§18. Life Time of Plasma States Near Transition Boundary

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A stochastic equation for the amplitude of the neoclassical tearing mode (NTM) has been derived, and the life time of a state free of the onset of NTM is obtained. The model and basis are explained in refs.1 and 2. One has an explicit form of the life time as [3]

$$t_{\text{life}} = \frac{2\pi}{\eta \sqrt{\Lambda_0 \Lambda_m}} \exp(S(A_m)), \quad (1)$$

where the time rates $\Lambda_{m,0}$ are given as

$\Lambda_m = 2A \left| \partial \Lambda / \partial A \right|$ at $A = A_m$ and $\Lambda_0 = \Lambda(\langle A_0 \rangle)$, and the nonlinear dissipation function was given as

$$\begin{aligned} S(A) = & \Gamma_0 \frac{r_s^2}{\rho_b^2} \left(-\frac{4}{3} \Delta'_0 A^{3/2} + h A^2 \right) \\ & + \Gamma_0 \frac{r_s^2}{\rho_b^2} \frac{\rho_p^2}{2r_s^2} \frac{L_q}{L_p} \frac{\beta_p}{\beta_{pn}} \ln \left(1 + \frac{r_s^4 A^2}{\rho_b^4} \right) \\ & - \Gamma_0 \frac{r_s^2}{\rho_b^2} \frac{\beta_p}{\beta_{pn}} \left(A - \frac{w_{\text{cut}}^2}{r_s^2} \ln \left(1 + \frac{r_s^2}{w_{\text{cut}}^2} A \right) \right) \end{aligned} \quad (2)$$

with $\beta_{pn} = L_p / 2a_{bs} \varepsilon^{1/2} L_q$ and

$$\Gamma_0 = \frac{2\ell}{R_M k^3 k_h^4 C^2 A_h^4 \tau_{ac}} \frac{\rho_b^2}{r_s^2}. \quad (3)$$

An explicit value of the transition rate was examined by specifying a micro mode for typical experimental parameters. For the L-mode plasmas, when one employs the current-diffusive ballooning mode (CDBM) as the micro mode, one has Γ_0 as

$$\begin{aligned} \Gamma_0 = & \frac{2 \times 10^{-4} \ell}{k^3 \left(-\alpha^{-1/2} (1 + \alpha) + s \sqrt{\beta m_i / m_e} \right)^2 s^4 R_M} \\ & \times \frac{r_s^6 \rho_b^2}{\delta^8} \alpha^{-11/2} \end{aligned} \quad (7)$$

where δ is the collisionless skin depth and $\alpha = \varepsilon r_s \beta_p / L_p$ is the normalized pressure gradient.

For a set of typical parameters, $r_s / \rho_b \simeq 10$, $r_s / \delta \simeq 10^2$, $R_M \simeq 10^8$, $\beta m_i / m_e \sim 10$, $kr_s = 3$, $s = 1$, $\alpha \sim \beta_p / \beta_{pn}$, one has $\Gamma_0 \sim 3 \left(\beta_p / \beta_{pn} \right)^{-11/2}$. The life time of the state $A = 0$ (i.e., free from the NTM) is

shown in Fig.1. The unit of the life time is $2\pi / \eta \sqrt{\Lambda_0 \Lambda_m}$, which is of the order of Rutherford growth time. The dependence on plasma beta is shown. (Other parameters are fixed, $\Delta'_0 = 0$ and $h \rho_b^2 r_s^{-2} = 1/40$.) The life time strongly decreases as the plasma beta increases. And if it exceeds the effective phase limit β_p^* , the life time becomes of the order of the magnetic diffusion time. The contour of the life time is shown in Fig.2.

Fig.1 Mean life time before the onset of the NTM as a function of the plasma beta value. ($\Delta'_0 = 0$) Other parameters are $h \rho_b^2 r_s^{-2} = 1/40$, $w_{\text{cut}} = \rho_b$ and $L_q / L_p = 2$.

Fig.2 Contour of life time on the (Δ'_0, β_p) plane.

Cusp for the multiple solution is also shown by the dotted line. Above the dotted line, multiple solutions are allowed and stochastic transition takes place. (Other parameters are $h \rho_b^2 r_s^{-2} = 1/40$, $w_{\text{cut}} = \rho_b$ and $L_q / L_p = 2$.)

Reference

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- [2] S.-I. Itoh, K. Itoh, M. Yagi: Phys. Rev. Lett. **91** (2003) 045003.
- [3] S.-I. Itoh, K. Itoh, M. Yagi: J. Phys. Soc. Jpn. **74** (2005) 947