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

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The Cauchy condition surface (CCS) method is a method for reconstruction of the outermost flux surface of toroidal plasmas from magnetic sensor signals outside the plasma. This method has been used successfully to JT-60 for real-time control of the plasma shape. The Improved CCS method is a new method for reconstruction of the OMFS including the effect of eddy currents induced in the vacuum vessel. The purpose of this collaboration is application of this new method to a real machine, RELAX RFP, to reconstruct the OMFS and eddy current distribution in the vacuum vessel at the same time, to evaluate the accuracy and possible sources of errors in this method. One of the advantages for RELAX is that the RFP equilibrium depends strongly on the eddy current distribution surrounding the plasma column.

A preliminary test of the ICCS method has been performed by using the equilibrium computation with RELAXFit code. [1,2] During the course of this test, we have shown that, in addition to the standard Single Value decomposition (SVD) method, the use of Truncated SVD (TSVD) method is effective in solving the inverse problem. Furthermore, we have shown that a rapid oscillation in the reconstructed current profile can be suppressed by using the Modified SVD (MSVD) method. Through these processes, the reason of the appearance of the rapid oscillation has been made clear, to determine the optimum number of current nodes.

We have also examined the effect of interpolation of the magnetic data on the final current distribution to match the number of real experimental data and the optimum number of input data for ICCS method. Figure 1 shows the dependence of the relative errors of the reconstructed current density on the number of interpolated data points. We should note that the number of input data for ICCS is 40. It is clear that even when we use the 15 experimental data points in a poloidal plane to interpolate the remaining 25 points for ICCS method, the maximum error (in the poloidal direction) in the reconstructed current density is around 3%. When we introduce the 3% σ noise, the maximum error increases to ~15%.

Figure 2 shows the experimental arrangement of magnetic sensor array in a poloidal cross section. The 14 magnetic sensor coils, 7 on top and 7 from bottom, distribute poloidally to measure the edge poloidal magnetic field at 2 mm from the inner surface of the vessel. The outboard side sensor is not located in the same poloidal plane, but we can use the data from the sensor at the neighboring diagnostic port, 22.5° (π/8) away in the toroidal direction. Since we have no poloidal flux loop inside the vacuum vessel, we have constructed the flux data as follows. The signal from the poloidal flux loop set on the outer surface of the vessel was time-integrated to obtain the poloidal flux which included the flux through the central hole of the torus. Since the vacuum vessel has two insulated poloidal gaps, it may be a good approximation to assume the poloidal flux at the inner surface of the vessel equals that on the outer surface. We have therefore used the time-integrated toroidal loop voltage as the flux signals.

Figure 3 shows the eddy current distribution and poloidal flux contours reconstructed from the experimental data with interpolation. The experimental eddy current density is much higher than the model calculation, however, the results capture the essential characteristics such as the maximum value at θ~3π/2. Since the spatial variation of the flux function is larger outside the vessel than that inside the vessel, the contours cannot capture the characteristics to date. The poloidal flux needed for the equilibrium reconstruction is that only inside the plasma which is independent of the discharge history. We need further effort to understand the roles of poloidal flux function, and possible introduction of iteration method to obtain convergent solutions.

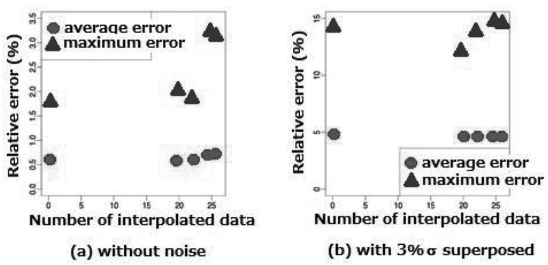

Fig.1. Dependence on the interpolated data number of the errors of the reconstructed eddy current density.

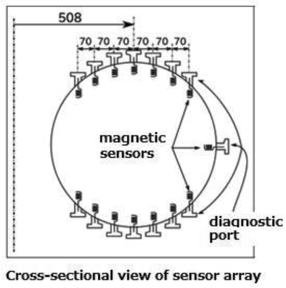

Fig.2. Experimental arrangement of magnetic sensors

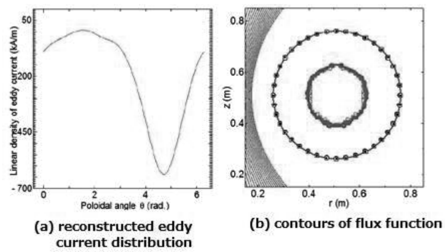

Fig.3. Experimental reconstruction of eddy current and flux function.

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