§4. Stability Analysis of Non-Resonant Pressure Driven Mode in Heliotron Plasma

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In the LHD configuration with the vacuum magnetic axis located at 3.6m (R_{ax}=3.6m), sawtooth-like oscillations were observed with the soft X-ray camera system in fairly high density plasmas produced by pellet injection, although the effect of the MHD activity on the global confinement was small[1)]. The instability is localized around the magnetic axis and has an $m = 3$ mode structure. For this vacuum magnetic configuration, there is no magnetic surface with $\iota = 1/3$. Therefore, there is a possibility that the mode observed experimentally is a non-resonant mode. Therefore, we numerically study the linear stability properties of such a non-resonant mode. We utilize the VMEC code to calculate the three-dimensional equilibrium under the constraints of the free boundary and the no net-current. We utilize the NORM code[2)] for the linear stability analysis.

The unstable ideal non-resonant mode is obtained only for a steep pressure profile. Figure 1 shows the growth rate of the $n = 1$ ideal modes for the pressure profile given by

$$P(\rho) = P_0 \begin{cases} (1 - a\rho^2) & \text{for} \quad 0 \le \rho \le \rho_f \\ b(1-\rho)(1-\rho^8) & \text{for} \quad \rho_f \le \rho \le 1 \end{cases} \qquad (1)$$

with $\rho_f = 0.1$. Here, ρ denotes a square-root of the normalized toroidal flux. The factors of a and b are determined so that the value and the first derivative of P are continuous at $\rho = \rho_f$. The growth rate for the profiles of eq.(1) with $\rho_f = 0.2$ and $P = P_0(1-\rho)(1-\rho^8)$ is also plotted as reference. A non-resonant $(m, n) = (3, 1)$ mode is unstable only in the range of $0.3\% \lesssim \langle\beta\rangle \lesssim 0.8\%$ for the pressure profile of eq.(1) with $\rho_f = 0.1$. In other cases, the $(m, n) = (2, 1)$ mode can be unstable. The non-resonant mode is also stable for the $P = P_0(1-\rho^2)^2$ and $P = P_0(1-\rho^2)^3$ profiles. The comparison of these pressure profile indicates that a large pressure gradient around the magnetic axis is necessary for the destabilization of the mode.

In order to investigate the equilibrium properties when the non-resonant mode is destabilized, we examine the beta dependence of the rotational transform for eq.(1) with $\rho_f = 0.1$. As shown in Fig.2, the rotational transform at the axis decreases and approaches to 1/3 for $\langle\beta\rangle \le 0.6\%$, and then increases as the beta value increases. Simultaneously, the magnetic shear is reduced in the region of $\rho \lesssim 0.2$ for $0.3\% \lesssim \langle\beta\rangle \lesssim 0.6\%$. Consequently, the non-resonant mode can be destabilized when the pressure profile is steep, the rotational transform is close to the rational number of the mode and the magnetic shear is weak around the axis. These features are similar to those of the infernal mode.

The non-resonant mode structure is quite different from that of the interchange mode. All components of the eigenfunction are localized around the magnetic axis. The sidebands of the mode are fairly large and the mode structure is similar to that of the ballooning mode. However, the contour of the perturbed pressure shows a clear $m = 3$ structure, as shown in Fig.6. This structure is consistent with the soft X-ray image shown in Ref.1).

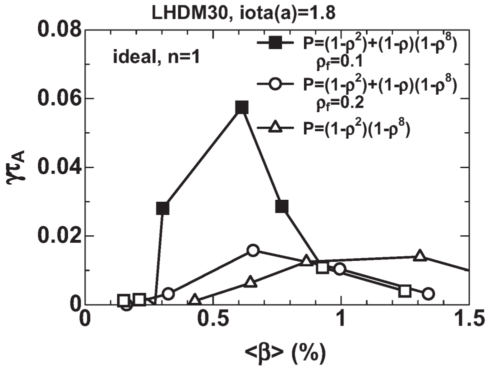

Fig.1 Growth rates of $n = 1$ modes. Closed and open symbols denote (3,1) and (2,1) modes, respectively.

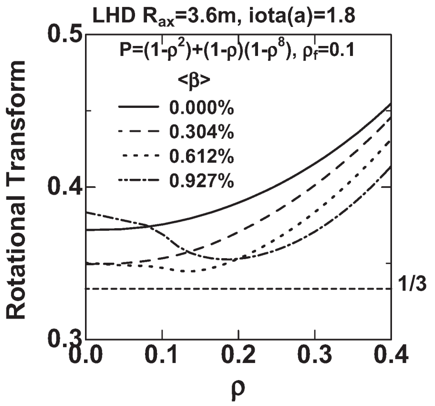

Fig.2 Rotational transform around the axis.

1) Ohdachi, S. et al.: Proc. Fusion Energy Conf. 2006, EX/P8-15.

2) Ichiguchi, K. et al.: Nucl. Fusion **43** (2003) 1101.