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Application of resonant magnetic perturbations to tokamak plasmas
トカマクプラズマへの外部共鳴摂動磁場印加実験

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Externally applied resonant magnetic perturbations (RMPs) are used for control of tokamak plasmas. The RMP field penetration processes into tokamak plasmas are investigated by the dynamic ergodic divertor in TEXTOR. Measurements of the plasma response to the RMP field are performed and the observed data are interpreted by theoretical models. It is observed that the growth of the magnetic island by the RMP field penetration is accompanied by a change of the toroidal plasma fluid rotation. The relative rotation frequency between the RMP field and the plasma plays an important role in the process of the RMP field penetration.

1. Introduction

Externally applied resonant magnetic perturbations (RMPs) are used in order to investigate a lot of applications in tokamak devices such as ergodic divertors [1], the control of MHD instabilities [2], and the suppression of edge localized modes (ELMs) [3]. In particular, the application of RMPs by in-vessel coils is one of the methods of foreseen to control ELMs in ITER. The ergodisation of the edge magnetic field is generally evaluated by adding the equilibrium magnetic field to the perturbation field produced by the RMP coils, where the RMP field propagates in vacuum. However, the plasma response to the RMP strongly modifies the level of edge ergodisation. It could affect the plasma transport and the stability of ELMs. As summarized in Fig. 1, the effect of plasma response on the expected heat and particle fluxes to plasma facing components between ELMs and during ELMs mitigated with the application of RMP has to be investigated.

The Dynamic Ergodic Divertor (DED) [4] in the TEXTOR tokamak has been installed to study a lot of applications connected to the interaction of RMP with tokamak plasmas. In this talk, both experimental and theoretical studies related to the RMP penetration in TEXTOR will be shown.

2. RMP coils in TEXTOR

The RMP coils in TEXTOR consist of 16 external perturbation coils at the high field side inside the vacuum vessel. The DED system can produce static or rotating RMP fields up to a maximum frequency of 10 kHz which covers the frequency range of the typical plasma diamagnetic drift in the TEXTOR tokamak. The base mode numbers of the RMP coils can be selected by the connections of the power supplies to the coils between m/n = 12/4, 6/2, and 3/1, where m, n refers to the poloidal and toroidal mode number. The m/n = 12/4 mode decays rather quickly, so that it affects mainly the plasma edge. On the other hand, the m/n = 3/1 mode penetrates deeply into the plasma. The strong sideband component of m/n = 2/1 is produced, so an m/n = 2/1 tearing mode is well reproduced [5].

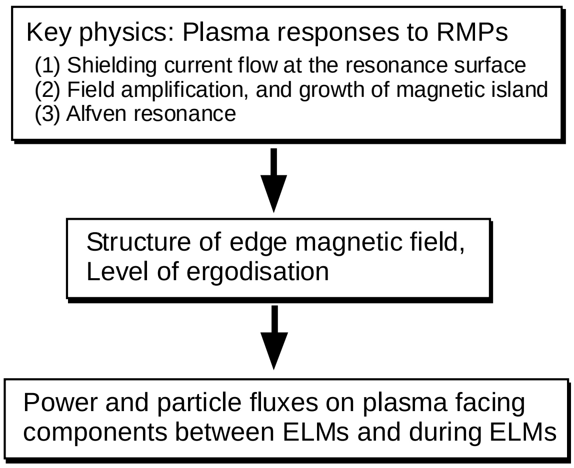

Fig. 1 Relation between plasma response to RMPs and PWI issues

3. RMP penetration into tokamak plasmas

The DED with m/n = 3/1 mode is mainly used in this study. The plasma response to the RMP is measured by a Hall probe. The Hall probe is located outside the plasma (r/a = 1.04). It reveals that two stages in the time development of the plasma response to the RMP field can be distinguished, where the RMP coils current is linearly increased in time during the discharge [6]. In the first phase, the induced plasma current at the resonant magnetic surface ($q = m/n$) is phased such that it shields the penetrating perturbation field. After passing the threshold of the RMP field amplitude, a phase jump of the plasma response to the RMP is observed and the current at the resonant surface amplifies the external magnetic perturbation.

The observed RMP field penetration in the experiment is compared with theoretical models as follows. Firstly, it is also observed that the RMP field penetration is accompanied by a change of the toroidal plasma fluid rotation in the experiment. The bifurcation of the RMP field penetration from the suppressed to the excited state is confirmed by a quasi-linear MHD simulation in cylindrical geometry [7]. Secondary, the threshold of RMP field amplitude for the bifurcation of the RMP field penetration depends on the rotation direction of the rotating RMP field in the experiment. A linear two-fluid model is also performed in order to include the effects of electron diamagnetic drift on the RMP penetration [6, 8]. It is concluded that the relative rotation frequency between the mode and the applied RMP field is important in determining the threshold for the bifurcation. This feature is also confirmed in a non-linear two-fluid model [9].

On the other hand, the RMP penetration is also affected by the Alfven resonance ($\omega_{\mathrm{RMP}}^2 = k_{\parallel}^2 v_{\mathrm{A}}^2$, $k_{\parallel}$ is the wave number parallel to the equilibrium magnetic field, and v_{A} is the Alfven velocity). When the distance between the two Alfven resonances is wide enough compared with that of the resistive layer at the resonant magnetic surface ($k_{\parallel} = 0$), two current sheets are formed there [7, 10]. However, it is considered that the Alfven resonances locate inside the resistive layer in the TEXTOR plasma. On the other hand, an rf current of ~ 5 A with frequencies swept from 100 kHz to 1 MHz is applied on the RMP coil in TEXTOR [11]. Minov coil signals indicate that Alfven eigenmode is excited by the RMP field. This experiment is conducted under the IEA-TEXTOR collaboration program.

Finally, it should be noted that pioneering studies related to RMP penetration processes into tokamak plasmas have been performed on small tokamaks, CSTN-IV [12] and HYBTOK-II [13] in Nagoya University. It is confirmed that the theoretical model can explain the observed radial profiles of the RMP field inside the plasma by inserting small magnetic pick-up coils in HYBTOK-II [14]. It is considered that these fundamental studies play an important role for understandings of the RMP penetration in TEXTOR.

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