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Effect of Aspect Ratio on the Stability of Tokamak Edge MHD Modes

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Introduction

For an accurate prediction of the ITER H-mode pedestal parameters, comparisons between the experimental results in existing devices are important [1]. Theoretical understanding about the dependence of the aspect ratio on the pedestal parameters can help to analyze experimental results of devices with different aspect ratios and predict the performance in ITER. In particular, since the heat load on the divertor plate due to Type-I ELMs, caused by the ideal magnetohydrodynamic (MHD) modes in the tokamak edge region [2], is a big issue, the dependence of the edge MHD stability on the aspect ratio is important. In previous works, Menard et al. discussed the effect of the aspect ratio on the low-*n* and infinite-*n* MHD mode stabilities[3], where *n* is the toroidal mode number, and Snyder et al. showed the dependence of the pedestal pressure limit on the aspect ratio in the different triangularity equilibria briefly[4].

In this paper, we numerically investigate the effect of the aspect ratio on the stability of edge MHD modes in different shape equilibria by the MARG2D code[5, 6]. Since the edge pedestal pressure limit is affected by the accessibility to the second stable region of ballooning mode, we will analyze the aspect ratio effect from the viewpoint of the change of the accessibility to the second stable region.

Effect of the Aspect Ratio on the Stability of Edge MHD Modes

To investigate the effect of the aspect ratio on the stability of edge MHD modes, we analyze the stability of the equilibria whose shape of the cross-section is (a) the ITER-like cross-section and (b) the quasi-double null (QDN) one as shown in Fig.1, which are to be realized in JT-60SA plasma. The ellipticity κ and the triangularity δ of these equilibria are $\kappa_{up} = 1.66$, $\kappa_{dw} = 1.95$, $\delta_{up} = 0.35$, $\delta_{dw} = 0.54$ in the ITER-like shape equilibrium, and $\kappa_{up} = 1.94$, $\kappa_{dw} = 1.95$, $\delta_{up} = 0.59$, $\delta_{dw} = 0.53$ in the QDN shape equilibrium, where the subscript up (dw) expresses the upside (downside) value. The stability of ideal MHD modes whose toroidal mode number *n* is from 1 to 60 is analyzed by the MARG2D code, and the infinite-*n* ballooning mode stability is also analyzed by the BETA code[7]. Profiles of the pressure gradient and the averaged parallel current density, shown in Fig.2, are given as

$$\frac{dp}{d\psi} \propto (1-\psi_N^3)^{1.2} + C_p \cdot \exp\left(-\frac{(\psi_N - 0.94)^2}{2\times(0.03)^2}\right), \tag{1}$$

$$\langle j \cdot B \rangle \propto (1 - \psi_N^{2.4}) + C_j \cdot \exp\left(- \frac{(\psi_N - 0.94)^2}{2 \times (0.03)^2} \right). \quad (2)$$

Here ψ is the poloidal magnetic flux, ψ_N is the poloidal flux normalized as $\psi_N = 0$ at the magnetic axis and $\psi_N = 1$ at the plasma surface, j is the plasma current density, B is the magnetic field, and the bracket $\langle X \rangle$ expresses the flux surface average of a variable X. The pressure gradient and the current density near $\psi_N = 0.94$ are changed by adjusting the parameters C_p and C_j, which are used to simulate the edge pedestal and the bootstrap current. The pressure p and the safety factor q profiles when $C_p = 2.0$ and $C_j = 0.5$ are also shown in Fig.2. The β_N values and I_p values are fixed as $\beta_N \simeq 2.2$, $I_p = 2.6$[MA] (ITER-like), and $\beta_N \simeq 3.1$, $I_p = 5.5$ (QDN), respectively. Note that since the parallel current density profiles are fixed as Eq.(2) and the toroidal magnetic fields are adjusted to fix the edge safety factor $q_{edge} \simeq 5.5$ when $C_p = 2.0$ and $C_j = 0.5$, the q profiles are different in each A equilibrium as shown in Figs.2 (b) and (d).

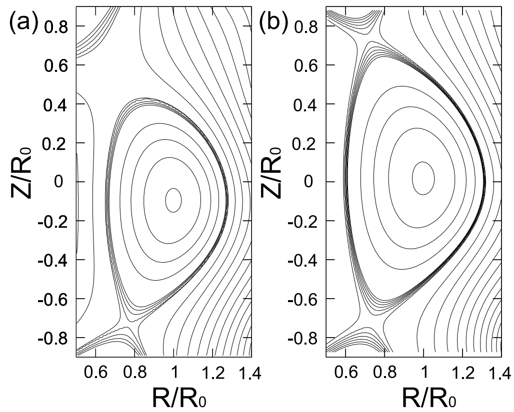

Figure 1: Contours of the poloidal flux (magnetic surfaces) of (a) the ITER-like shape equilibrium and (b) the quasi-double null (QDN) one.

Figure 3 shows the stability diagram of the ITER-like shape equilibrium on (a) the (s, α) plane and (b) the $(j_{//edge}/\langle\langle j \cdot B \rangle\rangle, \alpha)$ plane. Here s is the magnetic shear defined as $s = r(dq/dr)/q$, α is the normalized pressure gradient defined as $\alpha = -2\mu_0 R q^2 (dp/dr)/B^2$, μ_0 is the permeability in the vacuum, r is the minor radius of each magnetic surface, the subscript 94 means the value at $\psi_N = 0.94$, $j_{//edge}$ is the $\langle j \cdot B \rangle$ value at the plasma edge, and $\langle\langle X \rangle\rangle$ is the area average value of X. These results show that the maximum α value α_{max}, restricted by the peeling-ballooning mode stability, increases as the aspect ratio decreases. On the other hand, the

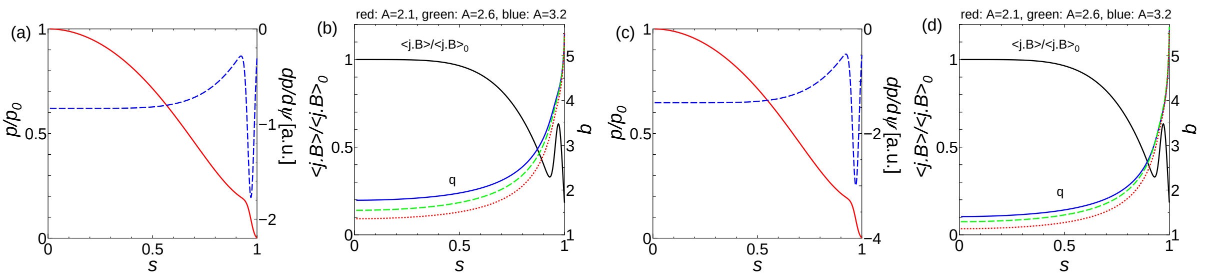

Figure 2: Profiles of the pressure p, pressure gradient $dp/d\psi$, parallel current $\langle j \cdot B \rangle$, and safety factor q in the ITER-like shape equilibrium ((a), (b)) and QDN shape one ((c), (d)).

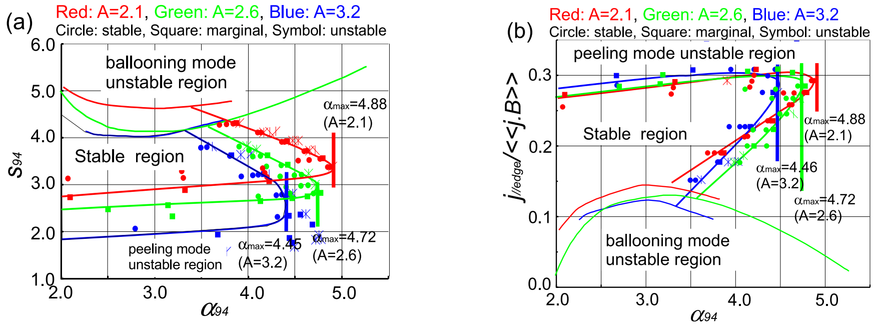

Figure 3: Stability diagram of the ITER-like shape equilibrium on (a) the (s,α) plane and (b) the $(j_{//edge}/\langle\langle j\cdot B\rangle\rangle,\alpha)$ plane at $\psi = 0.94$ surface. The maximum pressure gradient α_{max} increases as the aspect ratio decreases.

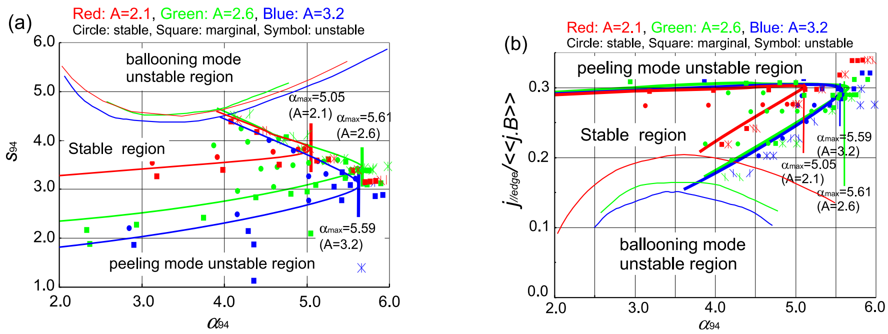

Figure 4: Stability diagram of the QDN shape equilibrium on (a) the (s,α) plane and (b) the $(j_{//edge}/\langle\langle j\cdot B\rangle\rangle,\alpha)$ plane at $\psi = 0.94$ surface. The dependence of α_{max} on A has a local maximal value between $A = 2.1$ and 3.2.

dependence of α_{max} on A in the QDN shape case has a local maximal value between $A = 2.1$ and 3.2 as shown in Fig.4.

Discussion

To investigate the reason why α_{max} decreases in the $A = 2.1$ QDN equilibrium case, we pay attention to the stability near the plasma surface, not at the maximum pressure gradient surface. Figure 5 shows the $j_{//edge}/\langle\langle j\cdot B\rangle\rangle - \alpha$ diagram at $\psi = 0.97$ of (a) the ITER-like shape equilibrium and (b) the QDN shape equilibrium. These results imply that the edge current density of the ballooning mode stability boundary approaches to that of the peeling mode stability boundary as A decreases. In particular, in the QDN shape case, these stability boundary values of $j_{//edge}/\langle\langle j\cdot B\rangle\rangle$ when $A = 2.1$ are close to each other more than those when $A = 2.6$ and 3.2, and the stable region in the stability diagram shrinks. On the other hand, in the ITER-like shape case, the difference between the areas of the stable region in each A equilibrium is less than that