§58. LHD Gauge by External Coil Currents

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The drastically improved plasma has been obtained through the LHD experiments started in 1998. In the recent experiments, the maximum averaged beta value $< \beta_{\rm dia} >$ of 4.5% was obtained by high power NBI heating up to 12MW in the configuration with $R_{\rm ax} = 3.6$m and $B_{\rm ax} = 0.45$T, where $R_{\rm ax}$ and $B_{\rm ax}$ are magnetic axis position and toroidal magnetic field on the magnetic axis, respectively. Up to now, the beta collapse phenomenon has not been reported in the LHD experiment. Steady state divertor operation with high performance plasmas was demonstrated for more than 30 minutes in the LHD-ICRF heating experiments.

The LHD achieves these high-performance plasma confinement by the coordination of magnetic surface region and chaotic field line layer. Therefore, it is necessary to establish a numerical method to analyze the high beta equilibrium that doesn't assume the existence of the magnetic surface.

The magnetic field $\boldsymbol{B}$ satisfies always the relation $\boldsymbol{\nabla} \cdot \boldsymbol{B} = 0$. The essential freedom of $\boldsymbol{B}$ is two and $\boldsymbol{B}$ can be expressed by a vector potential of 2 component. In the rotating helical coordinate system (X, Y, ϕ), we can express $\boldsymbol{B}$ as follows without loss of generality (LHD Gauge [1]).

$$\boldsymbol{B} = \boldsymbol{\nabla} \times \boldsymbol{A} \, , \boldsymbol{A} = \begin{pmatrix} \Phi \\ 0 \\ p\{\Psi + Y\Phi\}/r \end{pmatrix} , \qquad (1)$$

where p is the helical pitch (= 5 for the LHD) and $r = r_0 + X \cos p\phi - Y \sin p\phi$. LHD equilibrium composed of magnetic surface region and chaotic field line region can be obtained numerically by the force balance equation

$$\nabla P = \boldsymbol{J} \times \boldsymbol{B} \, , \quad \boldsymbol{J} = \frac{1}{\mu_0} \nabla \times \boldsymbol{B} \, . \qquad (2)$$

Profiles of $[P(X, Y, \phi), \Phi(X, Y, \phi), \Psi(X, Y, \phi)]$ are obtained as the solution of eq.(2) under the appropriate boundary conditions. To solve the equation (2), we have developed an analytical expressions for the LHD gauge (Φ, Ψ) created by external coil currents $\boldsymbol{J}_{\rm ext}(\boldsymbol{x})$.

Under the Coulomb gage, the vector potential of external coil currents $\boldsymbol{J}_{\rm ext}(\boldsymbol{x})$ is given by the Biot-Savart law. Therefore, vector potential under the LHD gauge is given by

$$\boldsymbol{A}(\boldsymbol{x}) = \frac{\mu_0}{4\pi} \int {\rm d}^3 \boldsymbol{x}' \frac{\boldsymbol{J}_{\rm ext}(\boldsymbol{x}')}{|\boldsymbol{x} - \boldsymbol{x}'|} + \boldsymbol{\nabla} \chi \, , \qquad (3)$$

where the scalar function χ is determined by

$$0 = A_Y \qquad (4)$$

Φ and Ψ are verified to be smooth and single-valued function in the vaccum vessel of the LHD (Fig.1).

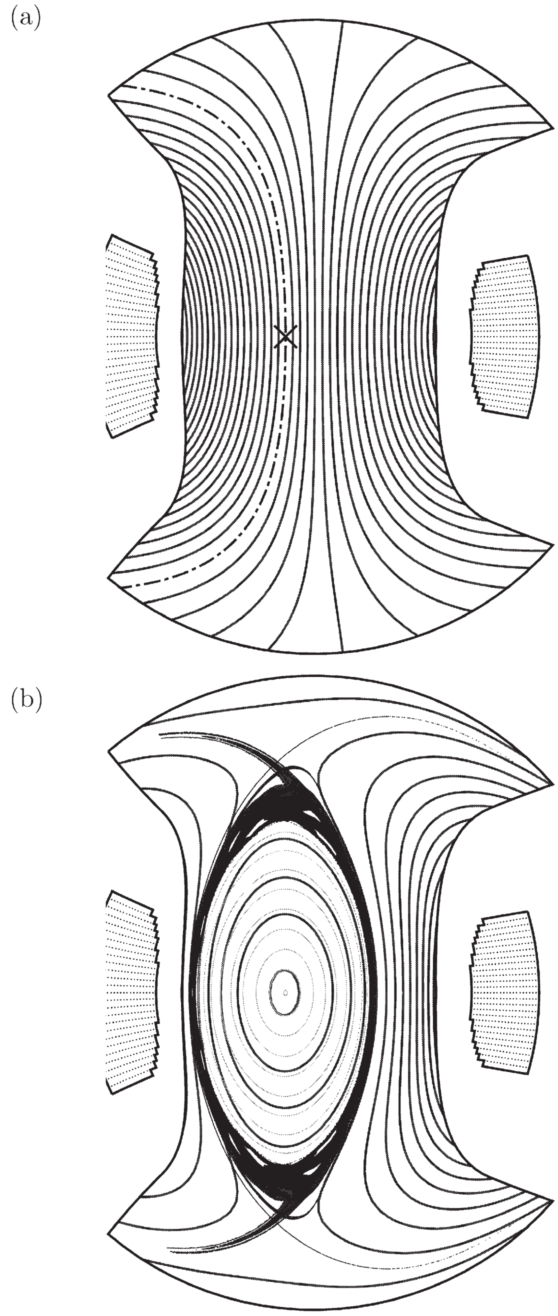

Fig.1. Numerical example of LHD gauge for the case of $R_{\rm ax} = 3.75$m. (a) $\Phi(X, Y, \pi/10)$: The chain line shows the line of $\Phi = 0$, and $\times$ represent the position of the magnetix axis. (b) $\Psi(X, Y, \pi/10)$: Poinvare pltos of lines of force corresponding coil currents are also shown. Ψ can approximate automatically the magnetic surface.

Reffernce

[1] T.Watanabe, et.al.: Nucl. Fusion **46** (2006) 291-305.