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# Optimization Study of Heliotron J Magnetic Configuration using particles orbit analysis

粒子軌道解析を用いたヘリオトロンJ磁場配位の最適化

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The straight part of Heliotron J has a small magnetic gradient, so we can control neoclassical transport by localizing particles there. Heliotron J has good accessibility because of a 1-pole helical coil , but has magnetic harmonics by the restriction of the helical coil. We think that we can improve about confinement of plasma. So in this study, we try to improve orbit confinement about Heliotron J by analyzing particle orbit , loss rate and loss time using STELLOPT, which is nonlinear optimization method.

## 1. Introduction

Helical plasma including heliotron and stellarator can confine steady state plasma in principle because their three-dimensional magnetic field for plasma confinement is mainly produced by external coils. However, magnetic field intensity change intricately because Helical magnetic field has no axial symmetry, and the complex nature of three-dimensional would lead to degradation of plasma confinement and optimization aiming at improvement of neoclassical and anomalous transport, and MHD stability is needed.

Optimization has been studied for a new helical device design. But it is difficult to change the coil configuration, once the device is completed. So this study is proceeding with finding a more optimal magnetic configuration which include additional trim coils based on the Heliotron J.

## 2. Optimized the value of *J* invariants and $B_{min}$

In order to improve the magnetic configuration of Heliotron J, we try to optimize it using stellarator optimizer “STELLOPT” [1]. In the previous optimization with regard to good particle confinement, we measured and optimized the values of both second adiabatic invariants *J* and *B* minimum($B_{min}$),which indicate the orbit of helically trapped particle. Figure 1 shows the $B_{min}$ contour of optimized configuration by STELLOPT. It shows the concentric circle contour, which well aligned the magnetic surface. However, $B_{min}$ contour do not continue around the $\theta$ ~ 0 (deg) where magnetic field tend to be modulated by high magnetic harmonics of Fourier component with small amplitude because magnetic field intensity is weak and constant. Figure 2 shows the orbit of particle, which moving at the optimized magnetic configuration. The particle moved along the magnetic surface at first, but it escaped to the outside of plasma .Figure 3 are the contour of magnetic field strength, and show that *J* invariants optimized configuration cannot confine the trapped particles because of unclosed $B_{min}$ contour, which coincide with the approximative trajectory of trapped particles.

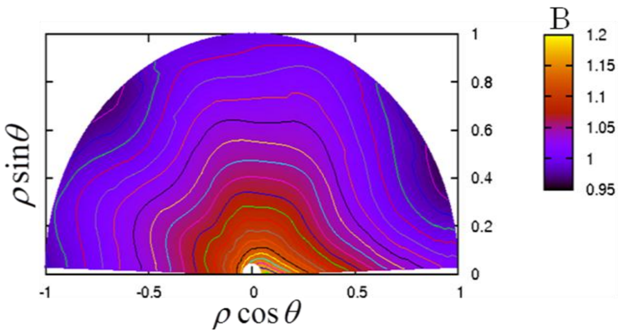


Fig.1. $B_{min}$ contour of optimized configuration.

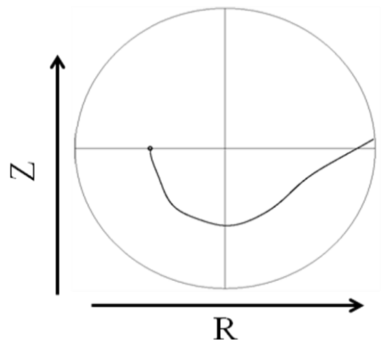


Fig.2. The orbit of particle, which moving at the optimized magnetic configuration.

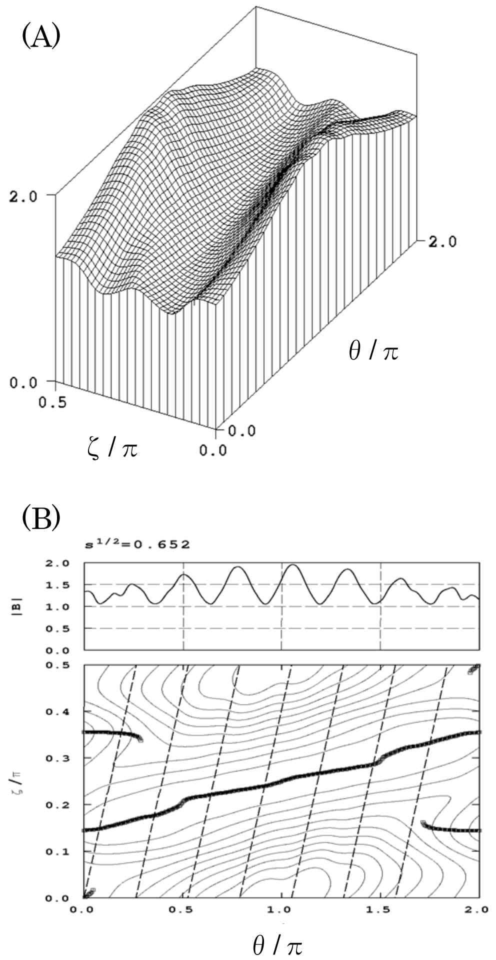


Fig.3. The contour of magnetic field strength,
(A) 3D figure, (B) 2D figure and heavy line indicates line of $B_{\min}$

It was found from these results that there is a limit to optimizing of magnetic configuration by using the value of second adiabatic invariants J. So in this study, we are analyzing the particle orbit to optimize the magnetic configuration.

### 3. Details of STELLOPT code

The STELLOPT code searches parameter space for a given set of parameters looking for a 'best-match' to desired values. This is accomplished through iteration of the VMEC routine, calculation of various values from other utility codes (in this study, we added ORBNEW which can analyze particle orbit[2]) and characterization of a given VMEC equilibria in terms of the desired parameters. This characterization is done in terms of Chi-squared values where

$$\chi^2 = \frac{1}{\sigma^2}\left(f_{target} - f_{equilbria}\right)^2 \quad . \qquad (1)$$

The sigma here represents the tolerance of the target value. A given VMEC equilibria can be characterized by a set of these chi-squared values (the sum of which characterizes the entire set of target values). The goal of the code is to minimize the total chi-squared value.

The algorithm for STELLOPT is quite conceptually simple. First a VMEC equilibria is found. Using this equilibria as input, various utility codes are run. These utility codes provide STELLOPT with equilibria values to compare against target values. The STELLOPT code then enters it's main minimization loop. Here all free parameters are varied and VMEC is run for each varied free parameter. The various equilibria are then passed to the utility codes for calculation of values. The equilibria with the lowest chi-squared value is then taken to be the equilibria of interest. If the chi-squared falls below a user defined value then iteration ceases, otherwise the free parameters are again varied. The choice of specific optimization algorithm modifies this loop slightly but essentially the algorithm remains intact. The modified Levenberg-Marquardt algorithm to see that the step produces a lower chi-squared value than that found by the Jacobian evaluation. If not, the code searches near the lowest Jacobian evaluation for the best fit.

### 4. Optimize the value of loss rate

In this study, we added ORBNEW code, which can analyze particle orbit, to STELLOPT code. Then, we are optimizing magnetic configuration with the helically trapped particle loss rate as one of the evaluation functions.

The results of this study is under consideration and will helpful to improve the confinement of stellarator plasmas.

### 5. Reference

[1] D.Spong,et al. : Nucl Fusion. **41**(2001) 711
[2] Allen H. Boozer : Phys. Fluids **23**(1980) 904