Finite beta effects on alpha particle heat loads in high-beta ripple tokamak plasmas 高ベータリップルトカマクにおけるα粒子の熱損失に与える有限ベータ効果

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The energetic ion confinement is deteriorated by the ripple magnetic fields in a tokamak plasma. Not only the finite number of external toroidal field coils but also the plasma currents change the magnetic field configurations. The magnetic field from the plasma current was calculated from the VMEC results with based on the Biot-Savart law. Three kinds of three-dimensional magnetic field configurations for ten beta scenarios were prepared to analyze the finite beta effects by calculating the orbits of alpha particles.

1. Introduction

A tokamak is usually assumed as the axisymmetric system, however, the finite number of the toroidal field (TF) coils creates the non-axisymmetric magnetic field, which is call as the TF ripple. The ripple field changes the orbit of energetic ions and increases the amount of loss particles. These losses produce several serious problems in a tokamak, such as the deterioration of the plasma heating efficiency and the concentration of heat loads on the first wall.

The accurate magnetic field structures with including the finite beta effects are necessary to be analyzed for these problems because the plasma current also changes configurations of magnetic fields. The finite beta effects can be categorized such as magnetic components (the todoidal or poloidal field) or non-axisymmetric components (the axisymmetric or non-axisymmetric field). We should estimate how the field from the plasma current affects on the ripple induced orbit losses of energetic ions.

In the previous study, 2D MHD equilibrium calculation code was usually used by assuming a plasma to be axisymmetric. Although resulting MHD equilibrium field was axisymmetric, 3D magnetic field can be approximately obtained by superimposing the ripple components of the vacuum field on it. This approximation method is called as the vacuum approximation. While, VMEC is one of the 3D, free boundary MHD equilibrium code and this code has been ordinary used in a helical plasma [1,2]. However, VMEC was used also for a ripple tokamak to obtain the full 3D MHD equilibria. The most serious problem of VMEC was limited calculating region because of using the magnetic coordinates. We developed the equilibrium magnetic field calculation code with VMEC results by the Biot-Savart law. The precise discussion was presented in the 8th APFA 2011 "Beta value dependence on the ripple induced losses and the heat loads".

The research method for this study was described in Sec.2 and these results were shown in Sec.3. Finally, summaries and conclusions were described in Sec.4.

2. Research method

VMEC code was used in this study to obtain the MHD equilibria and the field from the plasma current. The calculating configurations, such as the shape of TF coils and distribution of the safety profile q, were referred to the steady state operation of an ITER scenario 4 [3-5]. We prepared 10 beta scenarios by changing the scale of the plasma pressure to estimate the beta value dependence on the ripple induced losses. In addition, the magnetic field from the plasma current was divided to 3 parts, the axisymmetric poloidal field B_{θ} , axisymmetric

toroidal field B_{ϕ} and non-axisymmetric field *B*. The axisymmetric poloidal field was required to create the closed magnetic surfaces. We made 3 kinds of 3D magnetic fields for each beta scenario,

A). $B_{ext} + B_{\theta}$

B). $B_{ext} + B_{\theta} + B_{\phi}$

C). $B_{ext} + B_{\theta} + B_{\varphi} + B$,

where B_{ext} was the magnetic field from the external coil currents.

The each magnetic field component B_{θ} , B_{φ} and Bin the cylindrical coordinates (R,Z, φ) was obtained from VMEC results by the calculation code introduced in Sec.1. The orbits of alpha particles were calculated with these 3D fields by F3D-OFMC code to analyze the finite beta effects on the ripple induced losses [6].

3. Results

We calculated the orbits of 10000 alpha particles by F3D-OFMC with each magnetic field. The loss rate was defined as the ratio of the kinitic energy of all loss particles at the loss point to the initial energy of all particles and described in Fig.1, where the green, blue and red line showed the loss rate for A, B and C, respectively.

This figure showed that B_{θ} , B_{φ} and \tilde{B} enhanced the loss rate with increasing the volume averaged beta $<\beta>$. The poloidal magnetic field B_{θ} from the plasma current produced the Schafranov-Shift and the magnetic axis moved to the outer torus. The increased loss rate with B_{θ} came from this shift because the high ripple region was localized on the outer torus. The non-axisymmetric component also increased the loss rate, however, this change was smaller than other finite beta effects. While, the reason for the increasing loss rate by B_{φ} was not clear because this field did not affect on the shape of magnetic flux surfaces and the ripple components. The toloidal field worked as the diamagnetic for the high beta plasma and reduced the strength of the magnetic field. In a result, the contour of B_{min} became to be closed at outer torus, where B_{min} was the minimum strength of the magnetic field along the toroidal angle. The orbit of the deeply ripple trapped particles and the tip of banana particles mainly followed this contour. The detailed discussion and figures will be presented in the poster session.

4. Summary

In this study, we used the VMEC code to analyze the beta value dependence on the ripple induced losses. Three kinds of magnetic field configurations for ten beta scenarios were prepared and the orbits of 10000 alpha particles were followed by F3D-OFMC code.





Fig.1 The beta dependence on the loss rate for scenario A (the green line), B (the blue line) and C (the red line)

ripple induced orbit losses, while the change of loss rate from the non-axisymmetric field was small especially in a low beta plasma. The normal $<\beta>$ for the steady state operation of ITER scenario 4 was about 2%, therefore, we can conclude that 3D MHD equilibrium calculation was not required for an ITER plasma.

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