Impact of the toroidal rotation on the *n* dependence of the growth rate of the edge localized MHD modes

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Introduction

In tokamak plasmas, the H-mode plasma that has an edge transport barrier, called a pedestal, is favorable to reach burning plasma conditions. In such H-mode plasmas, an edge localized mode (ELM) usually occurs, and constrains the maximum pressure gradient in the pedestal[1]. Particularly, to diminish the heat load on the divertor and the fast wall of the reactor, the so-called type-I or giant ELMs need to be suppressed or their amplitudes need to be reduced.

The recent experimental results in JT-60U show that the plasma toroidal rotation near the pedestal has an impact on the ELM phenomena[2, 3]. However, this dependence of the ELM property on the toroidal rotation is complicated to understand only by the experimental approach. Fortunately, as discussed in Ref.[4] and many papers, the ideal MHD stability analysis can capture the properties of type-I ELMs and to comprehend the dependence between the ELM phenomena and the plasma rotation, it is necessary to understand the physics with theoretical and numerical analyses. From this viewpoint, we reported that the sheared toroidal rotation can destabilize the edge localized MHD mode[5], and this destabilization comes from the difference between the plasma rotation frequency and the unstable mode frequency[6]. However, as discussed in Ref.[7], the sheared toroidal rotation can stabilize the MHD mode by increasing the rotation shear and the toroidal mode number *n* of the mode To develop ELM control methods with the plasma rotation, it would be helpful to understand the dependence between the rotation and the MHD stability and the mechanism that changes the role of the rotation.

In this paper, we investigate numerically the toroidal rotation effect on the ideal MHD stability of edge localized MHD modes with the MINERVA code[7]. This code solves the Frieman-Rotenberg (F-R) equation [8] as not only the eigenvalue problem but also the initial value problem. To understand clearly the physics about the role of the toroidal rotation on the MHD stability, we pay attention to the *n* dependence of the stability of the edge ballooning mode.

Dependence of the growth rate on *n* including the sheared toroidal rotation effect

We investigate the effect of the sheared rotation profile on the stability of a finite-*n* edge ballooning mode; the range of the toroidal mode number *n* of the MHD mode analyzed numerically is from 1 to 150, and the fixed boundary condition is assumed. The plasma current I_p and

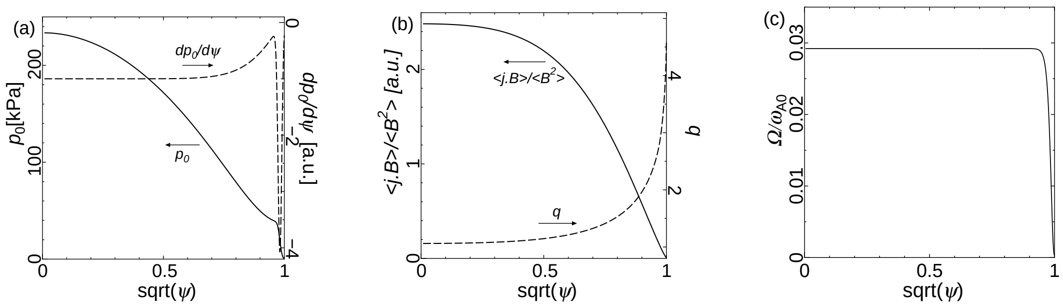

Figure 1: Profiles of (a) p_0, $dp_0/d\psi$, (b) $\langle j\cdot B\rangle/\langle B^2\rangle$, q and (c) Ω of the equilibrium.

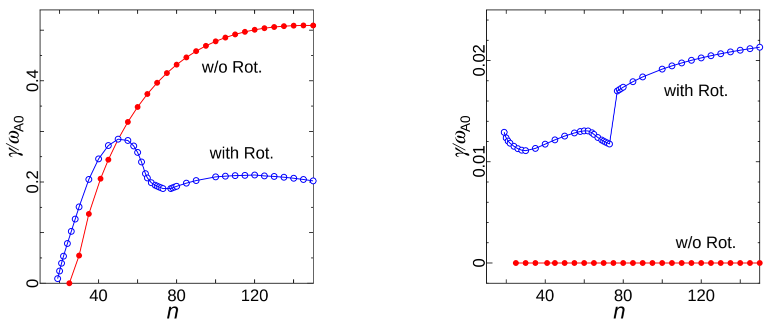

Figure 2: Dependence of (a) the growth rate γ and (b) the frequency ω of the edge ballooning modes on n.

the poloidal beta value β_p are given as $(I_p[\mathrm{MA}],\ \beta_p) = (3.0, 1.0)$, and the profiles of $dp_0/d\psi$, $\langle j\cdot B\rangle/\langle B^2\rangle$ and the toroidal rotation are determined as

$$\frac{dp_0(\psi)}{d\psi} = \beta_p\left(\left(1.0-\psi^{5.0}\right)^{1.5}+4.0\cdot\exp\left(-\frac{(\psi-0.96)^2}{2.25\times10^{-4}}\right)\right), \quad (1)$$

$$\frac{\langle j\cdot B\rangle}{\langle B^2\rangle} \propto \left(1.0-\psi^{1.5}\right)^{1.2}. \quad (2)$$

$$\Omega(\psi)[\mathrm{krad/s}] = (50.0-0.5)\left(1.0-\psi^{48}\right)^4+0.5. \quad (3)$$

The profiles of p_0, $dp_0/d\psi$, $\langle j\cdot B\rangle/\langle B^2\rangle$, q and Ω are shown in Fig.1.

Figure 2 shows the n dependence of (a) the growth rate γ and (b) the frequency ω of the edge ballooning modes; the rotation frequency normalized with the toroidal Alfvén frequency at the axis is $\Omega_A/\omega_{A0} = 2.92\times10^{-2}$. This stability analysis is performed as the initial value problem, and the growth rate is estimated as the gradient of $\ln(|\xi_r|^2)$ after convergence, where ξ_r is the radial component of the displacement ξ. As shown in this figure, by adding the sheared toroidal rotation, the growth rates of the $n \le 43$ modes increases but those of the $n > 43$ modes becomes smaller than those in the static equilibrium. Furthermore, near $n = 75$, the n dependence of γ with the toroidal rotation has local minimum, and that of the frequency ω has a gap; ω/ω_{A0} is about 0.012 when $n \le 75$ but is about 0.018 when $n > 75$.

Note that near $n = 75$, the time evolution of $\ln(|\xi_r|^2)$ does not converge well about $500\tau_{A0}$

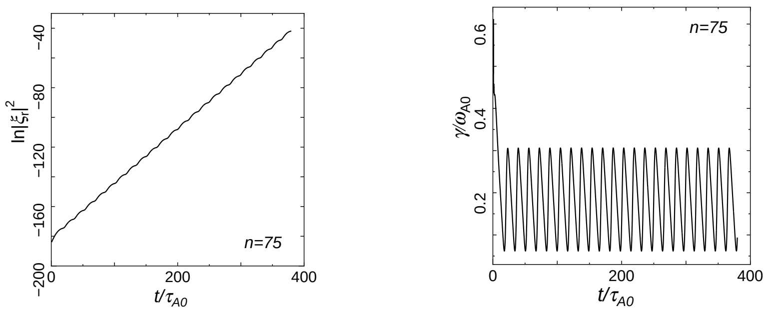

Figure 3: Time evolution of (a) $\ln(|\xi_r|^2)$ and (b) γ of the $n = 75$ mode.

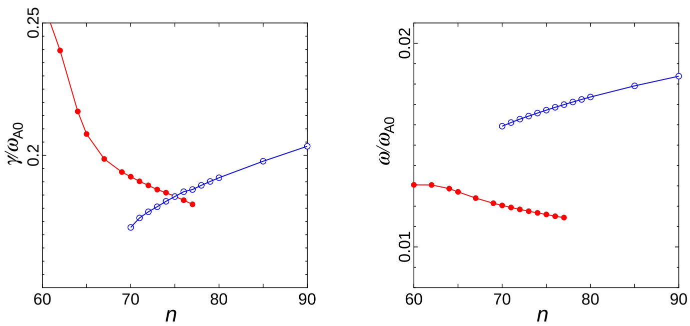

Figure 4: Dependence of (a) γ and (b) ω of the most unstable and secondary unstable mode on n near $n = 75$.

later, though that of other modes, whose γ/ω_{A0} is about 0.2, converge about $100\tau_{A0}$ later; such an phenomenon is never observed in the static equilibrium. For example, Fig.3 shows the time evolution of (a) $\ln(|\xi_r|^2)$ and (b) γ of the $n = 75$ mode. As shown in this figure, $\ln(|\xi_r|^2)$ no longer grows linearly, and as the result, γ oscillates with the frequency $\sim 0.06\omega_{A0}$.

To investigate the reason of such a non-exponential growth, we analyze the MHD stability by solving the eigenvalue problem. Figure 4 shows the n dependence of (a) γ and (b) ω of the most unstable and the secondary unstable modes around $n = 75$. As shown in this figure, there are two eigenmodes whose γ are similar to each other, but the frequencies of these modes are different from each other. Particularly, at $n = 75$, γ/ω_{A0} is almost identical to each other as $\simeq 0.184$, but one of $\omega_1/\omega_{A0} \simeq 1.15 \times 10^{-2}$ is different from the other $\omega_2/\omega_{A0} \simeq 1.65 \times 10^{-2}$. In this case, the time evolution of γ will oscillate around $\gamma \simeq 0.184$ with the frequency $n(\omega_2 - \omega_1)/2\pi \simeq 0.06$ as the beat frequency between two eigenmodes; this result is consistent with that shown in Fig.3. Note that these two eigenmodes are no longer orthogonal to each other, unlike in the static case.

Figure 5 shows the mode structure of (a) the eigenfunction whose $\omega = \omega_1$ and (b) that whose $\omega = \omega_2$; these are named as mode (1) and mode(2), respectively. As shown in this figure, the peak of the envelope of $\mathrm{Re}(\xi_r)$ of mode (1) is near $nq = 185$ ($\rho_{vol.} \simeq 0.974$), and this is closer to the plasma surface than that of mode (2) $nq = 176$ ($\rho_{vol.} \simeq 0.968$). This difference of the

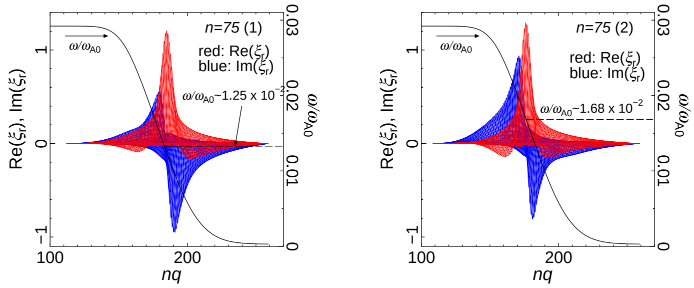

Figure 5: Mode structure of (a) the eigenfunction whose $\omega = \omega_1 = 1.15 \times 10^{-2}\omega_{A0}$, (b) that whose $\omega = \omega_2 = 1.65 \times 10^{-2}\omega_{A0}$, and the plasma rotation frequency.

peak position of the envelope can change the mode frequency[6], because the plasma rotation frequency decreases toward the plasma surface; in fact, the rotation frequency at $\rho_{vol.} \simeq 0.974$ ($\simeq 1.25 \times 10^{-2}\omega_{A0}$) is smaller than that at $\rho_{vol.} \simeq 0.968$ ($\simeq 1.68 \times 10^{-2}\omega_{A0}$).

Summary

In this paper, we investigate the dependence of the stability of the edge localized MHD mode on the toroidal mode number n with the MINERVA code. Unlike in the static case, the sheared toroidal rotation can induce the non-exponential growth of the MHD instability, and the growth rate oscillates in time. This oscillation is excited by the beat between two unstable eigenmodes whose growth rates are almost identical to but frequencies are different from each other. Due to the declination of the plasma rotation frequency at the peak of the envelope of the eigenmode structure, the frequencies of the eigenmodes become different from each other. The reason that makes such a difference of the peak position of the envelope is still under discussion, but this will come from the difference between the position where the ballooning mode can have the largest growth rate and that where the rotation can change the MHD stability effectively. This will be investigated and will be reported in near future.

References

[1] E. J. Doyle et al., Nucl. Fusion **47**, S18 (2007).

[2] N. Oyama et al., Plasma Phys. Control. Fusion **49**, 249 (2007).

[3] H. Urano et al., Nucl. Fusion **47**, 706 (2007).

[4] P. B. Snyder et al., Phys. Plasmas **9**, 2037 (2002).

[5] N. Aiba et al., Nucl. Fusion **49**, 065015 (2009).

[6] N. Aiba, M. Furukawa, M. Hirota, and S. Tokuda, Nucl. Fusion **50**, 045002 (2010).

[7] N. Aiba et al., Comput. Phys. Commun. **180**, 1282 (2009).

[8] E. Frieman and M. Rotenberg, Rev. Mod. Phys. **32**, 898 (1960).