§17. New Reconstruction Method for Eddy Current Distribution in Toroidal Machine: Verification from Real Experiments

Masamune, S., Sanpei, A. (Kyoto Institute of Technol.),
Itagaki, M. (Hokkaido Univ.),
Watanabe, K.Y., Suzuki, Y., Sakakibara, S.

The Cauchy Condition Surface (CCS) method is a reconstruction method of vacuum-plasma boundary only from magnetic sensor signals outside the plasma. This method had been successfully used on JT-60U tokamak for the active control of the plasma boundary shape. Recently a new method for reconstruction of the eddy current distribution in a vacuum vessel has been proposed in which the CCS method is modified to include the effect of eddy current in the vacuum vessel. A numerical test has been performed for a reversed field pinch machine by comparing the eddy current distributions from an exact toroidal equilibrium calculation and reconstruction result with the modified CCS method. In the latter case, an equilibrium solution outside the plasma is used to construct the model input data. The objectives of the present study include further optimization of the reconstruction procedure to increase the reliability of the proposed method, and to carry out the experiments in RELAX RFP machine in order to verify the method experimentally.

When the effect of eddy current is added to the original formulation of CCS method, we have shown that the Truncated Singular Value decomposition (TSVD) method is more effective in solving the inverse problem than the use of standard SVD method. Furthermore, the use of Modified TSVD method has been shown to be effective in reducing the residual oscillatory structure in the reconstructed eddy current distribution in the poloidal direction.

Figure 1 shows the arrangement of plasma column, magnetic sensors, CC nodes on the CCS well inside the plasma, and eddy current nodes on the inner surface of the vacuum vessel. In the present model analysis, the magnetic sensors are assumed to locate 2 mm and 8 mm from the wall in turn. From given values of poloidal flux function and its normal derivative on the CCS, we can obtain the poloidal field and flux function at all the locations of our interest. The eddy current contribution can also be included as the surface integral on the inner surface of the vacuum vessel. When the integral equation is transformed into matrix formula, the coefficient matrix is not necessarily square. Then, we have applied SVD method in solving the set of equations.

Figure 2 shows the dependence of normalized eigenvalues on the number of current nodes. When the number of current nodes is larger than 40, there appears small singular values (less than 10^{-3}), with a clear gap of singular values. And at the same time, an oscillatory behavior was observed in the reconstructed eddy current distribution as shown in ref.[1]. We have also carried out evaluation of the relative errors in the reconstruction results. In order to do so, we have added 3%-sigma noise to the sensor signals and the resultant error was calculated. The results show that the relative error decreases as the number of eddy current nodes increases; the error can be lower than 10% when we choose the current node number as 40. When the current node number is 40, as described in the previous paragraph, the SVD method does not require further modification (TSVD) because small singular values ($<10^{-3}$) do not appear in this case. Thus, we conclude that it would be the most effective to select the number of current nodes as 40 [2].

Figure 3 shows the diagnostic port arrangement in a particular poloidal plane where we have 14 ports for magnetic pick-up coils. Design and fabrication of a poloidal array of magnetic probes are in progress. Design study of poloidal flux loops inside the vacuum vessel is also in progress. As a whole the experiments are behind the schedule mainly because of the move of the RELAX machine into a new building. After the movement, it has taken some time to recover the plasma performance as it used to be before the movement. The first preliminary experiment for CCS data accumulation will start in June 2015.

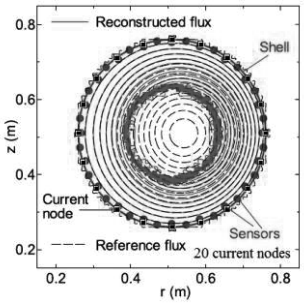

Fig.1. Arrangement of sensors, current nodes, and CCS.

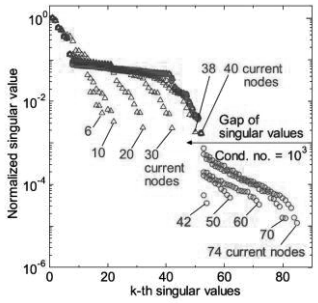

Fig.2. Dependence of errors on current node number.

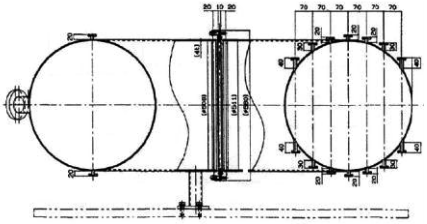

Fig.3. Diagnostic port arrangement in RELAX.

[1] M. Itagaki et al., Plasma Fusion Res. 9, 1402046, 2014.
[2] M. Itagaki et al., BEM/MRM 37, Vol.57, 2014.