupt large event (ALE) have been observed in the Japan Atomic Energy Research Institute Tokamak-60 Upgrade (JT-60U) plasmas heated with negative ion based neutral beam (NNB) injection. Frequencies of the three instabilities are in the range of shear Alfvén eigenmodes. Frequency sweeping of slow FS mode has a good correlation with equilibrium parameter evolution with time scale ~200 ms. On the other hand, time scales of the fast FS mode and the ALE are respectively 1-5 ms and 200-400 μs, much shorter than the equilibrium time scale. Frequency of the fast FS mode shifts rapidly by 10-20 kHz in 1-5ms both upward and downward. The starting frequency of the fast FS mode changes in the time scale of the equilibrium parameter evolution and follows the toroidal Alfvén eigenmode (TAE) gap frequency.

We have previously investigated the fast FS mode in a JT-60U plasma using a simulation code for magnetohydrodynamics (MHD) and energetic particles, MEGA. We reported that there is an unstable mode near the plasma center and frequency sweeping close to that of the fast FS mode takes place[1]. The ratio of the linear damping rate (γ_d) to the linear growth rate (γ_L) in the simulation is consistent with hole-clump pair creation which takes place when is greater than 0.4[2,3].

In this work[4], we focused on the linear properties of the energetic-ion driven instability in a JT-60U plasma where the fast FS mode was observed. The spatial profile of the unstable mode peaks near the plasma center where the safety factor profile is flat. The unstable mode is not a TAE because the spatial profile deviates from the expected location of TAE and the spatial profile consists of a single primary harmonic m/n=2/1 where m, n are poloidal and toroidal mode numbers. The real frequency of the unstable mode is close to the experimental starting frequency of the fast FS mode.

Simulations for various energetic ion orbit widths and energetic ion pressures were carried out to investigate energetic ion effects on the unstable mode spatial profile. Both energetic ion orbit width and energetic ion pressure broaden radial profile of the unstable mode. Energetic ion orbit width has significant effects on the mode spatial profile as is shown in Fig. 1. For the smallest orbit width, the spatial profile is extremely localized near the plasma center where the safety factor profile is rather flat at 0<r/a<0.2. For larger orbit width, the peak location moves radially outward and the radial width is broadened. The radial width of mode spatial profile differs by a factor of 3 between the smallest and the largest (=experimental) orbit width. The radial restoring force, which is a force component in the minor radius coordinate and contributes to real frequency of the oscillation, was analyzed. The MHD force and the energetic ion force were analyzed for various radial locations and converted to the real frequency. For the largest orbit width, the total frequency which is the sum of the MHD frequency and the energetic ion frequency takes roughly a constant value in the region 0<r/a<0.5 where the unstable mode has substantial intensity. The total frequency is close to the frequency of the unstable mode. What is important is that the MHD force alone cannot keep the frequency spatially constant. The energetic ion frequency amounts to -0.15 ω_A, which is about 60% of the unstable mode frequency. The energetic ions have significant effects on the unstable mode oscillation for the largest orbit width. For the smallest orbit width, the energetic ion frequency is only 10% of the total frequency near the plasma center. This might suggest the existence of a purely MHD eigenmode. However, if such a purely MHD eigenmode does exist without the presence of energetic ions, the spatial profiles of the unstable mode must be independent of the energetic ion parameters. We cannot find such a parameter region. Since we cannot investigate instabilities of low growth rate with the initial value approach, theoretical investigations are needed to clarify the existence of a purely MHD eigenmode near the plasma center with low magnetic shear.

The spatial width of the unstable mode with the smallest orbit width gives an upper limit of the spatial width which the MHD effects alone can induce. For the experimental condition of the JT-60U plasma, the energetic ions broaden the spatial profile of the unstable mode by a factor of 3. The major part of the spatial profile of the unstable mode is induced by the energetic ions. We conclude that the unstable mode is primarily induced by the energetic particles and the name ``nonlocal EPM" can be justified.

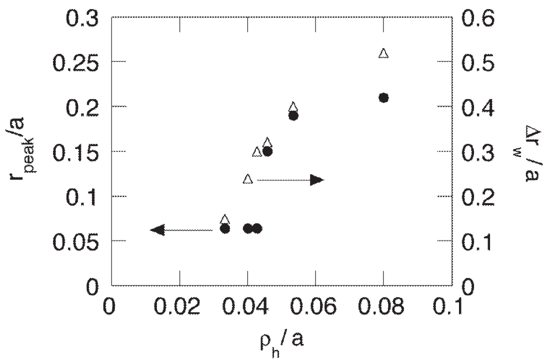

Fig. 1. Peak location (r_{peak}) and radial width (Δr_w) of the unstable mode spatial profile versus energetic ion parallel Larmor radius normalized by the minor radius.

References
1) Todo, Y. et al., J. Plasma Fusion Res. **79**, 1107 (2003), http://jspf.nifs.ac.jp/Journal/2003.html.
2) Berk, H. L. et al., Phys. Lett. A **234**, 213 (1997); **238**, 408(E) (1998).
3) Berk, H. L. et al., Phys. Plasmas **6**, 3102 (1999).
4) Todo, Y. et al., Phys. Plasmas **12**, 012503 (2005).