§14. Accessibility to a Double-Peaked E_r Shear Layer Structure by Double Electrode Biasing in Tokamak Plasmas

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Electrode biasing is one of the methods for controlling the radial electric field externally, and can induce a transition to an improved confinement state in tokamaks. An electrode is inserted into a plasma and a voltage is applied between this electrode and a toroidal limiter (Fig. 1). A peaked structure (solitary structure) in the radial electric field is observed by electrode biasing 1), and was explained by the nonlinearity in the conductivity of the radial current 2). Accessibility to a multiple-peaked structure is shown here. Multiple-peaked structure, which has multiple shear layers, has been predicted theoretically 3), but is not accessible in the usual way with a single electrode. We propose a double biasing method with a voltage rampup to obtain the double-peaked structure 4).

The radial electric field structure is determined by the following equation 3),

$$\frac{\partial}{\partial t}E_r = -\frac{1}{\varepsilon_0\varepsilon_\perp}(J_r^{\mathrm{NET}} - J_{\mathrm{ext}}), \qquad (1)$$

where J_r^{NET} is the net radial current in the plasma, 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. Only the structure in the radial direction is considered here. The neoclassical current and the shear viscosity current (anomalous) are taken into account in J_r^{NET}. The nonlinear E_r dependency of the neoclassical current gives a structural bifurcation in E_r, and a spatially constant solution and a solitary solution are obtained from Eq. (1) under the same condition. Multiple-peaked solutions are also possible, but the selection rule given by a mode stability analysis shows that the single-peaked structure, which is observed experimentally, is realized after the transition.

To obtain a double-peaked structure, inserting another electrode at the middle point of the biasing region is effective (Fig. 1). The biased region is divided by the additional electrode into two regions: regions 1 and 2 where the potential differences are denoted by V_1 and V_2 in Fig. 1, respectively. In fact, inserting another electrode is not sufficient to obtain a double-peaked structure. A voltage rampup at the transition point is needed. In order to obtain the transition rule, time evolutions of the E_r structure are calculated by solving Eq. (1). A spatially constant E_r structure (L-mode) is realized below a critical voltage. As in the case of single electrode biasing, this structure becomes unstable beyond a critical point. With a fixed applied voltage, the E_r structure makes a transition to an asymmetric structure, i.e., solitary in one region and spatially constant in another (an additional electrode can make the radial current discontinuous between regions 1 and 2). We find that ramping the applied voltage makes a transition to the double-peaked structure possible. The external control is chosen as follows: V_{ext} is increased from 490 V (critical point, given by parameters from an experiment in TEXTOR tokamak) linearly by the amount ΔV during the time $\Delta\tau$ and then V_{ext} is kept constant. It is found that ΔV must be larger than the critical value ΔV_c in order to realize the double-peaked structure ($\Delta V_c = 65$ V for $\Delta\tau = 1$ ms). ΔV_c is a weakly increasing function of $\Delta\tau$. The rampup must be sufficiently fast compared to the time scale of E_r variation by spontaneous instability. The transition under a fixed value of V_{ext} takes about 10 ms, giving a typical time scale of E_r variation by instability.

In summary, the double-peaked structure becomes accessible by the electrode at the middle point with the aid of the applied voltage rampup. Such structures can give double $E\times B$ flow shear layers. Therefore, electrode biasing can be used to make wider transport barriers. This analysis provides a new experimental test to provide new freedom in realizing further improvement of confinement.

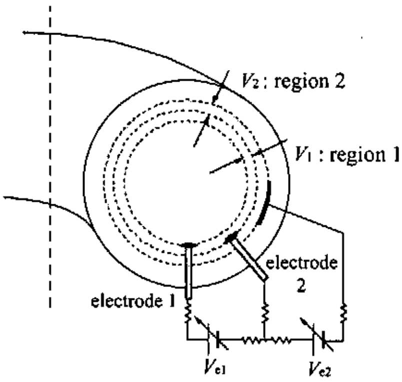

Fig. 1: Setup of a double biasing experiment. The usual electrode biasing uses only one electrode (without electrode 2).

Reference

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