Three-dimensional MHD equilibrium with stochastic field in tokamaks

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1. Introduction

In most of situations, tokamak equilibria are analyzed as two-dimensional (2D) systems with the axisymmetry. The nature of this symmetry gives many advantages for its analysis. However, as realistic tokamaks have discreteness of the toroidal field coils, this discreteness yields the toroidal field ripples (TF ripples) and, strictly speaking, realistic tokamaks could not be axisymmetric configurations. In previous work[1)], we pointed out the significance of three-dimensional (3D) effects, which are effects of plasma equilibrium currents along rippled field lines.

On the other hand, in recent tokamak experiments, it is noted that stochastic filed lines reduce strong heat load driven by the edge localize mode (ELM) on the divertor plate. Stochastic field lines are produced by the external helical perturbation and it is called the Dynamic Ergodic Divertor (DED). From the viewpoint of high-β stellarator equilibrium, 3D effects on the stochastic field are very important because finite-β perturbed field produces further stochasticity in the peripheral region. However, in present analysis of DED, 2D MHD equilibrium superimposed vacuum helical perturbed field was still used. In order to consider effects of DED to ELM, considerations of finite-β MHD equilibrium and the impact of 3D effects are critical and urgent issue.

In this study, the fully 3D MHD equilibrium of non-axisymmetric tokamak is solved numerically and equilibrium responses are studied. For this study, we use a 3D MHD equilibrium code HINT[2)], which is widely used to analyze the 3D equilibrium in stellarator researches. Since the HINT uses the real coordinate system, it can treat magnetic island and stochastic field in the computational domain. Thus, as first step, we study the equilibrium response to the error field. Special attention is the equilibrium response on the test blanket module (TBM).

2. Vacuum field in the ITER

At first, we discuss the vacuum field in the ITER. The TF ripple in the ITER is usually around 1% and the ripple is already very small. However, the ripple loss of alpha particles is not negligible for the heat load on the first all. To reduce the TF ripple furthermore, the ferritic steel is installed in the inside of the first wall. Install the ferritic steel, the ripple is reduced less than 1%. On the other hand, to breed the tritium, installing the test blanket module (TBM) is planning. Since the TBM will be shielded, the ripple is superposed with low-*n*.

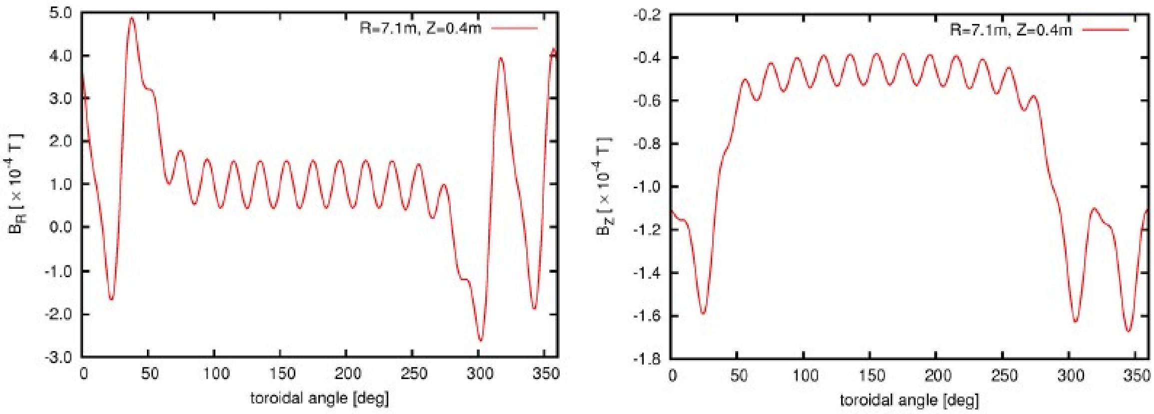

Figure 1 Magnetic fields B_R and B_Z for the vacuum are shown along the toroidal angle. The magnetic field is the total field including the TF coils, superposed the ferritic insert and superposed ferritic insert with the TBM.

Figure 1 shows the magnetic fields B_R and B_Z for the vacuum are shown along the toroidal angle. The TBMs will be installed in 3 sections and those section are localize at $\phi \sim 0$. This means TBMs will be the source of external perturbed fields. In fig.2, B_R and B_Z in the section of TBMs is larger than 10^{-4}. This seems appearing magnetic island on rational surfaces.

3. 3 D MHD equilibrium for the steady-state discharge

In this study, we study an ITER scenario for the inductive current drive, so-called Senario2. In the scenario 2, the safety factor in the plasma core is close to 1 or smaller than 1. Figure 2 shows the safety factor profile for the scenario 2. A green lines indicates q=1 constant. This means if the perturbed field resonated with n/m=1/1 is superposed then the magnetic island appears on q=1 surface. Figure 3 shows puncture plots of magnetic field lines for the vacuum approximation and 3D MHD equilibrium. Color bars indicate the connection length of the magnetic field line. The connection length is limited to 1000m. For the vacuum approximation, an n/m=1/1 island appeared on q=1 surface. In addition, near the separatorix, magnetic field lines become stochastic but the connection length is still very long. On the other hand, for the 3D MHD equilibrium, the magnetic island still appeared.

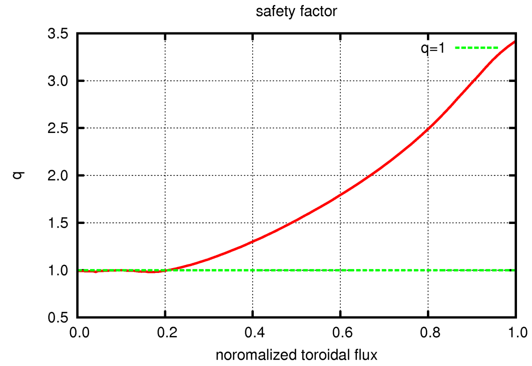

Figure 2 A profile of the safety factor profile for the scenario 2 is shown as the function of the normalized toroidal flux.

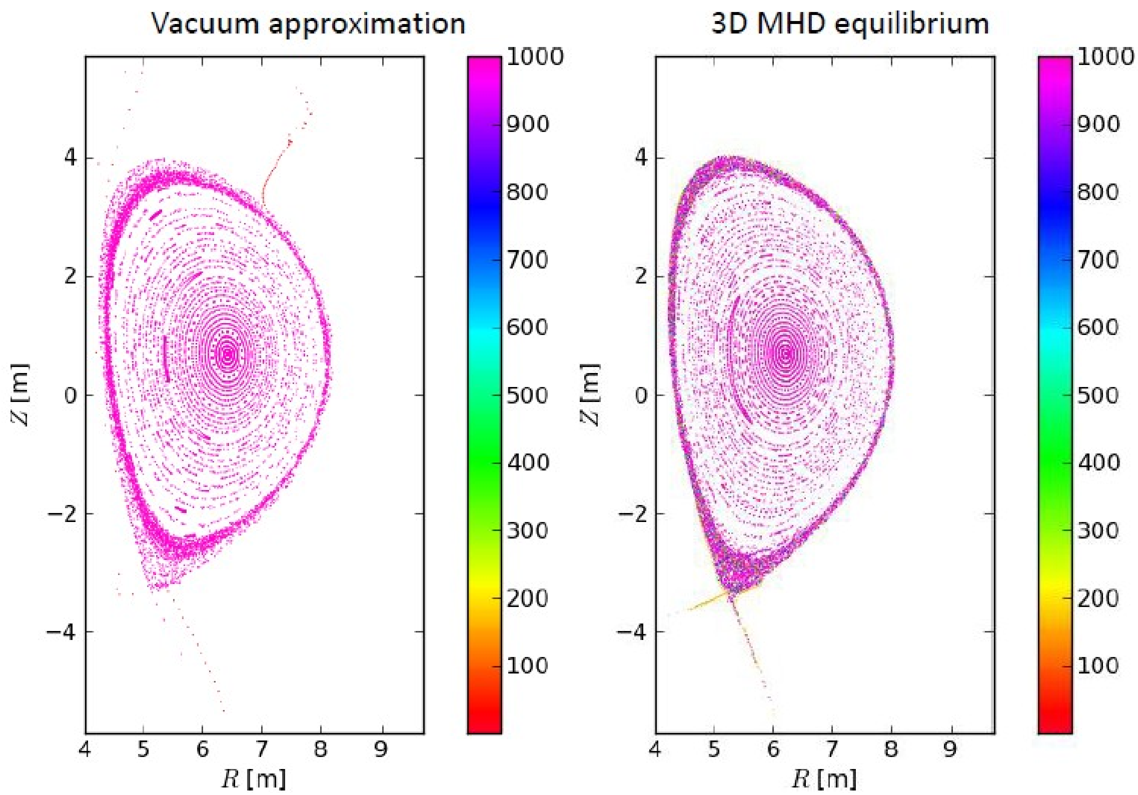

Figure 3 Puncture plots of magnetic field lines for the vacuum approximation and 3D MHD equilibrium are shown. Color bars indicate the connection length of the magnetic field line.

From puncture plots, the width of magnetic islands is almost same. However, major difference between the vacuum approximation and 3D MHD equilibrium is the connection length of the magnetic field line. For the vacuum approximation, in spite of appearing the stochastization, the connection length does not change. On the other hand, for the 3D MHD equilibrium, in the stochastic region near the separatorix, the connection length becomes shorter than the vacuum approximation. A special attention is that magnetic field lines of long and shot connection length are overlapped in the stochastic region. This is an important result in this study.

4. Summary

3 D MHD equilibrium of an ITER plasma, which includes the effect of the TF ripple and TBM, was studied. For the scenario2, m/n=1/1 island appeared by the perturbation of the TBM. Comparing the vacuum approximation, we found the difference of the edge structure between the 3D MHD equilibrium and vacuum approximation.

1) Y. Suzuki, Y. Nakamura and K. Kondo, Nucl. Fusion **43** (2003) 406

2) Y. Suzuki *et al*., Nucl. Fusion **46** (2006) L19