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# 球状トカマク合体実験装置UTSTへの渦電流効果を含んだCCS法による最外殻磁気面推定の実装

# Reconstruction of Last Closed Flux Surface in UTST by the CCS Method Including the Eddy Current Term

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Many tokamak devices employ EFIT code for poloidal flux surface reconstruction. In the first phase of EFIT, Fast Boundary Identification (FBI) method is used for reconstructing the last closed flux surface (LCFS). However, it is reported that FBI has less robustness than the Cauchy Condition Surface (CCS) method [1].

The CCS method is one of the methods for estimating the magnetic flux and field in the vacuum region. Moreover, the CCS method has capability of reconstructing the eddy current profile [2]. Thus, the Modified CCS (M-CCS) method that includes the contribution from the eddy current is available to reconstruct LCFS even in a particular situation with large contribution from eddy current, e.g., disruption and start-up phase.

In the University of Tokyo Spherical Tokamak (UTST) device, the merging formation method, that is one of the center-solenoid-free start-up methods of spherical tokamak (ST), is under development. In the merging formation, two STs are inductively formed using poloidal-field coils and are then merged into one ST via magnetic reconnection. During the ST formation process, it is expected that large eddy current flows on the vacuum vessel. In this research, the M-CCS method is implemented on the UTST device to reconstruct magnetic flux, field, and eddy current profile in the start-up and quasi-steady phases.

33 flux loops and 39 field sensors are equipped inside the vacuum vessel. The solution (Dirichlet and Neumann condition on the CCS and eddy current density at node points on the vessel wall) is obtained by solving the following boundary integral equations of

$$c_i A_i - W_i = \oint \left( \frac{A^*}{r}\frac{\partial \psi}{\partial n} - \frac{\psi}{r}\frac{\partial A^*}{\partial n} \right) d\Gamma_{CCS} + \mu_0 \oint j_{eddy} A^* d\Gamma_{shell}, \qquad (1)$$

where $c_i$: constant value, $A_i$: flux or field sensor signal, $W_i$: contribution of the coil current, $A^*$: flux or field base function, $\psi$: flux on the CCS, $\frac{\partial \psi}{\partial n}$: normal derivative of flux on the CCS, $j_{eddy}$: eddy current on the vessel wall and $\mu_0$: permeability of vacuum magnetic constant and $c_i$ is 1 or 1/2 at the sensor position and on the CCS, respectively. Equations (1) are discretized as

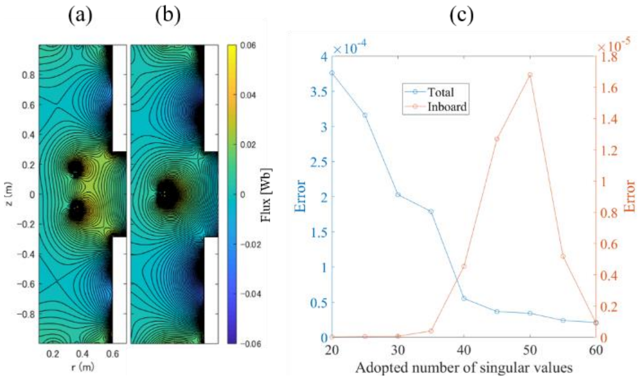


Fig.1. (a) and (b) show the reconstruct flux at the merging and after merging phase. Black line and color show flux contour and the value of flux. (c) shows the dependence of error. The vertical and horizontal axises show the error $|Dp^* - g|$ and singular value number which is adopted. Blue line and orange are total error and in-board flux error.

$$Dp = g,$$

where $D$, $p$ and $g$ are the coefficient matrix, the solution vector and the measurement value vector, respectively.

Flux surfaces reconstructed from the experimental data during merging formation are shown in fig. 1 (a) and (b). Here, the truncated singular values decomposition (TSVD) method was used for preventing numerical oscillation.

Fig. 1 (c) shows the residual error calculated as

$$|Dp^* - g|,$$

where $p^*$ is the solution vector obtained by the TSVD method. The total error decreases as increasing the number of singular values, however, the inboard-side flux error increases when too many singular values are adopted. Further improvement on determining the adequate number of singular values is required.

In the conference, comparison between the reconstruction result by the M-CCS method and the direct measurement result by two dimensional magnetic probe array will be presented as well as the optimization of node points and the number of singular values.

## References

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