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Characteristics of fast-ion driven GAM in the LHD plasmas
LHDにおける高速イオン励起GAMの特性

Takeshi Ido, Masaki Osakabe, Akihiro Shimizu, Masaki Nishiura, Tetsuo Watari, Kunihiro Ogawa, Kimitaka Itoh and LHD experiment group
井戸　毅, 長壁正樹、清水昭博、西浦正樹、渡利徹夫、小川国大、伊藤公孝、LHD実験グループ

National Institute for Fusion Science
322-6, Orochi, Toki, Gifu 509-5292, Japan
核融合科学研究所　〒509-5292　岐阜県土岐市下石町322-6

The spatial structure and the frequency of an energetic-particle driven mode with the toroidal mode number (*n*) of 0 have been investigated in LHD. The toroidal and radial structures correspond to those of the geodesic acoustic mode (GAM). The temperature dependence of the frequency does not agree with the energetic particle-driven GAM(EGAM) frequency predicted in earlier works where the slowing down velocity distribution function is assumed, but can be explained by the taking into account the observed energy distribution function. Therefore, the characteristics of the n = 0 mode corresponds to those of the EGAM. The EGAM has large electrostatic potential fluctuation (~ several kV), and the linear relation between the electrostatic potential and the magnetic field potential has been observed.

1. Introduction

Geodesic acoustic mode(GAM) is a branch of zonal flow in toroidal plasmas, and driven by not only turbulence but also energetic particles (EPs)[1]. In LHD, an energetic-particle driven mode with the toroidal mode number (*n*) of 0 has been observed, and the candidate of the mode is the energetic-particle driven GAM(EGAM). Recently, the increase in the energy of bulk plasma has been observed during the excitation of the *n* = 0 mode[2], and the phenomena may suggest a new energy path from the energetic particle to the bulk ions via GAM[3], such as alpha channeling. Thus, revealing the characteristics of the *n* = 0 mode is important from the practical aspect as well as academic interests. In this study, we have investigated the *n* = 0 mode through the direct measurement by heavy ion beam probe(HIBP) in LHD.

2. Apparatus and experimental condition

The experiments were performed under the condition that the magnetic field strength is 1.375 T. The major radius and the averaged minor radius of the plasma are 3.75 m and about 0.6 m, respectively. The plasmas were produced and sustained by tangential neutral beam injection (NBI) with the beam energy of 175 keV, and the absorbed NBI power is about 85 kW.　The line averaged electron density is about 0.1 x 10^{19} (m^{-3}), and the central electron temperature is about 2 keV and it increases to 10 keV by superposition of ECH with the power of 760 kW.

In order to measure the electrostatic potential(ϕ),

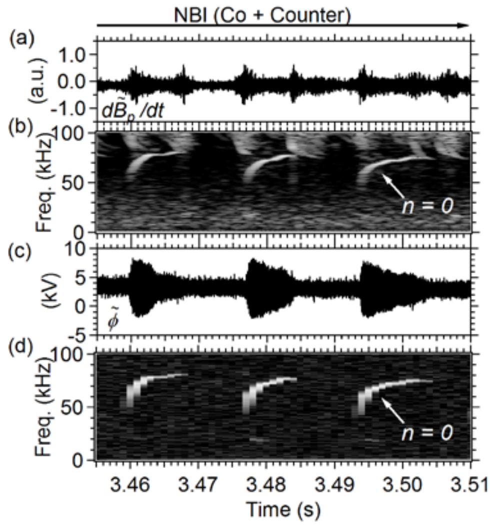

Fig.1 a) Magnetic field fluctuation, and (b) its spectrogram. (c)Electrostatic potential measured using HIBP at a normalized minor radius of 0.1 and (d) its spectrogram

its fluctuations($\tilde{\phi}$) and density fluctuations($\tilde{n}_e$), HIBP using a gold ion beam is installed on LHD. The temporal and spatial resolution is 2 μs and a few centimeters, respectively. Since the beam energy(E_b) is 1.134 MeV in this experiment. To measure the spatial structure of magnetic fluctuation($\tilde{B}_p$), Mirnov coil array is installed in the toroidal direction.

Figure 1 shows the temporal evolution of $\tilde{B}_p$ measured by a Mirnov coil and $\tilde{\phi}$ measured by HIBP. Up-chirping modes are observed in the frequency range 50-80 kHz, and their toroidal mode number is 0. The radial structures of $\tilde{\phi}$ and $\tilde{n}_e$ can be estimated by analyzing the phase between $\tilde{\phi}$

and $\tilde{B}_p$ and between $\tilde{n}_e$ and $\tilde{B}_p$, respectively. The phases of $\tilde{\phi}$ and $\tilde{n}_e$ have an up-down symmetry and asymmetry across the equatorial plane[4], respectively. Thus, the mode structure agrees with that of GAM.

3. Temperature dependence of the frequency

The temperature dependence of the n = 0 mode are shown in Fig. 2. The bold line indicates the ordinary GAM frequency. The open and filled circles indicate the observed data, and the latter indicates the data obtained during the electron temperature scan in a discharge. The observed temperature dependence is weaker than that of the ordinary GAM frequency. In addition to that, some frequencies are larger than the ordinary GAM frequency unlike the prediction in earlier studies[1,3,5], where the frequency of the EGAM becomes smaller than the ordinary GAM frequency.

In this study, the dispersion relation has been examined, taking into account the energy distribution function observed by neutral particle analyzer (NPA) in LHD. The results are indicated by the dashed curve and the dash-dot curve in Fig.2, where the density ratio of the energetic particles to the bulk ions are assumed to be 3 % in the former case and 10 % in the latter case. The calculation agrees with the experimental data, although the density ratio and the energy distribution function should be examined more carefully in the future. Judging from the mode structure and frequency, the characteristics of the n = 0 mode corresponds to those of the EGAM.

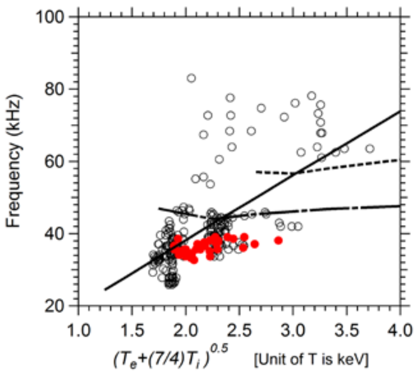

Fig. 2 Temperature dependence of the n = 0 mode. The open and filled circles indicate the data obtained in several discharges, and the latter indicate the data obtained in a discharge. The calculated GAM frequencies are also shown, where the density ratio of the energetic particles to the bulk ions are assumed to be 0 % (bold line), 3 % (dashed curve) and 10 % (dash-dot curve).

4. Electrostatic potential fluctuation associated with the EGAM

In the previous experiments, the amplitude of $\tilde{\phi}$, associated with the EGAM is so large that it exceeded the measurable electrostatic potential by HIBP. Since the upper limit of the measurable range of the electrostatic potential is proportional to the probe beam energy, higher beam energy is required to increase the upper limit of the measurement. The probe beam energy is determined so that the Larmor radius of the probe beam is comparable to the size of the plasma. Thus, lighter probe ions are required for increasing the beam energy, and we developed Cu^- ion source instead of Au^- ion source. Figure 2 shows the relation between $\tilde{B}_p$ and $\tilde{\phi}$. The large $\tilde{\phi}$ has detected (~ several kV), and the linear relation agrees with a theory[6].

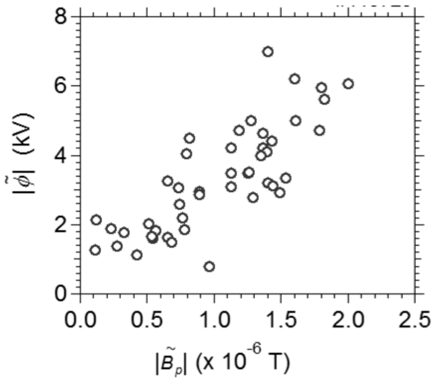

Fig. 3 Relation between $\tilde{B}_p$ measured by a Mirnov coil and $\tilde{\phi}$ by HIBP.

5. Summary

The spatial structure and the frequency of n = 0 mode has been clarified by HIBP and Mirnov probe, and they corresponds to the EGAM. A large electrostatic potential associated with The EGAM has been detected. It may relate to the increase in the energy of bulk ions.

Acknowledgments

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