25F08

Simulation Study of Energetic Particle Driven Geodesic Acoustic Mode in LHD Plasma

高エネルギー粒子駆動測地音響モードのシミュレーション研究

Hao Wang[1)], Yasushi Todo[1,2)]
王　灏[1)], 藤堂　泰[1、2)]

[1)] *The Graduate University for Advanced Studies*
Oroshi-Chou 322-6, Toki 509-5292, Japan
[2)] *National Institute for Fusion Science*
Oroshi-Chou 322-6, Toki 509-5292, Japan
[1)] 総合研究大学院大学　〒509-5292　土岐市下石町３２２−６
[2)] 核融合科学研究所　〒509-5292　土岐市下石町３２２−６

The energetic particle driven geodesic acoustic modes (GAM) in the Large Helical Device are investigated using a hybrid simulation code for magnetohydrodynamics (MHD) and energetic particles. It is found that the mode frequency is lower and the growth rate is higher for higher energetic particle β values. Both the chirped frequency and the constant frequency evolutions take place. The resonant particle distribution in velocity space is investigated, and the transit frequency of the resonant particles is in good agreement with the mode frequency. In addition, both the inward propagating and the outward propagating modes are observed in the simulation results.

1. Introduction

The GAM is an oscillation of toroidal plasma for which the m = n = 0 electrostatic potential is linearly coupled (by toroidal effects) to the m = 1, n = 0 sideband density perturbation.[1] This mode is normally driven by plasma micro-turbulence, but in these years, energetic particle driven GAM is also observed in many tokamaks and helical device.[2,3] The energetic particle driven GAM is important since it may enhance the radial transport of energetic particles, and deteriorate the performance of fusion reactors.[4] In this manuscript, the energetic particle driven GAM is simulated with MEGA code, a hybrid simulation code for MHD and energetic particles.[5]

2. Simulation Model

In the MEGA code, the bulk plasma is described by the nonlinear MHD equations and the energetic ions are simulated with the δf particle method. The energetic ion contribution is included in the MHD momentum equation as the energetic ion current density. This model is accurate under the condition that the energetic ion density is much less than the bulk plasma density.

The energetic particle distribution function in the present simulation is anisotropic in pitch angle Λ, and it peaks at $\Lambda=\Lambda_{peak}$. Here $\Lambda=\mu B_0/E$, μ is magnetic moment, B_0 is magnetic field strength at the magnetic axis, and E is particle energy. Realistic LHD experimental parameters are used for simulation whereas axisymmetric equilibrium with concentric circular magnetic surfaces is employed. The helical effect is not considered.

3. The Mode Linear Property

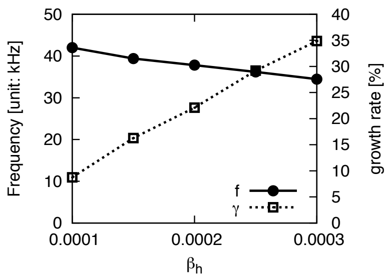

Fig.1. The frequency and growth rate versus energetic particle β value.

The simulated energetic particle driven GAM is 34kHz with energetic particle β value equals 0.2%. For comparison, the theoretical (MHD) GAM frequency is 37.5kHz with $f=\sqrt{(\gamma P/\rho R^2)(1+\iota^2/8\pi^2)}/2\pi$, the measured GAM frequency in LHD is 32kHz. These three frequencies are close to each other.

The simulation is performed with different energetic particle β value in order to clarify how the frequency and growth rate are affected by energetic particles. We see lower frequency and higher growth rate for higher β_h as shown in Fig. 1. The simulated NBI energy is 40keV. In the case of E_{NBI}=170keV, the results are similar with

E_{NBI}=40keV case.

4. Frequency Evolution

In LHD, both the chirping frequency and the constant frequency evolutions are observed. In the present work, with the parameters β_h=0.03%, Λ_{peak}=0.3 and NBI energy equals 170keV, the mode frequency chirps from 50kHz to 65kHz in a fraction of a millisecond, as shown in Fig. 2. Different simulation conditions are compared to investigate the energetic particle driven GAM frequency evolution behavior, and the results are shown in Table I.

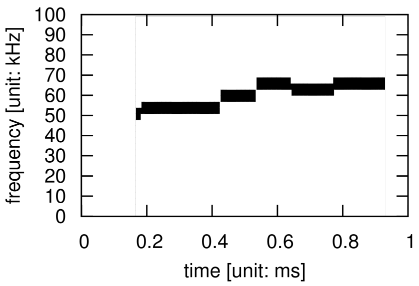

Fig.2. The frequency chirps from 50kHz to 65kHz.

Table I. The frequency evolution is affected by energetic particle energy E_{NBI} and peak pitch angle Λ_{peak}.

	E_{NBI}=40keV	E_{NBI}=170keV
Λ_{peak}=0.3	constant	chirped
Λ_{peak}=0.5	constant	constant

The time derivative of particle energy is investigated in velocity space. The result is shown in Fig. 3. We see two regions of strong energy transfer around (E=60keV, Λ=0.4) and (E=40keV, Λ=0.15). The signs of the energy transfer are different from each other. The region around E=60keV (E=40keV) is destabilizing (stabilizing) the GAM. The transit frequency f_{tr}, is defined as

$$f_{tr} = \sqrt{1-\Lambda} \, v/(2\pi q R_0),$$

where v is the energetic particle velocity, q is the safety factor and R_0 is the major radius. The transit frequencies of the two regions are close to the mode frequency. The solid curve in Fig. 3 presents a constant transit frequency $f_{tr}=f_{GAM}\equiv$52.6kHz. The energetic particles in the two velocity space regions are resonating with the GAM.

5. Mode Propagation

The energetic particle driven GAM can propagate inward and outward, and both of propagations are observed in experiment. They are also simulated in the present work. Figure. 4 shows the inward propagating case.

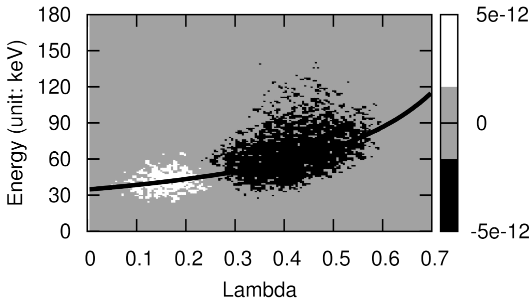

Fig.3. The energetic particle dE/dt distribution in E-Λ space.

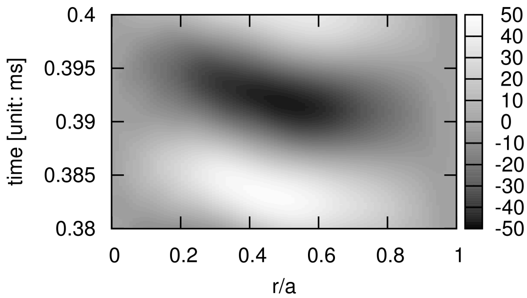

Fig.4. The mode amplitude evolution.

6. Summary

In summary, the energetic particle driven GAM in LHD was simulated. As the linear properties, the mode frequency decreases and growth rate increases with β_h increases. Both the chirped frequency and the constant frequency evolutions take place. The resonant particle distribution in velocity space was investigated, and the transit frequency of the resonant particles is in good agreement with the mode frequency. In addition, both the inward propagation and the outward propagation were observed in the simulation results.

References

[1] P H Diamond, S-I Itoh, K Itoh and T S Hahm: Plasma Phys. Control. Fusion **47** (2005) R35.

[2] R. Nazikian, G. Y. Fu, M. E. Austin, H. L. Berk, R. V. Budny, N. N. Gorelenkov, W. W. Heidbrink, C. T. Holcomb, G. J. Kramer, G. R. McKee, M. A. Makowski, W. M. Solomon, M. Shafer, E. J. Strait, and M. A. Van Zeeland: Phys. Rev. Lett. **101** (2008) 185001.

[3] T. Ido, A. Shimizu, M. Nishiura, S. Nakamura, S. Kato, H. Nakano, Y. Yoshimura, K. Toi, K. Ida, M. Yoshinuma, S. Satake, F. Watanabe, S. Morita, M. Goto, K. Itoh, S. Kubo, T. Shimozuma, H. Igami, H. Takahashi, I. Yamada, K. Narihara and the LHD Experiment Group: Nucl. Fusion **51** (2011) 073046.

[4] G. Y. Fu: Phys. Rev. Lett. **101** (2008) 185002.

[5] Y. Todo: Phys. Plasmas **13** (2006) 082503.