§30. Self-Organized Dynamics and Thermal Instability in Steady State Tokamaks

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Important role of current profile on the improved confinement has been recognized these days. Based on the self-sustained turbulence, it has been shown that a new link is generated between the profiles of the pressure, current and χ, causing the improved confinement such as the PEP and high-β_p mode [1]. The analysis is extended to the burning plasma and new dynamics is found [2].

The energy confinement time for the high-β_p mode was theoretically predicted as $\tau_E = f_\tau^{2.5} L^1 I_p^2 T^{-1.5}(1+\beta_p^4)^{0.5}$ where the plasma volume is replaced by L^3. (we choose the approximation $n_D = n_T = n/2$). The temperature dependence of the cross section is written as $<\sigma v> = <\sigma v>_0 g(T)$. The dimensionless function g(T) is normalized to unity at the temperature $T = T_*$, where the condition $dg/dT = 2.5g/T$ holds. The steady state solution is written as

$$I_p^2\left(1+\zeta\frac{T^4}{I_p^8}\right)^{0.5} = C_f T^{2.5} g(T)^{-1} \qquad (1)$$

where ζ and C_f are the coefficients, $\zeta = (8\pi^2\mu_0^{-1}a^2 n)^4$, $C_f = 4/f_\tau^{2.5} nLQ_f < \sigma v>_0$.

Equation (1) predicts new branch in the ignition curve as is shown in Fig.1. In the limit $\zeta = 0$, the prediction by the L-mode confinement law holds. When the confinement improvement by the Bootstrap current is effective (i.e., ζ is finite), there appears new branches. The asymptotic form of the left hand side of Eq.(1) behaves as $\sqrt{\zeta}T^2 I_p^{-2}$ in the low current limit. This allows a solution of the form
$I_p \simeq C_f^{1/2}\zeta^{-1/4} T^{-1/4} g(T)^{1/2}$
This solution gives the low temperature branch and the high temperature branch for the fixed plasma current. These two branches merge, in the small ζ limit, at the temperature $T = T_{**}$, where the condition $dg/dT = g/2T$ holds.

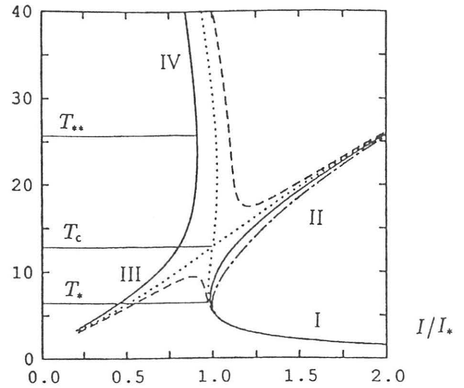

Fig.1 Phase diagram in the ignited plasma. The stationary solution (solid line) is compared to that of the L-mode plasma (dashed line).

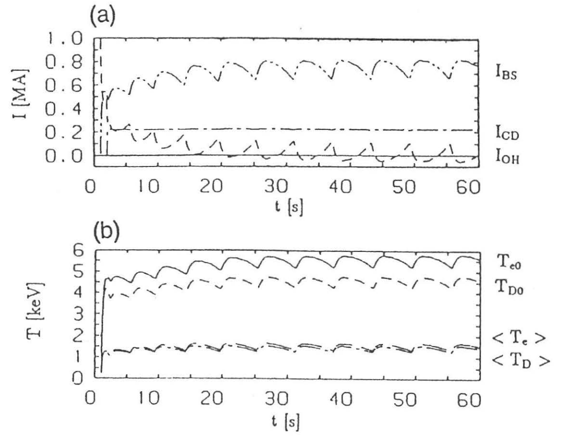

Fig.2 Self-generated oscillation in the steady state plasma with improved confinement.

Figure 2 predicts the self-generated oscillation in the steady-state plasma in present-day- large tokamaks. The total current is chosen as 1MA. (The central heating power is taken as 13.5MW. The central current drive power is 0.5MW and the off-axis current drive power is 1MW. The Bootstrap current is dominant due to the lower plasma current.) The spatial-temporal evolution of this self-generated oscillation is investigated.

These analyses provide a new picture for the dynamics in burning plasmas and identify the issue related to thermal instability . It illuminates that the transport analysis of the steady state and ignited plasma is the key issue in the fusion research.

1) A. Fukuyama et al., Plasma Phys. Contr. Fusion 36 (1994) 1385.
2) A. Fukuyama, et al., Nucl. Fusion 35 (1995) 1669.