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# MHD Simulation of Pressure Driven Modes in LHD Plasmas with RMP
# RMPを含むLHDプラズマにおける圧力駆動型モードのMHDシミュレーション

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The interaction between pressure driven modes and magnetic islands generated by a resonant magnetic perturbation (RMP) in a Large Helical Device (LHD) configuration is numerically analyzed, utilizing three-dimensional (3D) magnetohydrodynamics (MHD) equilibrium and dynamics codes. The deformation of the equilibrium pressure profile due to the RMP changes the mode structure from the interchange type to the ballooning type that is localized around the X-point. The nonlinear evolution of the mode causes a pressure collapse which spreads from the X-point to the core. Therefore, the spatial phase of the collapse is fixed to the island geometry. The fixed phase is consistent with the LHD experimental results with a natural error field.

## 1. Introduction

In the recent study of magnetically confined fusion plasmas, resonant magnetic perturbations (RMPs) are studied from the viewpoint of the magnetohydrodynamics (MHD) stability against pressure driven modes, because RMPs can locally change the pressure gradient. In tokamaks, the mitigation of the edge localized modes with the RMPs in the H-mode plasmas has been widely studied [1]. In heliotrons, since pressure driven modes are the most dangerous instabilities, the change of the pressure gradient can directly influence the global stability. Therefore, the effects of the RMPs on the MHD behavior are also extensively studied in the Large Helical Device (LHD) experiments [2]. Here, the interaction between pressure driven modes and magnetic islands generated by an RMP is numerically analyzed in an unstable LHD configuration.

For the MHD analysis of the RMP effects, an equilibrium with a pressure profile consistent with the magnetic structure disturbed by the RMPs is necessary. To obtain such an equilibrium, we utilize the HINT2 code [3], which finds a three-dimensional (3D) equilibrium without any assumption of the existence of nested surfaces. To examine the linear stability and the nonlinear dynamics of the plasma in the equilibria, a 3D dynamics code is desirable. We utilize the MIPS code [4], which solves the full 3D MHD equations by following the time evolution.

## 2. 3D LHD Equilibrium with RMP

In the equilibria calculation with the HINT2 code, we employ an LHD configuration with a high aspect ratio and a magnetic hill. A parabolic pressure profile with the beta at the magnetic axis of 4.4% is assumed in the case without the RMP. The equilibrium with the RMP is obtained by including a constant horizontal magnetic field. The direction and the amplitude of the RMP are chosen so as to correspond to the natural error field observed in the LHD [5].

In the case without the RMP, nested flux surfaces are obtained in the whole plasma region. The $\iota/2\pi=1$ surface exists in the plasma column, where $\iota/2\pi$ denotes rotational transform. On the other hand, in the case with the RMP, an $m=1/n=1$ magnetic island appears, which is resonant at the $\iota/2\pi=1$ surface, where m and n are the poloidal and the toroidal mode numbers, respectively. The pressure profiles consistent with the magnetic configurations are obtained in both cases. In the case with the RMP, the pressure profile has a local flat region around the O-point with the gradient kept at the X-point.

## 3. Effects on Linear Mode Structure

The MIPS code solves the full MHD equations. The fourth order central finite difference method is utilized for the directions of R, Z and $\phi$, respectively. The dynamics of the plasma is studied with the code involving the resistivity, the viscosity, and the perpendicular and the parallel heat conductivities in the present study. The parameters are chosen so that pressure driven modes are destabilized.

In the time evolution of the kinetic energy of the perturbations, after the linear growth phase, the modes are nonlinearly saturated in both cases without and with the RMP. However, the linear mode structure is different between the cases without and with the RMP. In the case without the RMP, the mode pattern of the perturbed pressure is localized around the $\iota/2\pi$ =1 surface in the radial direction and is distributed almost uniformly in the poloidal direction. This pattern indicates the modes are typical interchange modes. On the other hand, in the case with the RMP, the mode is localized around the X-point of the island like a ballooning mode. This difference in the mode structure is attributed to the equilibrium pressure profile. In the case without the RMP, the pressure gradient is constant on the resonant surface. However, in the case without the RMP, the gradient is reduced at the O-point and is the steepest at the X-point in the poloidal direction. Therefore, the mode can utilizes the driving force most efficiently by being localized around the X-point.

## 4. Nonlinear Dynamics

By following the time evolution of the pressure driven modes, we analyze the nonlinear dynamics of the pressure driven modes. In the case without the RMP, the pressure profile is deformed by the convection of the interchange mode. A mushroom-like shape is generated, and then, the total pressure collapses. The magnetic surfaces are also destroyed by the convection and the magnetic field lines become stochastic. In this case, there is no special phase of the structure in the poloidal and the toroidal direction. Therefore, the phase can be changed depending on the choice of the initial condition.

In the case with RMP, the pressure collapse starts at the X-point, and then, spreads to the core region. This is because the linear mode structure is localized at the X-point. The magnetic surfaces are also destroyed from the X-point, however, the island structure in the puncture plot of the field lines survives even when the pressure collapses in the position of the original magnetic axis. Thus, the spatial phase of the collapse is fixed to that of the island geometry.

## 5. Summary and Discussion

In this study, the effect of an RMP on pressure driven modes is numerically analyzed. The mode structure changes depending on the local deformation of the equilibrium pressure profile. Therefore, it is crucial to calculate correctly the equilibrium where the pressure is consistent with the magnetic field including the RMP. For such calculation, 3D equilibrium calculation code is necessary. In the present analysis, the HINT2 code is utilized for the 3D equilibrium calculation. A high aspect ratio LHD plasma including a constant horizontal error field as the RMP is analyzed A magnetic island is generated and the equilibrium pressure profile is locally flat around the O-point. This deformation of the pressure localizes the mode structure around the X-point as in the case of a ballooning mode. This structure is quite different from that of an interchange mode that is destabilized in the equilibrium without the RMP.

In the case with the RMP, the collapse occurs from the X-point, and therefore, the spatial phase of the mode is fixed to that of the magnetic island. In the LHD experiments of the same configuration [2], collapses are observed in the profile of the electron temperature in both cases of the existence and the reduction of the error field. The spatial phase in the toroidal direction of the saturated mode is fixed in the existence of the error field, while the phase is changed in the reduction of the error field. This property is consistent with the present result.

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### References

[1] EVANS, T., et al., Nature Physics. **2** (2006) 419..

[2] SAKAKIBARA, S., et al., Nucl. Fusion, **53**, (2013) 043010..

[3] SUZUKI, Y,. et al, Nucl. Fusion **46** L19 (2006).

[4] TODO, Y., et al, Plasma and Fusion Res. **5** S2062 (2010).

[5] MORISAKI, T., et al, Fusion Sci. Tech. **58** 465 (2010).