§14. Linear Analysis of the Resistive Drift Wave Instability in Cylindrical Plasmas

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Structural formation mechanisms in magnetically confined plasmas are crucial issues in plasma physics. We have been developing a three-dimensional numerical simulation code called Numerical Linear Device (NLD), which models a cylindrical plasma configuration [1]. The three-field (density, potential and parallel velocity of electrons) reduced fluid model is adopted. Using this code, linear eigenmode analyses are performed to examine the condition for drift wave excitation in LMD in Kyushu University [2]. The result of the parameter scan is reported here.

Simulation parameters are chosen, referring to the typical parameters in LMD with plasma turbulence: an argon discharge with $B < 0.12$ [T], $T_e < 5$ [eV], $a = 50$ [mm], $\lambda = 1.7$ [m], $n_0 = n_e(r = 0) \sim 1\times10^{19}$ [m^{-3}], and neutral pressure $p_0 \sim 3$ [mTorr]. Collision frequency ν_{ei} is given by coulomb collisions. With these parameters, ν_{ei} is larger than ν_{en} given by elastic collisions [3]. One has $\nu_e \sim \nu_{ei} = 400$, which is normalized by Ω_{ci}, and ν_{in} around 0.05 is used as a test parameter. The background density profile n_{bg} is fitted to the form

$$N_{bg} = \ln(n_{bg}/n_0) = N_0\left(\exp\left[-(r/L_N)^2\right]-1\right),$$

where $N_0 = 4$, and gradient length $L_N = 60$ are chosen based on the measurement in experiments.

Using these parameters, a linearly unstable eigenmode is obtained. The contour of the mode shows a weakly twisted shape in the θ direction. This corresponds to the existence of the imaginary part in $\tilde{N}$. Similarly, the contour of $\tilde{\phi}$ shows a twisted shape. The dependency of the eigen frequency and growth rate on the azimuthal mode number m shows that modes with low m are unstable.

There are adjustable parameters, which contribute to excite the drift wave turbulence. Dependencies of the mode growth rate and eigen frequency on the strength of the magnetic field, the device length, and the collision frequency are investigated for the $(m, n) = (1, 1)$ mode to obtain an operation window. Figure 1 shows the dependency of the growth rate and frequency of the $(m, n) = (1, 1)$ mode on the magnetic field in the case with $T_e = 2$ [eV], $a = 5$ [cm], $\nu_{in} = 0.03$, $\nu_e = 400$, $N_0 = 2.0$, $L_N = 50$, $\phi_{bg} = 0$ and $V_{bg} = 0$. The strength of the magnetic field should be sufficiently high to obtain plasma turbulence. On the other hand, if the magnetic field is too strong, then the drift velocity becomes small, which gives a smaller growth rate of an unstable mode. There exists a maximum value of the growth rate as a function of the strength of the magnetic field. A wave with the wave length larger than the device length cannot be excited, so that the device length restricts the value of $k_{//}$. This is also the important factor to excite resistive drift wave. The dependency of the growth rate on the device length shows that the necessary device length exists for resistive drift wave excitation. In this case, $\lambda > 2$ [m] and $B > 0.07$ [T] is necessary for the $(m, n) = (1, 1)$ mode to be unstable.

The collision frequencies play an important role in the excitation of the resistive drift wave. The electron collision destabilizes the drift wave, so that it should be large. Since the ion-neutral collision strongly stabilizes the drift wave, it should be small. The stability boundaries for various strengths of the magnetic field on the $\nu_{in} - \nu_e$ phase space are summarized in Fig. 2. The suitable parameters are $B = 0.1$ [T] and $\lambda = 4$ [m] for which wider unstable regime exists. It is found that on the experimental condition, ν_e has a weak dependence and the threshold of ν_{in} exists for the stability boundary. The smaller values of ν_{in} by reduction of the neutral density or increase of the ionization ratio, or both, are necessary for excitation of the resistive drift waves [4]. It is also desirable to produce a steep density profile.

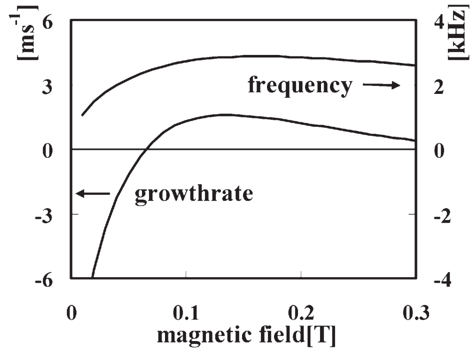

Fig. 1: Growth rate and frequency of linear eigenmodes $(m, n) = (1, 1)$. The dependencies on the strength of the magnetic field B with $\lambda = 4$ [m] are shown.

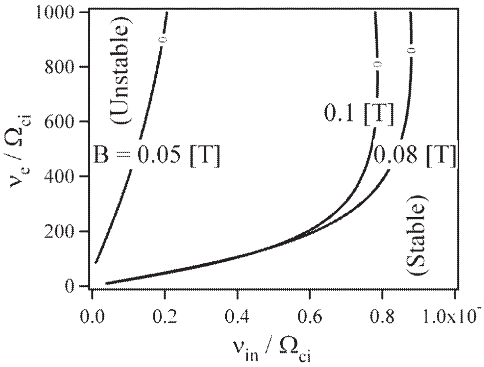

Fig. 2: Stability boundaries of the $(m, n) = (1, 1)$ mode on the $\nu_{in} - \nu_e$ phase space. The boundaries for various strengths of the magnetic field with $\lambda = 4$ [m] are shown.

References
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