§ 13. Selection Rule for the Radial Electric Field Structure Formed by Biased Electrodes in Tokamak Plasmas

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The transition from L-mode to H-mode is characterized by a sudden change of the radial electric field (E_r) structure in tokamaks. Imposing a radial electric field at the plasma edge can also lead to an improved confinement state. In TEXTOR biasing experiments the spatial profile of the radial electric field measured at the plasma edge changed from a flat one before transition to a peaked one after transition.1) We have obtained various E_r structures between an electrode and a limiter. A stability analysis of these E_r structures is carried out, and a selection rule for a structure after the transition induced by electrode biasing is clarified.

A model equation for the radial electric field structure is a combination of Poisson's equation and the charge conservation law,

$$\frac{\partial}{\partial t}E_r = -\frac{1}{\varepsilon_0\varepsilon_\perp}(J_{visc} + J_r + J_{orbit} - J_{ext}), \qquad (1)$$

where J_{visc} is the current driven by shear viscosity, J_r is the local current, J_{orbit} is the current driven by ion orbit losses, J_{ext} is the current driven into the electrode by the external circuit, ε_0 is the vacuum susceptibility, and $\varepsilon_\perp$ is the dielectric constant of a magnetized plasma. Nonlinear E_r dependencies of the local current and orbit loss current are the origins of structural bifurcation. Here the orbit loss current is neglected for simplicity.

The radial electric field equation Eq. (1) is a nonlinear differential equation and is solved with the boundary condition $\partial E_r/\partial r = 0$. In stationary state, spatially constant solutions (L-mode) and solitary solutions with at least one peak (H-mode) are obtained. 2) The electrode is part of an electric circuit, and the electrode current must satisfy the circuit relationship.

A stability of the solutions is evaluated by the linear growth rate of perturbations. Both stable and unstable regions exist in stationary solutions, and these boundary points give critical points of transition from one state to the other. While the applied voltage increases from zero, the E_r structure is a spatially constant one at low applied voltage, but when it comes to point B in Fig. 1, a certain perturbation can grow so that the structure becomes unstable. The perturbation p=1, where the number p corresponds to the mode number of perturbation, becomes unstable first in this situation. This point is given by the intersection of branch T2 and branch S1. Time evolution of the E_r structure is calculated by Eq. (1), and the structure acquires one peak. When the perturbation p=2 grows, the structure acquires two peaks, and similarly for p=3, but p=1 mode becomes unstable before other modes become unstable, so branch S1 is taken after the transition. Other branches are not accessible in the quasistatic process. This result agrees with experiments in which only a single-peaked structure is observed. If the structure with multiple peaks is attained, it can stay on that state because this structure can be stable with an appropriate applied voltage.

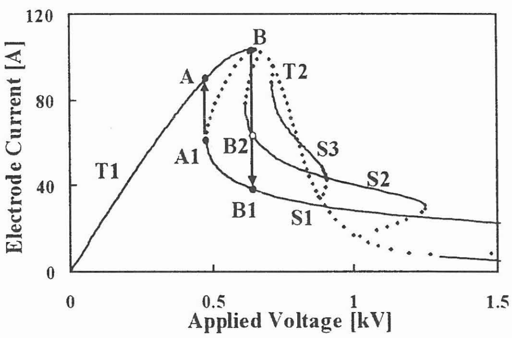

Fig.1 Relationship between the applied voltage and the electrode current. T1 and T2 are spatially constant branches and S1~S3 are solitary solution branches with 1~3 peaks, respectively. A, B, A1, B1, etc. denote transition points. Solid lines are stable and dotted lines are unstable on each branch.

Reference

1) Weynants, R. R., et al., Nucl. Fusion **32** (1992) 837
2) Kasuya, N., et al., Plasma Phys. Control. Fusion. **44** (2002) A287