§4. Proposal of New Magnetic Scaling and Consideration of Poloidal Coil Position for Heliotron-type Reactors

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i) New magnetic scaling

The ratio of the maximum field on the helical coil to the average toroidal field on the center of windings $B_{\max}/\langle B_t \rangle$ is one of the key parameter in the design of heliotron reactors because the former strongly relates to the engineering design and the latter affects the plasma confinement property. Since there is no analytical solution of the magnetic field generated by the heliotron configuration, numerical analysis is necessary to obtain the accurate value. However, fast computation rather than high accuracy is required in the phase of the parametric scan over a wide design space. Since magnetic field ratio is a non-dimensional parameter and sholud be uniquely determined by the geometry of helical coils, it is expected to be described with the function of several non-dimensional parameters related with the coil geometry. With a simplified analytical consideration, 5 parameters were selected for the candidate; α, m, γ_c, ξ and ζ. Here α, m, γ_c are pitch modulation parameter, toroidal pitch number and helical pitch parameter, respectively. ξ is related to the maximum field strength of an infinite-length linear coil that has a rectanglar cross-section with width-to-height ratio of x;

$$\xi = \sqrt{x}\left\{\ln\left(1+\frac{4}{x^2}\right)+\frac{4}{x}\tan^{-1}\left(\frac{x}{2}\right)\right\}. \qquad (1)$$

ζ is defined with coil cross-sectional area S_c and coil major radius R_c as $\sqrt{S_c}/R_c$.

A parametric scan was carried out with the finite-volume current element code that developed in accordance with the procedure proposed by Todoroki[1]. Applying a regression analysis to the calculation result, the new scaling has been proposed as:

$$\frac{B_{\max}}{\langle B_t \rangle} = 0.211(1+\alpha)^{-0.117} m^{-0.854} \gamma_c^{0.156} \xi^{0.796} \zeta^{-0.815} \qquad (2)$$

Figure 1 shows the comparison of the value of magnetic field ratio calculated by numerical computation by the finite- volume current element code and that estimated by the new scaling. You can see the estimation results are in fairly good agreement with the computation result within 3% error.

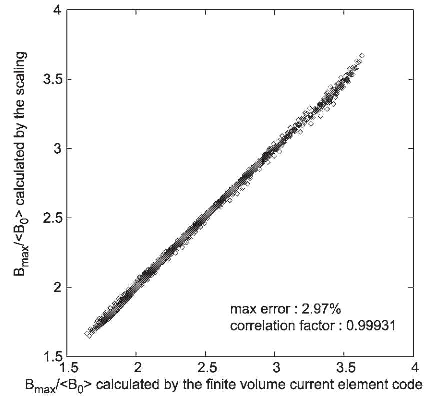

Fig. 1: Comparison of magnetic field ratio by the numerical calculation and that predicted by the scaling.

ii) Adjustment of poloidal coils for FFHR

FFHR (Force Free Helical Reactor) is the main candidate for the LHD-type heliotron fusion reactor. The design of FFHR is based on the result of LHD experiment and it has similar shape to LHD (about 4.4 times larger). To ensure the large space for the ports, however, the position of poloidal coils (PCs) is different.

At first the position and current of PCs were determined by considering the dipole/quardupole field strength, the minimization of leakage field, and the reduction of magnetic stored energy. However, it was found that the magnetic surface structure strongly depends on the vertical field profile at not only plasma center but also plasma edge. Then the volume in last closed flux surface (LCFS) is about 10 % smaller than the expected value with the original PC position. Thus the position and current of PCs were adjusted to reduce the difference of vertical field profile from that of LHD.

It has been clarified that the volume of stochastic region decreases with the decrease of vertical field. On the other hand, there is little change in the position of plasma edge. As shown in Fig.2, 26 % enlargement of LCFS volume has been achieved without significant changes in leakage field and magnetic stored energy. This change also does not affect the space for the blanket.

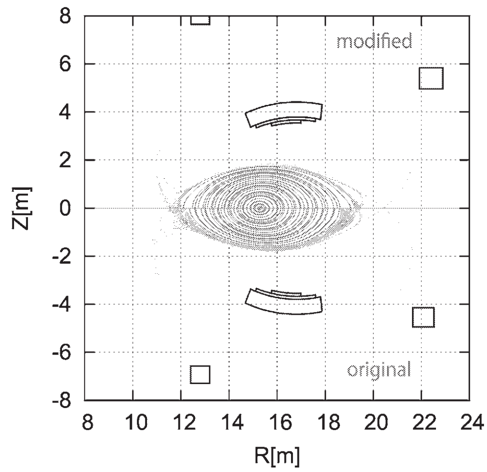

Fig. 2: Comparison of magnetic surface structure of FFHR with modified (upper) / original (lower) PC position.

1) J.Todoroki, "Magnetic Field Calculation of Finite Size Helical Coils with Rectangular Cross Section": Kakuyugo-Kenkyu **57** (1987) 318.