Velocity Shear Stabilization of Double Tearing Mode

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Abstract. Linear and nonlinear stability for double tearing mode with poloidal rotation are examined. Weak differential rotation between the each mode rational surfaces can't affect on linear growth rate but it can prevents core crash. Larger differential rotation suppress the double tearing mode in some case.

1. introduction

It is important to improve the MHD stability for the enhancement of plasma performance of tokamak reactor. A strongly negative magnetic shear configuration with a large bootstrap current [1] is considered to be one of the promising configuration to realize it. Recently reversed shear configuration with internal transport barrier shows very high performance confinement[2]. However, this configuration sometimes terminated by MHD events even at a low beta value sufficiently below the MHD beta limit and it is an agent task to clarify the mechanism of the operation limit and to develop the methods to sustain the high performance configuration for a long time.

The double-tearing mode is induced due to the current density gradient near the resonant surfaces and is enhanced when the positions of two rational surfaces become close each other[3]. Typically, when a double tearing mode is destabilized, two chains of magnetic island grow in the initial phase. the growth rate doesn't change much from the initial phase until each islands width growth to the size comparable to the distance between the rational surfaces. It scales on resistivity as $\eta^{1/3}$ for a moderate distance between two rational surfaces. In this case there is no slowly growing phase, so called Rutherford region scales as η^1, which is observed for usual tearing mode with single resonant surfaces. In the final stage, current sheets are formed between outer islands and core plasma and between inner islands and outer plasma and merging between them occur. The safety factor profile/current profile is completely flattened from outer resonant surface to inner resonant surfaces and, in some cases, the crash extends to the magnetic axis and the reversed shear configuration is destroyed[4].

We attempted in this paper, to analyze the effects of plasma rotation on the fast growing double tearing mode ($\gamma \sim \eta^{1/3}$) in a cylindrical geometry and show that in some case, for sufficiently large rotation velocity difference between the mode rational surfaces, the merging process is prevented and the island growth is slowed down to transport time scale, resistive skin time or viscous damping time.

2. model

As for the example, we employ the equilibrium q-profile (q:safety factor)

$$q(r) = 1.04[1 + (\frac{r}{0.412})^2][1 + 3\,\mathrm{exp}(-(\frac{r}{0.273})^2] \quad for \quad 0 \le r \le 1.$$

This q-profile has two resonant surfaces at r_{s1}=0.3 and r_{s2}=0.54 and is unstable for m=3/n=1 double tearing mode. To apply differential rotation,

$RFD \equiv m\mathrm{v}_{p0}(r_{s2})/r_{s2} - m\mathrm{v}_{p0}(r_{s1})r_{s1}$, m : a poloidal mode number.

We set initial poloidal rotation as

$$\mathrm{v}_{p0} \propto r\left\{1-\exp-\left(\frac{r-0.56}{0.21}\right)^2\right\} \quad \text{for} \quad r \le 0.56$$

$$= 0 \qquad\qquad \text{for} \quad 0.56 < r \le 0$$

and figure 1 shows equilibrium safety factor and initial velocity profile.
The linear growth rate and the real part of the mode frequency given by eigen value code are shown in figure 2. *RFD* dose not influence on the linear growth rate of double tearing mode for *RFD*< 0.3 and almost stabilizes for *RFD*>0.4.

We perform numerical simulations based on the nonlinear reduced MHD equations for the stream function Φ and the flux function Ψ with resistivity η and viscosity ν in cylindrical geometry[5]. Basic equations are

$$\frac{\partial \Psi}{\partial t} = \{\Psi,\Phi\} + \frac{B_0}{R_0}\frac{\partial \Phi}{\partial \varphi} + \eta J - E^w,$$

$$\frac{\partial U}{\partial t} = \{U,\Phi\} + \{J,\Psi\} + \frac{B_0}{R_0}\frac{\partial J}{\partial \varphi} + \nu \Delta_\perp^* U,$$

where

$$U = \Delta_\perp^* \Phi, \quad J = \Delta_\perp^* \Psi, \quad \mathbf{v} = \mathbf{z} \times \nabla_\perp \Phi \quad \textit{and} \quad \mathbf{B} = \mathbf{z} \times \nabla_\perp \Psi + B_0 \mathbf{z}$$

here

$$\Delta_\perp^* = \frac{\partial^2}{\partial r^2} + \frac{1}{r}\frac{\partial}{\partial r} + \frac{1}{r^2}\frac{\partial}{\partial \theta^2} \quad \textit{and} \quad \{a,b\} = \frac{1}{r}\left(\frac{\partial a}{\partial r}\frac{\partial b}{\partial \theta} - \frac{\partial a}{\partial \theta}\frac{\partial b}{\partial r}\right)$$

Without poloidal rotation, an m=3/n=1 double tearing mode is unstable for a given safety factor profile and figure 3 shows a simulation result for $\eta=10^{-4}$, where a crash event occurs and after reconnection event, a current profile is flattened to the axis (core crash). For slow poloidal rotation, *RHS* ~ 0.1, the linear growing phase doesn't change. However, final crash phase are influenced by the poloidal rotation and current flattening doesn't extend to the axis and a crash event is limited to annular one in this equilibrium q-profile. Under a moderate poloidal rotation of the plasma column, *RHS* ~ 0.33, the reconnection process doesn't complete and one rotating island chain on the outer resonant surface remains as shown in figure 4.

If we further increase the rotation velocity difference, we can suppress the growth of the double tearing mode as shown in figure 5. However, the velocity shear itself feeds a free energy for instability[6] and another type of inertial instability is driven by velocity shear for larger velocity shear, *RFD*>0.6. Such a velocity shear driven mode has larger amounts of the kinetic energy than the magnetic energy and induce a large momentum transfer. They saturated in smaller magnetic fluctuation level and dose not induce reconnection/current flattening.

3. discussion and conclusion

It is assumed that the growth of island is in a slow resistive time scale(the Rutherford region) and the costs of the control are reasonable in usual control systems for tearing modes, a local heating/current drive or external feedback coil systems, are However, as the initial growth of the double tearing mode and the subsequent reconnection process proceeds in faster time scale, the direct applicability of these control system for double tearing modes becomes doubtful. However, when the velocity difference exceeds some critical value, the difference of Doppler shifted frequencies becomes to the value much larger than the linear growth rate of the double taring mode, the speed of island growth reduces to slower time scale. In such a case, the profile modification due to transport processes may change the equilibrium profile to stable one before the island width grows to the size which induce the crash or even stay to unstable profile the above control systems works effectively for stabilization of the double taring mode.

References

[1]T. Ozeki et al., in *Plasma Physics and Controlled Nuclear Fusion Research, Wurzburg, 1992* (IAEA,Vienna,1993), Vol.2, p. 187.
[2] S. Ishida et al.,Phys. Rev. Let. **79** 3917 (1997).
[3] P.L. Pritchett, Y.C. Lee and J.F. Drake, Phys. Fluids **23** 1368 (1980).
[4] B. Carreras, H.R. Hicks and B.V. Waddell, Nuclear Fusion **19** 583 (1979).
[5] G. Kurita, T. Tuda, M. Azumi, T. Takizuka and T. Takeda, Nuclear Fusion **34** 1497 (1994).
[6] A. Bondeson and M. Persson, Phys. Fluids **29** 2997 (1986).

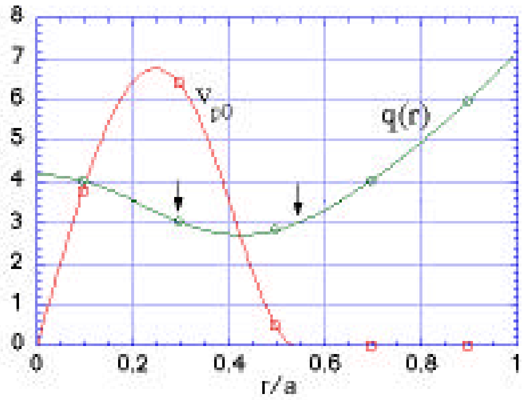

Figure 1. The equilibrium safety factor profile and poloidal velocity profile. Two vertical arrows indicate the position of two resonant surfaces.

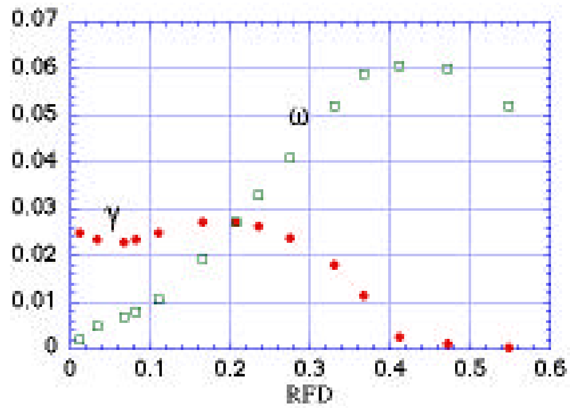

Figure 2. Linear growth rate and the real part of eigen value versus the frequency difference for m=3 mode between two resonant surfaces.

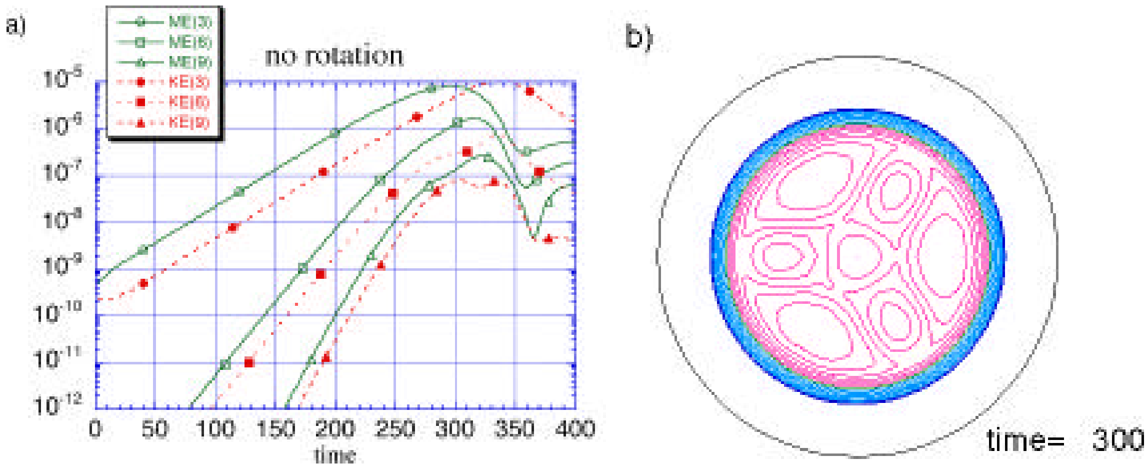

Figure 3. a) Time evolution of the Fourier components of magnetic and kinetic energy for no rotation case and b) flux conture for t/τ_A=300. $\eta=\nu=10^{-4}$ and linear growth rate is $0.025/\tau_A$.

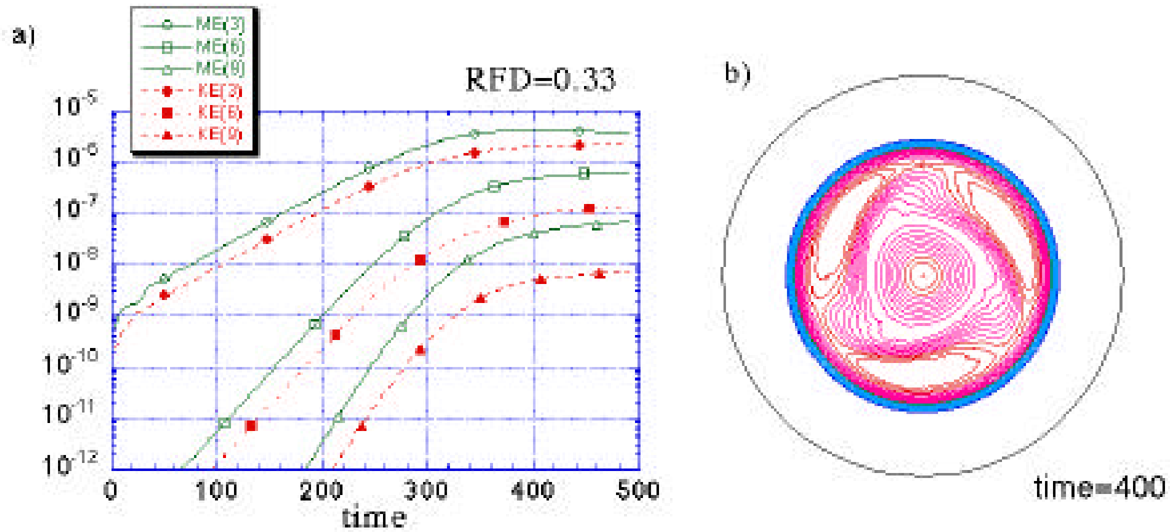

Figure 4. a) Time evolution of the Fourier components of magnetic and kinetic energy and b) flux contour for t/t_A=400. Doppler shifted rotation frequency at each rational surfaces differ by $0.33/\tau_A$. $\eta=\nu=10^{-4}$

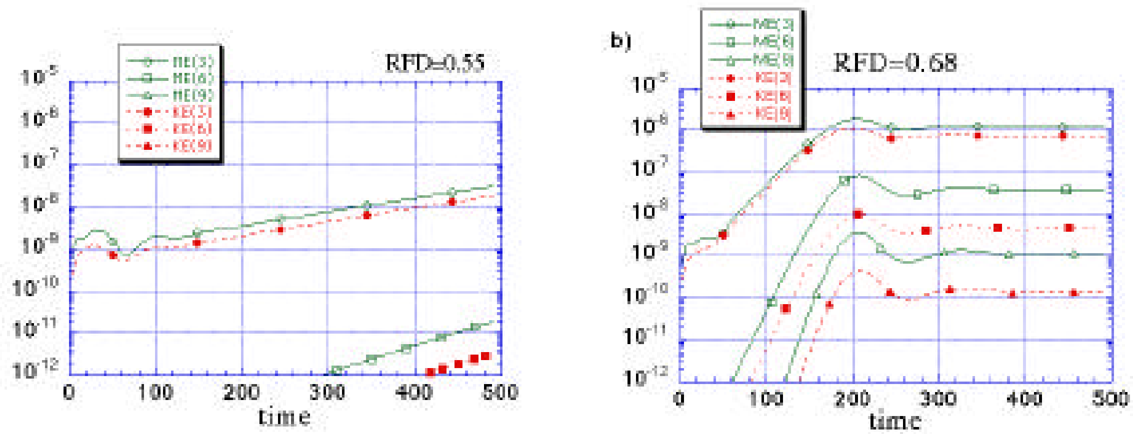

Figure 5. Time evolution of the Fourier components of magnetic and kinetic energy Doppler shifted rotation frequency at each rational surfaces differ by a) $0.55/\tau_A$ and b)$068/\tau_A$. $\eta=\nu=10^{-4}$.