§23. Computer Simulation of Fishbone Oscillation

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Fishbone instability was first observed during near-perpendicular neutral beam injection in the PDX tokamak [1]. The instability takes place in recurrent bursts, accompanied by frequency decrease during each burst. Two types of fishbone modes, precessional fishbones [2] and thermal ion diamagnetic drift fishbones [3], were theoretically prediced. Little is known about self-consistent nonlinear evolution of the precessional fishbones. Perturbative approach is not valid for the precessional fishbones, since the mode frequency emerges from the shear Alfvén continuous spectrum and depends intrinsically on the energetic ion distribution.

We carried out particle-Magnetohydrodynamic (MHD) hybrid simulations [4] with parameters similar to the PDX experiments. In this model plasma is divided into two parts, bulk plasma and energetic ions. The bulk plasma is described by the nonlinear full MHD equations. Electromagnetic field is given by the MHD description. This approximation is reasonable under the condition that the energetic ion density is much less than the bulk plasma density. The drift-kinetic descrirtion is employed for the energetic ions. In order to reduce numerical noise, the δf particle simulation method is applied to the energetic ions. The effect of the energetic ions on the MHD fluid is taken into account in the MHD momentum equation through the energetic ion perpendicular current. It must be noted that we start simulation from correct MHD equilibrium. In the PDX experiment NBI injection was nearly perpendiicular. Therefore, the Grad-Shafranov equation should be extended. We solve an extended Grad-Shafranov equation found in Ref. [5].

The following simulation parameters are employed. The major and minor radii are R=1.43m, a=0.44m, respectively. The magnetic field at the magnetic axis is 1.5T. The bulk ions and the beam ions are hydrogen and deuterium, respectively. NBI injection energy is 50keV. Initial energetic ion distribution in the velocity space is assumed to be a slowing down distribution. The number of particle used is 5.2×10^5. The number of grid point is $101 \times 48 \times 101$ for cylindrical coordinates (R, ϕ, Z)

Figure 1 shows growth rate of $m/n = 1/1$ harmonic for various energetic ion beta values. In case of nearly perpendicular NBI injection, it is found that kink mode is not so stabilized as that of isotropic NBI injection. We have investigated energy evolution. For low energetic ion beta values only the magnetic energy is decreasing, and MHD fluid kinetic energy, MHD thermal energy are increasing. While for relatively high energetic ion beta values only the energetic ion energy is decreasing, and all of the MHD energy are increasing. This clearly indicates that instability driving source is different between low energetic ion beta values and high energetic ion beta values. We call the latter fishbone instability.

Amplitude evolution of $m/n = 1/1$ harmonic of the radial velocity V_r is shown in Fig. 2. Solid line and dashed line show the case of central energetic beta value = 2.0% and 3.0%, respectively. The saturation level of the radial velocity is almost constant ($\sim 5.0 \times 10^{-3}$) in each case. In other words, saturation level dose not depend on energetic ion beta value.

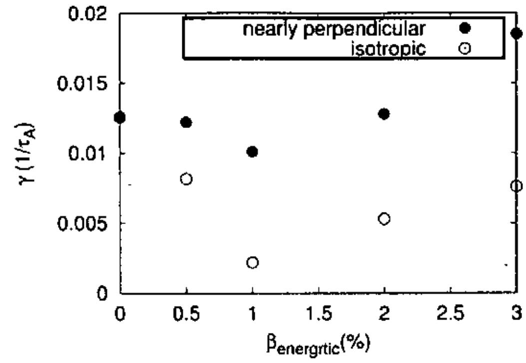

Fig. 1 Growth rate of $m/n = 1/1$ harmonic for various β_h values.

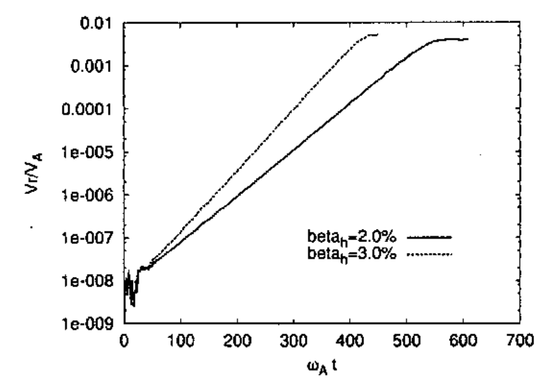

Fig. 2 Amplitude evolution of $m/n = 1/1$ harmonic of radial velocity V_r.

Reference

[1] K. Mcguire, R. Goldston, M. Bell *et al.*, Phys. Rev. Lett. **50**, 891 (1983).

[2] L. Chen, R. B. White, and M. N. Rosenbluth, Phys. Rev. Lett. **52**, 1122 (1984).

[3] B. Coppi and F. Porcelli, Phys. Rev. Lett. **57**, 2272 (1986).

[4] Y. Todo and T. Sato, Phys. Plasmas **5**, 1321 (1998).

[5] E. V. Belova, N. N. Gorelenkov, and C. Z. Cheng, Phys. Plasmas **10**, 3240 (2003).