§41. Preliminary Identification of the Last Closed Magnetic Surface in the Large Helical Device by Use of 3-D Cauchy-condition Surface Method

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1. Introduction

A 3-D version of Cauchy-condition surface (CCS) method code is now under development to identify the last closed magnetic surface (LCMS) in the Large Helical Device [1]. The present report describes the recent results of LCMS, which is obtained from the magnetic field profiles reconstructed using the CCS method with magnetic sensor signals.

2. Three-dimensional CCS method

The 3-D CCS is assumed to have a torus shape and to be located in the plasma region. The Dirichlet and the Neumann conditions along the CCS are the vector potential $\mathbf{A}$ and its derivative $\partial \mathbf{A} / \partial n$, respectively. One here adopts the Cartesian coordinate system for the analysis so that the vector Laplacian has the simple relationship

$$(\nabla^2 \boldsymbol{A})_k = \nabla^2 A_k \quad (k = x, y, z). \tag{1}$$

The first step of the CCS analysis is to obtain both types of boundary conditions on the CCS in such a way that they will be consistent with the magnetic sensor signals. One assumes that 100 magnetic flux loops in the toroidal direction, 26 loops in the poloidal direction and 440 field sensors are arranged outside the plasma. Each of the field sensors is hypothetically assumed to detect all of the 3 components of magnetic field.

3. Calculate magnetic field

Once all the values of vector potential and its normal derivative on the CCS are known, the magnetic fields for arbitrary points can be calculated using the formula.

$$\begin{aligned} B_j = & \int_{\Gamma_{\mathrm{CCS}}} \left\{ \left(L_x^j \phi_i^* \right) \frac{\partial A_x}{\partial n} - A_x \left(L_x^j \frac{\partial \phi_i^*}{\partial n} \right) \right\} d\Gamma \\ & + \int_{\Gamma_{\mathrm{CCS}}} \left\{ \left(L_y^j \phi_i^* \right) \frac{\partial A_y}{\partial n} - A_y \left(L_y^j \frac{\partial \phi_i^*}{\partial n} \right) \right\} d\Gamma \\ & + \int_{\Gamma_{\mathrm{CCS}}} \left\{ \left(L_z^j \phi_i^* \right) \frac{\partial A_z}{\partial n} - A_z \left(L_z^j \frac{\partial \phi_i^*}{\partial n} \right) \right\} d\Gamma \\ & + W_j^{(B)}. \qquad (j = r, \varphi, z) \end{aligned} \tag{2}$$

Here, the detailed forms of operators L_k^j depends on the parameters j and k. The quantity $W_j^{(B)}$ represents the contribution of external coil current to the field. The fundamental solution ϕ_i^* in Eq.(2) satisfies the 3-D scalar Laplace equation with the Dirac delta function:

$$\nabla^2 \phi_i^* = \delta_i . \tag{3}$$

A 3-D test calculation has been made for non-axisymmetric plasma in the LHD. Outside the LCMS the reconstructed magnetic field caused by only the plasma current agrees fairly well with the reference solution obtained using the HINT2 code [2], while a good agreement is observed when adding the coil current effect to the magnetic field.

4. Magnetic field line tracing

Once the 3-D magnetic field distribution has been obtained, the magnetic field line can be traced. This trace is performed using the MGTRC code [3]. Two traces were carried out. One was for the reference field given beforehand using the HINT2 code; the other was for the reconstructed field from the CCS analysis. A field line was launched from the same point $(r, z, \varphi) = (4.47m,\ 0.0m,\ 18°)$ for these two fields, and each trace was terminated when the circulations reached 100.

Figure 1 shows the Poincare plots of the magnetic field line on the horizontally elongated cross section ($\varphi = 18°$). The solid closed line is based on the reference magnetic field, while the round symbols are the results following the reconstructed field. The former represents the LCMS clearly. The latter does not form a sharp closed line, however, the round symbols are distributed almost along the LCMS. One possible reason for this is that even outside the LCMS (in the stochastic region) there exist plasma currents to some extent. The CCS method, which assumes vacuum fields hypothetically outside the CCS, does not give accurate solutions for such a region. One should seek a way out of the difficulty.

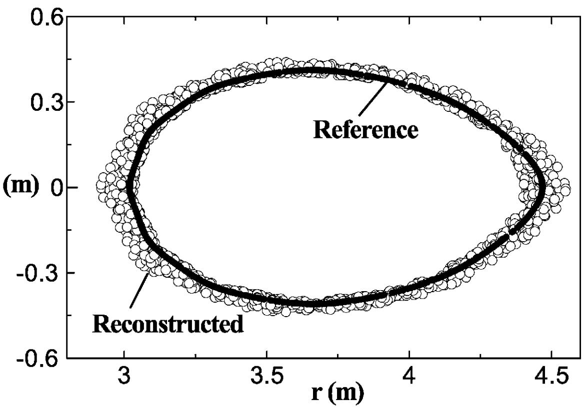

Fig.1 Results of magnetic field line tracing

4. Summary

(1) A prototype of 3-D CCS method code has been developed, in which the formulation is based on the 3-D distribution of vector potential.
(2) The LCMS drawn using a magnetic field line tracing agrees fairly well with the reference one.
(3) It is concluded that the magnetic field outside the plasma and also the LCMS can be reconstructed with a fairly acceptable accuracy if a large number of magnetic sensors can be located outside the plasma.
(4) One should make more effort to improve the accuracy in the reconstructed results.

[1] Itagaki, M. et al., Annual Report of NIFS April 2009 - March 2010, p.65.
[2] Suzuki, Y., et al., 2006 *Nucl. Fusion* **46** L19.
[3] NIFS, 2009 *LHD Experiment Technical Guide 2009*