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Effect of zonal flow caused by microturbulence on the double tearing mode

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The effect of zonal flow shear on the double tearing mode is investigated by solving the linear reduced two-fluid equations for the equilibrium including zonal flow. The zonal flow caused by microturbulence is obtained from nonlinear simulation results presented by A. Ishizawa and N. Nakajima [Phys. Plasmas **14**, 040702 (2007)]. There is no clear evidence that could indicate whether the double tearing mode is stabilized or destabilized by the zonal flow. © 2008 American Institute of Physics. [DOI: 10.1063/1.2969439]

In our recent paper, we suggested a stabilizing effect of zonal flow on the macro-magnetohydrodynamic mode (macro-MHD mode) in a quasisteady equilibrium including microturbulence.¹ This is because we observed that zonal flow shear is strong between two resonant surfaces of $q=2$ before the appearance of the macro-MHD mode (double tearing mode), and the flow shear becomes smaller after the appearance of the macro-MHD mode in Fig. 6(b) of Ref. 1. However, linear stability analysis shows that the stabilizing effect is not clear. We report this analysis in this Brief Communication.

In order to clarify the effect of zonal flow on the double tearing mode, we numerically solve the linearized version of nonlinear two-fluid equations in Ref. 1, and we evaluate the linear growth rate of the double tearing mode for the equilibrium including zonal flow. We remark that the calculation does not include turbulence at all. We linearize the reduced two-fluid equations in Ref. 1 by decomposing the quantity f into an equilibrium part f_{eq} and a fluctuating part $\tilde{f}$ as $f = f_{\text{eq}} + \tilde{f}/\tilde{a}$, where $\tilde{a} = a/\rho_i$ is the ratio of minor radius to the ion Larmor radius. Neglecting the square of $\tilde{f}$ gives a set of linearized equations. For instance, the linearized parallel component of the ion velocity equation is

$$\begin{aligned} n_{\text{eq}} \frac{\partial \tilde{v}_{\parallel}}{\partial t} = & -n_{\text{eq}} \tilde{\Phi}'_{0,0} i k_{\theta} \tilde{v}_{\parallel} - i \epsilon k_{\parallel} \tilde{p}_e - \beta \tilde{a} P'_{\text{eq}} i k_{\theta} \tilde{\psi} \\ & + \beta \tilde{\psi}'_{0,0} i k_{\theta} \tilde{p}_e - i \epsilon k_{\parallel} \tilde{p}_i - \beta \tilde{a} P'_{\text{ieq}} i k_{\theta} \tilde{\psi} + \beta \tilde{\psi}'_{0,0} i k_{\theta} \tilde{p}_i \\ & - \mu_v k^2 \tilde{v}_{\parallel}, \end{aligned} \quad (1)$$

where $f' \equiv df/dr$, $k_{\theta} \equiv m/r$, $k_{\parallel} \equiv m/q - n$, $P_{\text{eq}} = \pi n_{\text{eq}} T_{\text{eq}}$, $P_{\text{ieq}} = n_{\text{eq}} T_{\text{eq}}$, $\tilde{p}_e = \tau T_{\text{eq}} \tilde{n}$, and $\tilde{p}_i = T_{\text{eq}} \tilde{n} + n_{\text{eq}} \tilde{T}_i$. The equilibrium q profile, density profile, and temperature profile are $q = 1.05 + 2(r/a)^2 + 1/(3r/a + 0.01)^4$, $n_{\text{eq}} = 0.8 + 0.2 \exp(-2(r/a)^2)$, and $T_{\text{eq}} = 0.55 + 0.45(1 - (r/a)^2)^2$, respectively. Other quantities are described in Ref. 1. In the equations, we retain the zonal flow term $\tilde{\Phi}'_{0,0} i k_{\theta} \tilde{v}_{\parallel}$ and the zonal magnetic field term $\tilde{\psi}'_{0,0} i k_{\theta} \tilde{f}$. The first term on the right-hand side of Eq. (1) represents the effect of zonal flow. We numerically solve the linearized equations for the equilibrium including zonal flow at each time $t=t_0$ of nonlinear simulation in Ref. 1 and obtain an

exponential growth of $(m,n)=(2,1)$ mode, which is the double tearing mode. The zonal flow and zonal magnetic field at time $t=t_0$ are obtained by taking the average of their numerical data in Ref. 1 over a time period from t_0-4 to t_0+4 as

$$\tilde{\Phi}_{0,0} \equiv \frac{1}{2T} \int_{t_0-T}^{t_0+T} \tilde{\Phi}(m=0, n=0) dt \quad (2)$$

and

$$\tilde{\psi}_{0,0} \equiv \frac{1}{2T} \int_{t_0-T}^{t_0+T} \tilde{\psi}(m=0, n=0) dt, \quad (3)$$

where $T=4$ and time is normalized by a/v_{ti} . This average over period $2T$ is performed in order to reduce the effect of temporal fluctuation of $\tilde{\Phi}_{0,0}$ and $\tilde{\psi}_{0,0}$. We remark that each linear calculation at time $t=t_0$ is independent.

Figure 1 shows the linear growth rate of the double tearing mode obtained by solving the linearized equations for the equilibrium including zonal flow at each time $t=t_0$. The

FIG. 1. Linear growth rate of the macro-MHD mode (double tearing mode) obtained by solving the linear reduced two-fluid equations for the equilibrium including zonal flow at each time $t=t_0$ in the numerical simulation presented in Ref. 1. The dotted line indicates the linear growth rate of the double tearing mode for the initial equilibrium that does not have any zonal flow.

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dotted line indicates the linear growth rate of the double tearing mode for the equilibrium that does not have any zonal flow. The linear growth rate begins to decrease around $t_0=50$ and it remains smaller than the initial growth rate until around $t_0=100$. After $t_0=100$, the growth rate is similar to that of initial equilibrium or larger than it. The quasisteady equilibrium continues until around $t_0=150$ and the macro-MHD mode grows around $t_0=150$ in Ref. 1. Hence, at present, there is no clear evidence that could indicate whether the double tearing mode is stabilized or destabilized by zonal flow in quasisteady equilibrium (stage 2). However,

in the particular case studied here, fluctuations of the double tearing mode growth rate of up to 50% are observed.

The analysis of the present case has not revealed any evidence that the suppression of zonal flow shear is correlated with the destabilization of the macro-MHD mode. The growth of the macro-MHD mode can include some nonlinear interaction with the turbulence, and thus the mechanism is complicated. In order to understand the mechanism, we need further work on the interaction between microturbulence and the macro-MHD mode.

¹A. Ishizawa and N. Nakajima, [Phys. Plasmas](#) **14**, 040702 (2007).