§6. Identification of Effective Plasma Boundary in High-beta Plasmas

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In the Large Helical Device (LHD) experiments, the volume averaged beta value $\langle\beta\rangle$ was achieved to 5% in the quasi-steady state. For such high-β plasmas, the change of the magnetic field structure is expected, because the 3D MHD equilibrium analysis predicts the stochastization of magnetic field lines. Since the magnetic field of the LHD is intrinsically 3D structure, the plasma current in the MHD equilibrium flowing along 3D field lines drives perturbed field to break nested flux surfaces in the vacuum field, so-called the "3D plasma response". The 3D plasma response leads the stochastization without the perturbations of MHD instabilities. Therefore, the study of the 3D plasma response and identification of the plasma boundary are important and critical issues in stellarator and heliotron researches.

The 3D plasma response to the magnetic field were studied theoretically and numerically. However, experimental studies of the 3D plasma response are not many because the identification of the magnetic field structure is difficult. Limited studied were reported the change of the magnetic field structure by the 3D plasma response. Recently, in the LHD experiment, the identification of the magnetic field structure by the measurement of the radial electric field, E_r, is studied [1]. If electrons are lost along opening field lines on stochastic field, the positive E_r might be appeared. This means appearing the positive E_r or strong E_r shear suggests the "*effective plasma boundary*" between opened ans closed field lines. However, since E_r or strong E_r shear suggest to only the boundary between opened and closed field lines, comparing the E_r measurement and 3D MHD equilibrium analysis, the identification of the magnetic field structure can be done.

In figure 1, a comparison between measured E_r and prediction of 3D MHD equilibrium analysis is shown for $\langle\beta\rangle \sim 3\%$. On that figure, Poincarè plots of field lines calculated from the HINT2 code (color dots) and measured E_r shear (black lines with points) are plotted at same poloidal cross section. Colors of Poincarè plots indicate the connection length of magnetic field lines L_C to the vessel wall. The connection length is limited to 1000m. if $L_C > 1000$m, it is assumed as the closed field lines. Positions of vacuum magnetic axis and LCFS are R=3.56m and 4.42m, respectively. For $\langle\beta\rangle \sim 3\%$, the magnetic axis shifts to R=3.76m. The stochastic region appears in the peripheral region. The edge of the stochastic region archives to $R \sim 4.6$m. In that region, magnetic field lines of long (> 100m) and short (< 100m) L_C are overlapped. Strong E_r shear appears in the region. Meanwhile, strong E_r shear position moves more than 15cm from the vacuum LCFS. However, strong E_r shear does not appear on clear boundary between closed and open field lines.

From studies in figure 1, 3D MHD equilibrium analyses suggest followings. First is magnetic field structure is changed by the 3D plasma response. Second is the connection length of magnetic field lines is still long in the stochastic region. These mean the stochastic region might be still the confinement region and "effective plasma boundary" is not the vacuum LCFS. To study the correlation between L_C and the position of strong E_r shear, L_C and positions of maximum E_r shear are compared for various β. Figure 2 shows a contour map of L_C as a function of R and β. Positions of maximum E_r shear are also plotted in the figure (blue symbols). Colors on the contour map indicate the connection length L_C and the range of L_C is limited to 1000m corresponding to figure 1. With increased β, the region of closed field lines moves to the outward of the torus. This is comparable to figure 1.

1) K. Kamiya, *et al.*, Nucl. Fusion, **53** (2013) 013003.

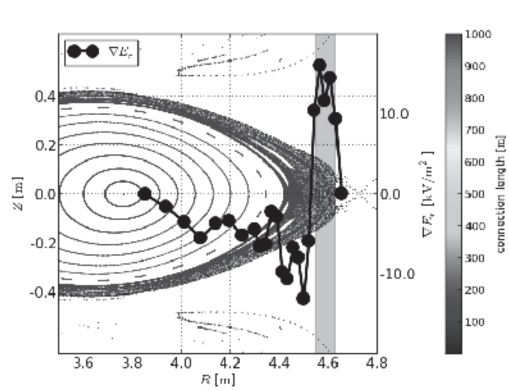

Fig. 1: A result of the electrode biasing experiment without the external perturbed field.

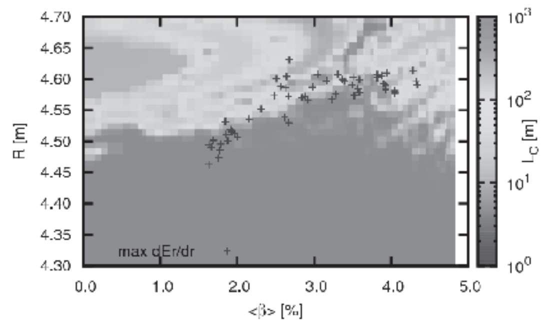

Fig. 2: Results of the biasing experiment with different perturbed field. Increasing the island width, the current to transit is also increased.