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Study of Axisymmetric Electrostatic Magnetohydrodynamic Oscillations in Tokamaks with General Cross-sections and Toroidal Flow

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In tokamak plasmas, the Zonal Flow (ZF) and its high frequency counterpart, i.e., the Geodesic Acoustic Mode (GAM), are torodially symmetric oscillations with poloidally varying potential perturbations on the flux surface determined either by the Phirsch-Schluter return flow or the particle magnetic drift. These electrostatic oscillations are linearly stable and nonlinearly driven by microturbulence， and thus plays a crucial role in regulating plasma pressure induced turbulence and the relevant transport [1]. Extensive efforts, including both experimental and theoretical, have been devoted to advance the related physics and provide a basis for utilizing these modes towards the goal of effectively regulating plasma confinement. Recently, there have been a few works on the study of the effect of plasma rotation on these electrostatic modes based both on the MHD [2] and kinetic[3,4] plasma models. The effect of aspect ratio and shaping, such as elongation and triangularity, on these electrostatic modes have also been investigated both experimentally[4] and theoretically[5]. In this work, we report on the recent progress as part of the continued overall effort in achieving this goal.

Starting from the MHD energy principle, the general behavior of the electrostaic modes in a rotating tokamak with arbitrary cross-section is studied.[6] This is a generalization of the work by Wang[2] to arbitrary shaped tokamaks and covers the whole range of the frequency spectrum of these modes. We first prove that these electrostatic modes are stable in all tokamaks and are not destabilized by any toroidal flow. The frequency of the ZF is explicitly obtained over the whole range of flow Mach numbers. The frequencies of the SW and GAM are analytically solved for both the low and high ranges of Mach number. We show that aside from the usual countable infinite set of eigen-modes with discrete eigen-frequencies, a new mode each with a lower frequency appears for both the SW and the GAM. This latter new GAM was first discovered by Wahlberg[7] for the large aspect ratio tokamak, although with a frequency dependence different from our more general finding. The Euler equations based on the energy principle for these electrostatic eigen-modes are obtained and used in the development of a numerical code for the investigation the frequency spectrum of these axi-symmetric electrostatic modes. The frequencies of these modes are then numerically obtained over the whole range of flow Mach numbers.

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