§9. 3D Plasma Response to Resonant External Magnetic Perturbation and its Impact on Fast Ion Confinement in JT-60SA Plasmas

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The reduction of the heat load on divertors caused by Edge Localized Modes (ELMs) is a key issue in the ITER. Large energy flux of Type-I ELMs is expected to cause melting of the tungsten divertors in ITER. One of the methods to control ELMs is an application of RMP fields;, in fact, mitigation or suppression of ELMs by RMPs are observed in many tokamak experiments. However, those results are not verified in the steady state operation. Therefore, to extrapolate those results to the ITER, RMPs experiments in the JT-60SA tokamak are critical and urgent issues. In the JT-60SA experiments, EFCCs will be utilized as RMP coils. For this reason, we have qualitatively and quantitatively studied the magnetic field topology with superposed RMPs by EFCCs to develop scenarios of RMPs experiment in the JT-60SA. In the operational aspects, how much the EFCC current to stochastize the magnetic field structure can be available is necessary since EFCCs must be used for the error field correction and the capacity of EFCC power supplies is limited.

At first, the 3D MHD equilibrium with RMPs is calculated and compared with the vacuum approximation. The 3D MHD equilibrium is calculated by the HINT2 code, which is a 3D MHD equilibrium calculation code without the assumption of nested flux surfaces. Using the HINT2 code, we can correctly study correctly effects of the 3D plasma response. In this study, n=3 perturbed field, which will be used in ITER, is applied for a scenario with I_p=5.5MA. In this scenario, the safety factor profile increases monotonically from 0.7 to 3.5. The 3D MHD equilibrium with helical perturbations by RMPs is calculated to satisfy the local force balance resulting in the 3D plasma displacement. Namely, the plasma column shifts to the inward and the helical distortion of the magnetic axis appears. In addition, the stochastization of magnetic field lines due to nonlinear couplings of resonant and non-resonant components of RMPs is observed. Magnetic islands are generated by n=3 RMPs. In addition, magnetic field lines of the separatrix cause large radial excursions. For $\rho \geq 0.95$, magnetic field lines open and becomes stochastic. Compared with the vacuum approximation, magnetic islands of m/n=3/3, 4/3 and 5/3 surfaces evolve but higher-m magnetic islands ($m > 6$) shrink. Therefore, it seems that the stochasticity in the edge region decreases.

To compare the magnetic field structures with the effects of the 3D plasma response and the vacuum approximation, the Chirikov parameter, which is a criteria of overlapping magnetic islands if it becomes unity, is calculated. Here, the Chirikov parameter at $\rho > 0.9$ where ELMs appear is focused. Radial profiles of the Chirikov parameter for the HINT2 result (I_{EFCC}=10, 20, 30kA) and the vacuum approximation (I_{EFCC}=10kA). For the vacuum approximation, the Chirikov parameter is almost unity at $\rho > 0.9$. However, for the HINT2 calculation including the 3D plasma response, the Chirikov parameter becomes smaller than unity in the same I_{EFCC}. Therefore, the 3D plasma response shields RMPs. With increased I_{EFCC} of HINT2 results, the Chirikov parameter increases. For I_{EFCC}=30kA, the Chirikov parameter is almost the same as the vacuum approximation of I_{EFCC}=10kA. The total current of the power supply for EFCCs is 45kA. Thus, the operation of I_{EFCC}=30kA will be possible in the experiments.

A Global change ofin the magnetic field also leads to the fast ion loss. In recent experiments, the difference in energetic ion losses between the vacuum approximation and MHD model has been suggested. 3D Monte Carlo simulations by the OFMC code are performed with n=3 RMPs. The vacuum approximation and the HINT2 result of I_{EFCC}=10kA are compared in Fig. 1. Although profiles of the Chirikov parameter are almost same in both cases, it is found that the significant difference of the fast ion lossbetween two models. The prompt loss of fast ions is enhanced in the HINT2 results. This suggests the 3D plasma response strongly affects the magnetic field topology.

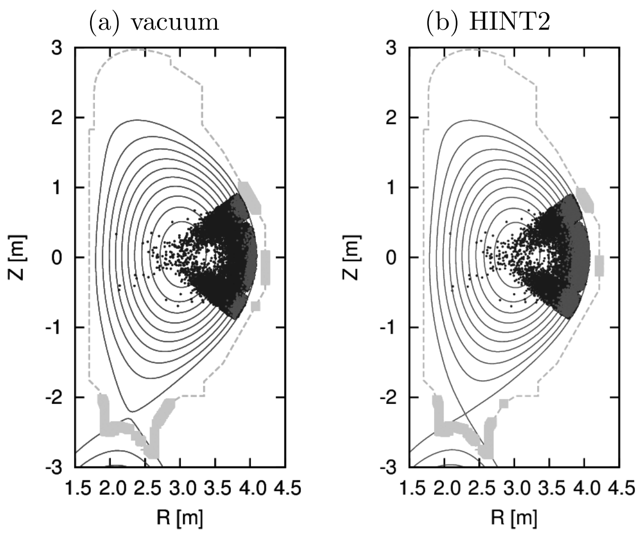

Fig. 1: birth profiles (blue), birth points of lost ions (perpule), loss points of fast ions on the vessel (light blue), and the vacuum vessel (green) for (a) the vacuum approximation and (b) HINT2 results are shown respectively. For a reference, flux surfaces (red) are also indicated. The $I_{\rm EFCC}$ is 10 kA.