23P072-P

Numerical MHD Analysis of LHD Plasmas in Magnetic Axis Swing Operation
磁気軸スイング放電におけるLHDプラズマのMHD数値解析

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In the magnetic axis swing operation of Large Helical Device experiments, local pressure collapse was observed. In the operation, the background magnetic field was controlled during the discharge so that the corresponding vacuum magnetic axis should be shifted inwardly. The collapse phenomenon is analyzed numerically. The equilibria calculation with the pressure profile assumed as the shape of the square of parabola show that the magnetic hill is formed and the magnetic shear is reduced at the resonant surface in the change of the magnetic field. This property can enhance the driving force of the pressure driven modes, such as interchange modes and infernal modes.

1. Introduction

MHD Stability is one of the crucial issues in the design of future reactors. Coil arrangement has to be determined so that collapse phenomena should be avoided. In the heliotoron configurations, pressure driven modes are the most dangerous instabilites which can cause the collapses. Therefore, the determination of the collapse boundary due to the pressure driven mode is inevitable to construct a heliotron type machine. In the design of the Large Helical Device (LHD), linear stability limit against the ideal interchange mode was employed for the estimation of the collapse boundary. The linear stability analysis shows that the LHD configuration with Rax < 3.75 m is unstable, where Rax denotes the horizontal position of the vacuum magnetic axis. In the LHD experiments, however, good confinement has been obtained in the configuration with Rax=3.6m. Particularly, the highest beta vale of $<\beta>=5.1\%$ is achieved[1] in the configuration. This result indicates the discrepancy between the linear stability results and the experiments.

Recently, so-called magnetic axis swing experiment was carried out to find out the collapse boundary concerning with the position of the vacuum magnetic axis[2]. In this experiment, the currents in the poloidal field coils are changed during each shot so that the corresponding vacuum magnetic axis position should be shifted inwardly. In the case where the corresponding vacuum magnetic axis position is changed from Rax=3.60m to Rax=3.50m, plasma collapse is observed after the corresponding vacuum axis position is about Rax=3.55m. The collapse is localized around the magnetic surface with the rotational transform of 1/2 in the core region. This result indicates the collapse boundary may exist around Rax=3.55m. Thus, in the present work, we investigate the mechanism of the collapse with numerical MHD approach.

2. Numerical Method

To analyze the results of the magnetic axis swing experiment, we have to treat the time evolution of the background equilibrium as well as the perturbations, because the equilibrium quantities vary depending on the change of the coil currents. However, there is big difference between the time scales in the change of the equilibrium and the perturbed quantities. The equilibrium quantities changes in the order of 10ms, while the perturbed quantities changes in the order of 1μs.Therefore, in the analysis of the axis swing experiment, we have to solve a multi-scale problem.

We have already established a numerical scheme to treat such multi-scale problems [3-6]. In the scheme, time-dependent nonlinear dynamics calculation and update of the static equilibrium is iterated. The NORM code[7] and the VMEC code[8] are used for the dynamics and the equilibrium calculations, respectively. The NORM code follows the dynamics based on the reduced MHD equations. In the equilibrium calculation, the deformation of the average part of the pressure is incorporated. This scheme is applied to the LHD plasma in the configuration with Rax=3.6m to investigate the stability mechanism in the plasma. The result indicates a stable scenario to high beta regime with self-organization of the plasma.

In the present work, we utilize this scheme in the numerical analysis. Particularly, we incorporate the change of the magnetic field due to the change of the poloical coil currents in the VMEC equilibrium calculation.

3. Equilibrium Property

Before the nonlinear dynamics calculation, we examine the Rax dependence of the equilibrium quantities. We calculate the free boundary equilibria with the VMEC code under the no net-current condition. The pressure profile of $P=P_0(1-s)^2$ is employed and the beta value at the axis is fixed to β_0=4.2%, where s denotes the normalized toroidal magnetic flux. In the free boundary calculation, a virtual limiter is set at R=4.2m. We change the vacuum magnetic field from that of Rax=3.6m to that of Rax=3.5m.

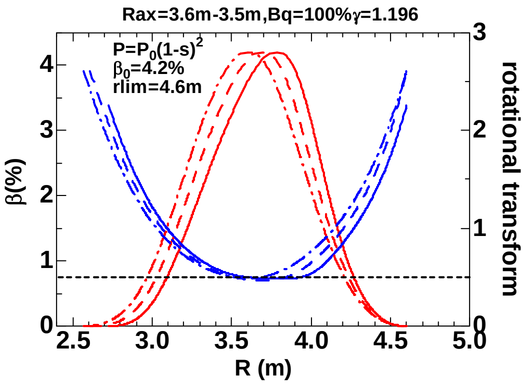

Fig.1. Rax dependence of pressure profile and rotational transform profile as functions of major axis R. Solid, dashed, and dot-dashed lines correspond to Rax=3,60m, 3,55m and 3.50m, respectively.

As shown in Fig.1, the magnetic axis is located more inward as Rax decreases. The rotational transform at the magnetic axis is slightly smaller than 1/2 in all cases. As shown in Fig.2, the Rax dependence of the profile is not necessarily monotonic, however, the position of the ι=1/2 surface approaches to the magnetic axis. The magnetic shear becomes weak at the surface simultaneously. The profile of the magnetic well corresponds to the property of the position of the magnetic axis. In the case of Rax=3.6m, the magnetic well spreads from ρ=0 to ρ=0.42 and the surface of ι=1/2 exists in the well region. As Rax decreases, the well region shrinks and there is no well region in the case of Rax =3.5m.

As a result, in the change of the magnetic field from Rax=3.6m to 3.5m, there is a tendency that the magnetic shear is reduced and the magnetic well changes to the magnetic hill. This tendency indicates that an interchange mode is more easily destabilized for smaller Rax. Since the position of the ι=1/2 surface is located near the magnetic axis and the magnetic shear is weak at the surface, a non-resonant mode like an infernal mode can be unstable in these configuration. Based on the knowledge, we study the nonlinear behavior of the unstable modes and investigate the collapse mechanism by applying the multi-scale scheme.

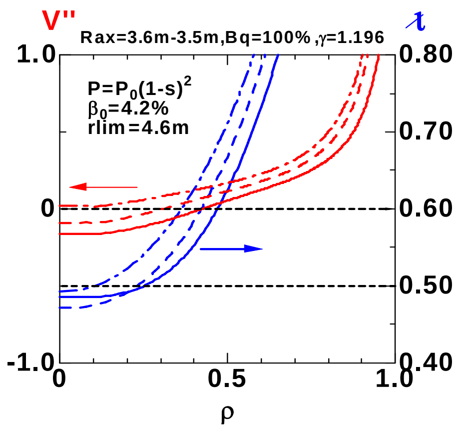

Fig.2. Rax dependence of V'' profile and rotational transform profile as functions of ρ. Solid, dashed, and dot-dashed lines correspond to Rax=3,60m, 3,55m and 3.50m, respectively.

Acknowledgments

This work is supported by a budget NIFS11KLTT001 of the National Institute for Fusion Science, and Grant-in-Aid for Scientific Research (C) 22560822 of JSPS Japan.

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