§31. Edge Localized Modes as New Bifurcation in Tokamaks

S.-I. Itoh, M. Yagi (Kyushu Univ.)
Kimitaka Itoh,
A. Fukuyama (Okayama Univ.)

A model of giant edge localized modes (ELMs) in tokamaks is developed. Theory of self-sustained turbulence of current-diffusive ballooning mode is extended. Bifurcation from H-mode to third state with magnetic braiding, M-mode, is found to occur, if the pressure gradient reaches a critical value. Nonlinear excitation of magnetic perturbation takes place, followed by catastrophic increase of transport. With back-transition to H(L)-mode, new hysteresis is found in gradient-flux relation. Process repeats itself.

We study CDBM turbulence in tokamaks. Introducing normalization as $\hat{\phi} = \tilde{\phi}/(\varepsilon a v_A B_0)$, $\hat{k}_{\theta,r} = a k_{\theta,r}$, $\hat{B}_r = \tilde{B}_r/\varepsilon B_0$, we have $\hat{\phi}_{H,L} = \hat{\chi}_{H,L}$,
$\hat{B}_r = s\left(\hat{k}_\theta^2 a^2/\delta^2 \hat{k}_\perp^4 \hat{k}_r\right)\hat{\phi}/\hat{\chi}$,
$\hat{k}_r = s g^{-1/2}(1+G\omega_{E1}^2)^{1/4}\hat{k}_\theta$
$\hat{k}_\theta = \left(g\cdot(1+G\omega_{E1}^2)\alpha^{-1}\right)^{1/2} a/\delta$, respectively [1]. ($\chi$: thermal conductivity, $\alpha = -q^2 R\beta'$, $s = rq'/q$, $\omega_{E1} = E_r'\tau_{Ap}/B$). The critical condition for the magnetic island overlapping is derived. The magnetic island size Δ_{is} is estimated as $\Delta_{is}/a = s^{-1}\hat{B}_r$ for the odd-ψ (even-ϕ) mode where ψ is the parallel component of vector potential. The magnetic island width expands in proportion to $\alpha^{3/2}$. The separation distance of each rational surfaces, d, can be estimated by $\hat{d} \equiv d/a = (s\hat{k}_\theta)^{-1}$. It grows in proportion to $\alpha^{1/2}$. The Chirikov condition for island overlapping, $\hat{\Delta}_{is} = \hat{d}/2$, is satisfied if the pressure gradient becomes high enough. The threshold condition is given as

$$\alpha > \alpha_c^H. \qquad (1)$$

$$\alpha_c^H \equiv \frac{\sqrt{g}}{2}(1+G\omega_{E1}^2)^{5/4}\left(1+s^2 g^{-1}\sqrt{1+G\omega_{E1}^2}\right)^2.$$

When α increases and reaches α_c^H, fluctuating islands overlap. The condition Eq.(1) shows that the critical value α_c^H is close to unity and that it is increased by the magnetic shear or by the radial electric field shear.

Figure 1 shows the critical condition for the magnetic braiding in the s-α diagram. The thick solid line shows the case of weak radial electric field shear, and the thick dashed line indicates the stronger case. The critical boundary α_c^H increases approximately linearly in the high shear case. The M-mode transition disappears in low shear and high α region. The boundary for linear ideal ballooning instability is also shown, which turns out to be close to the boundary for nonlinear bifurcation.

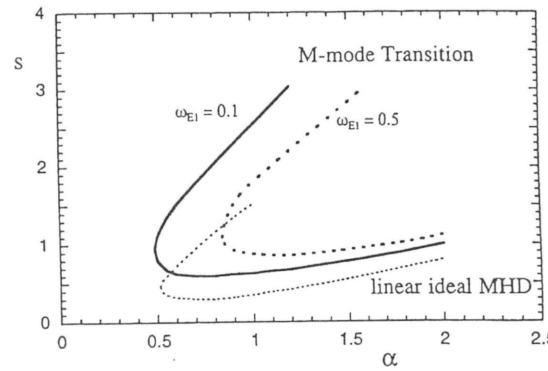

Fig. 1

The back transition condition from the M- to the H(L)-mode is obtained as $\alpha < \alpha_1^M$, where $\alpha_1^M = g s^{-2}(1+G\omega_{E1}^2)^{-1/2} q^2\beta_i$. The region of the multifold branches is derived as

$$\alpha_1^M \le \alpha \le \alpha_c^H \qquad (2)$$

The enhanced transport coefficient in the M-state, and the multifold branches in the self-sustained turbulence provide a new hysteresis in the flux-gradient relation. The schematic drawing of the various branches are shown in Fig.2.

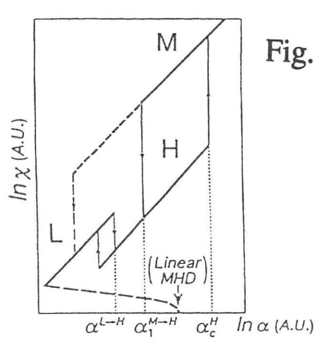

Fig. 2

A cycle, the sequence of which is consist of (1) the build-up of pressure gradient in H-mode, (2) the H-to-M transition at $\alpha = \alpha_c^H$, (3) the crash of plasma profile by the M-mode transport and (4) the back transition to the H-mode at $\alpha = \alpha_1^M$, is attributed to a Giant ELM.

1) S.-I. Itoh, et al. Phys. Rev. Lett. 76 (1996) 920.