Geodesic Acoustic Mode Spectroscopy II

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(Received 16 January 2009 / Accepted 16 February 2009)

An extension of geodesic acoustic mode (GAM) spectroscopy [Plasma Phys. Control. Fusion **49**, L7 (2007)] is proposed. The ratio between the lowest frequency of the co-existing ion acoustic mode (IAM) and the frequency of GAM enables us to identify the safety factor of toroidal plasmas. The lowest frequency can be detected by bispectrum analysis when both GAM and IAM are excited. The possibility of measuring the safety factor is discussed.

Keywords: geodesic acoustic mode, ion acoustic mode, toroidal plasma, safety factor, new diagnostics, bicoherence

DOI: 10.1585/pfr.4.014

In this brief communication, a variation of geodesic acoustic mode (GAM) spectroscopy [1] is proposed in order to measure the safety factor q in toroidal plasmas. The safety factor is a fundamental parameter that characterizes toroidal magnetic confinement, dictating the stability and transport of toroidal plasmas. The measurement of the internal q profile has been a central issue in experiments both for tokamaks and for toroidal helical plasmas.

Recently, GAM [2–4] and zonal flows [5] have attracted wide attention owing to their important role in turbulent transport in toroidal plasmas. Measurements of both are now routinely performed [6–12]. In particular, the nonlinear interaction associated with GAM has been studied experimentally by means of a novel method of bispectrum analysis.

The dispersion relation of GAM has previously been studied (e.g., [2, 3, 13, 14]) and the eigenfrequency obtained [15]. Measuring GAM frequency at the peak of the radial eigenmode gives us the value of $\omega_{\mathrm{GAM}} \sim c_{\mathrm{s}}/R$, where c_{s} is the ion sound velocity and R is the major radius of the torus. It has previously been proposed to deduce the ion species from this measurement [1]. The lowest frequency of the ion acoustic mode (IAM), on the other hand, is given as $\omega_{\mathrm{IAM}} \sim c_{\mathrm{s}}/qR$. If the low-frequency IAM could be identified, GAM spectroscopy can be extended to deduce the q value in the plasma. The IAM is stable in high-temperature toroidal plasmas. However, low-frequency IAM can be excited by microscopic instabilities such as GAM and zonal flows. The plausibility of this new method is discussed from here on.

We first consider the dispersion relation for GAM and IAM. An example, which is deduced from collisionless kinetic-fluid equations, is given in [13]. The zonal flow, GAM and IAM, which are nonlinearly excited by ion-temperature gradient-driven turbulence, have been studied in large-aspect-ratio tokamaks. A closed set of equations for fluctuations of the potential (constant on magnetic surface), parallel ion pressure, perpendicular ion pressure, parallel flow and density are derived, which yields the dispersion relation of the form:

$$\omega^5 + c_1\omega^4 + c_2\omega^3 + c_3\omega^2 + c_4\omega + c_5 = 0, \tag{1}$$

where ω is a frequency and coefficients $c_1 \cdots c_5$ are given in [13]. A solution to Eq. (1) is shown on the complex frequency plane for the parameters $T_{\mathrm{e}} = T_{\mathrm{i}}$ and $q = 1.5$ (Fig. 1). The higher frequency mode (ω_1) is the GAM branch and is not sensitive to the safety factor. The branch of intermediate frequency (ω_2) is the IAM, and the solu-

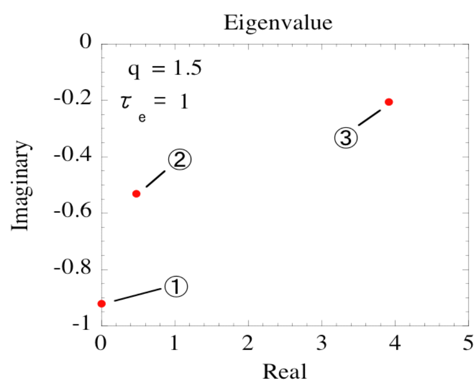

Fig. 1 Frequencies of GAM (#3), IAM (#2), and zonal flow (#1) on a complex frequency plane. (Unit of frequency is $\omega qR/v_{\mathrm{th,i}}$).

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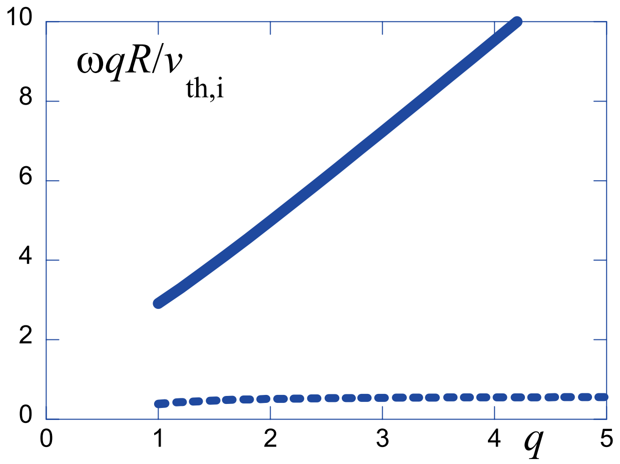

Fig. 2 Frequencies of GAM (solid line) and IAM (dashed line) as a function of the safety factor for $T_e = T_i$.

tion of zero frequency ($Re\,\omega_3 \simeq 0$) corresponds to the zonal flow. The frequencies of GAM and IAM, ω_1 and ω_2, are plotted in Fig. 2. We see that the simultaneous measurement of GAM and IAM can give us the safety factor in toroidal plasmas. The frequencies of waves can be more precise if one employs kinetic theory. For instance, kinetic analysis gives

$$\omega_{\mathrm{GAM}} = \frac{v_{\mathrm{th,i}}}{R}\sqrt{\frac{7}{4} + \tau + \frac{23 + 16\tau + 4\tau^2}{14 + 8\tau} q^{-2}}, \qquad (2)$$

where $v_{\mathrm{th,i}}$ is the ion thermal velocity, and $\tau = T_e/T_i$ [14, 16]. Equation (1) provides an approximation to the kinetic solution.

Linear stability analysis is straightforward, and the key issue is whether or not the relevant IAM can be identified. GAM, IAM, and zonal flow are all excited by turbulence in the range of drift wave frequency. Figure 1 shows that the damping rate of low-frequency IAM is smaller than that of zonal flow. Thus the excitation of IAM is expected (see, e.g., [17]), because the zonal flow has been experimentally measured [18].

GAM has been measured experimentally in previous studies, and bispectrum analysis performed [10, 19–21]. Figure 3 shows an example of bispectrum analysis for the case of the JFT-2M tokamak [19]. The straight lines correspond to the GAM frequency. We also observe that there is a prominent bispectrum peak for fluctuations with frequencies $\omega \sim 2$ kHz and $\omega \sim 7$ kHz. The isolated peaks of the bispectrum strongly indicate the presence of fluctuations for these frequencies. The finite value of the bispectrum brings to an end the unambiguous nonlinear coupling between them. This fact provides a further basis to search for the fluctuation associated with low-frequency IAM. We note here that the bispectrum analysis in Fig. 3 has been performed with a resolution of frequency that is of the order of 1 kHz. Thus the present bispectrum (in Fig. 3) is not suitable for the identification of the frequency of IAM

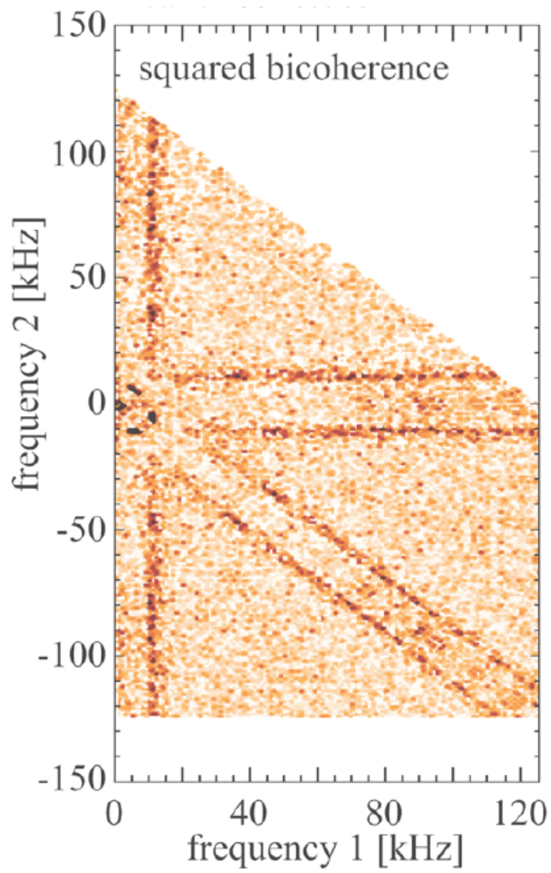

Fig. 3 Bispectrum analysis of turbulence for the case of JFT-2M plasma (see [19] for details). Sharp lines indicate the coupling between GAM and background turbulence. The isolated peak near the origin indicates the coupling between GAM and IAM.

with the lowest real frequency. This implies, the analysis must be performed using higher frequency resolution in the future. Using this method, the frequency of nonlinearly driven IAM will be measured by bispectrum analysis.

In this note, we have proposed an extension to GAM spectroscopy. The possibility of measuring the safety factor by studying the nonlinear excitation of GAM and IAM was discussed. The frequencies of GAM and IAM are influenced by plasma shaping; however, this method can be directly applied to shaped plasmas by calculating the frequencies, taking into account the shape of the plasmas. By combining GAM spectroscopy with this technique, a more precise knowledge of plasma profiles can be acquired.

We acknowledge the discussions with Dr. M. Sasaki and Prof. M. Yagi. This work was partially supported by a Grant-in-Aid for Specially Promoted Research (16002005) from MEXT, Japan [Itoh project], by a Grant-in-Aid for Scientific Research (19360418) from JSPS, Asada Research Foundation, and by the collaboration programs of RIAM of Kyushu University, and of NIFS (NIFS07KOAP017, NIFS06KDAD005).

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