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Effects of the Sawtooth Period Control in Tokamak Plasma
トカマクプラズマにおける鋸歯状振動の周期制御の効果

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The effects of the sawooth period control by ECCD on the critical β_N for triggering NTMs was analyzed by 1.5-dimensional transport code TOTAL. It is found that the critical β_N increases by up to approximately 35~50% and the sawtooth period normalized by the resistive diffusion time decreases by up to approximately 47~57%. In addition, it is found that the effects of ECCD increase when the current drive amount increases.

1. Introduction

In inductive operation of tokamak plasma such as the standard operation of ITER, the safety factor at the center of plasma becomes below unity through penetration of the plasma current, so that the sawtooth oscillation occurs in the central region of plasma. The sawteeth eject plasma energy from the plasma center and limit the fusion power. Furthermore, the sawteeth with long periods may trigger other instabilities such as the neoclassical tearing modes (NTMs). NTMs reduce the plasma confinement capability significantly. Therefore, it is necessary to control the sawteeth so as not to trigger NTMs for achieving a high performance. Using the feature that the onset of the sawtooth crashes depends on the magnetic shear at $q=1$ surface, the sawtooth period control is attempted by changing the magnetic shear at $q=1$ surface by the electron cyclotron current drive (ECCD) as the method of the sawtooth period control.

We simulated the sawteeth by using a 1.5-dimensional transport code TOTAL (toroidal transport analysis linkage) [1]. In this study, we adopted the Porcelli model [2,3] as the triggering model for the sawtooth crashes. In this model, the sawtooth crashes are triggered when one of the three conditions is satisfied. We focused on triggering NTMs by the sawteeth and analyzed the effects of the sawtooth period control.

2. Numerical Model

The thermal diffusivity χ is described as $\chi = \chi^{NC} + \chi^{AN}$ where χ^{NC} is the neoclassical part and χ^{AN} is the anomalous part. For χ^{AN}, we used two type models. One is the Bohm like model [4] and the other is the mixed Bohm/gyro-Bohm model [5].

As a localized current drive model, we adopted ECCD with a Gaussian function j_{CD} which is given by

$$j_{CD}(\rho) \propto \exp\left[-\left\{(\rho-\rho_{CD})/w\right\}^2\right], \qquad (1)$$

where ρ is the normalized minor radius, ρ_{CD} is the normalized radius of deposition of ECCD and w is the normalized full width at half maximum. The current drive amount I_{CD} is given by

$$I_{CD} = \int_S j_{CD}(\rho) dS\,, \qquad (2)$$

where S is the plasma poloidal cross section. ECCD was applied to change the magnetic shear at $q=1$ surface.

The threshold beta for sawtooth-triggered NTMs depends on the sawtooth periods. NTMs are triggered at the lower plasma pressure when the sawtooth periods become longer. There is the following empirical scaling of the critical β_N for triggering NTMs derived from a database of plasma parameters with the sawteeth, including both crashes which trigger NTMs and do not [6].

$$\beta_N^{NTM} = 2.614\left(\frac{\tau_{saw}}{\tau_r}\right)^{-0.4084} \rho_\theta^{0.5721}\left(\frac{P_{aux}}{P_{LH}}\right)^{0.4204} \times \bar{n}_e\left[10^{19}\mathrm{m}^{-3}\right]^{0.4948}, \qquad (3)$$

where β_N^{NTM} is the critical β_N at which the sawtooth crashes will trigger NTMs, τ_{saw} is the sawtooth period, τ_r is the resistive diffusion time, ρ_θ is the poloidal ion Larmor radius normalized by the minor radius of the $q=1$ surface, P_{aux} is the auxiliary heating power, P_{LH} is the L-H threshold power and $\bar{n}_e$ is the line average electron density.

We used the ITER parameters for the plasma parameters. The typical plasma parameters used in the simulation are shown in Table I. The radio frequency (RF) heating is added with a profile of $\exp\left\{-(\rho/0.6)^2\right\}$ as the external heating.

Table I. The typical parameters of ITER

R[m]	6.2	a[m]	2.0
B_t[T]	5.3	I_p[MA]	15
κ	1.7	δ	0.33
$\bar{n}_e$[10^{20}m^{-3}]	1.0		

3. Simulation Results

We simulated β_N^{NTM} when the sawtooth period was controlled in three cases of the RF heating power $P_{RF}=50$MW, 73MW and 110MW. Co-ECCD with $w=0.06$ was applied on $\rho_{CD}=0.58$ where we obtained the shortest sawtooth periods with a fixed RF power. We simulated with both the Bohm like model and the mixed Bohm/gyro-Bohm model and the sawtooth period is longer in the mixed Bohm/gyro-Bohm model than in the Bohm like model. This is because the sawtooth period is affected by the transport process. In this proceeding, we showed the results of the mixed Bohm/gyro-Bohm model. Figure 1 shows the dependence of τ_{saw}/τ_r on I_{CD}. On the other hand, Figure 2 shows the dependence of β_N^{NTM} and β_N on I_{CD}. In both Fig. 1 and Fig. 2, $I_{CD}=0.0$MA implies the operation without ECCD. In Fig. 2, β_N^{NTM} is slightly higher than β_N. β_N^{NTM} is an indicator, so it is necessary for operating with an adequate margin to increase β_N^{NTM}.

τ_{saw}/τ_r became shorter by up to approximately 47~57% and β_N^{NTM} became larger by up to approximately 35~50% when the sawtooth period was controlled by ECCD. In addition, the higher I_{CD} is, the larger the effects of ECCD are. This is because a high I_{CD} prevents the magnetic shear at $q=1$ surface increasing and the sawtooth crashes occur at the slightly lower plasma pressure.

The sawtooth periods are affected not only by the transport process but some plasma parameters. Therefore, simulation using other transport models and in other conditions is necessary for estimating the sawteeth behaviors.

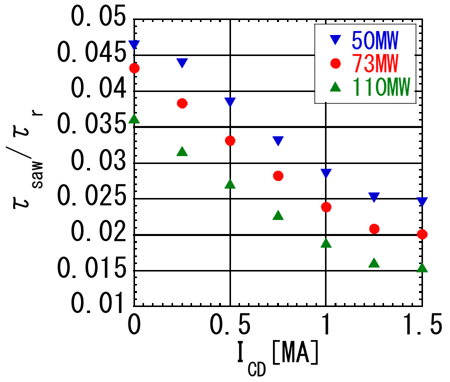

Fig.1. Dependence of τ_{saw}/τ_r on I_{CD} in the mixed Bohm/gyro-Bohm model

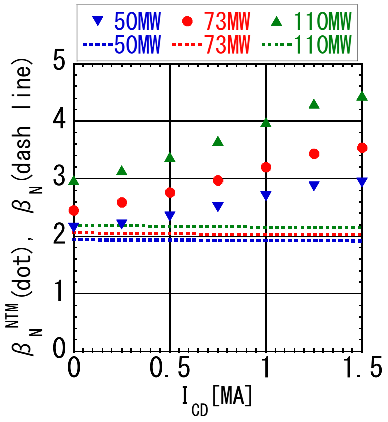

Fig.2. Dependence of β_N^{NTM} and β_N on I_{CD} in the mixed Bohm/gyro-Bohm model

Acknowledgments

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References

[1] K. Yamazaki and T. Amano, Nucl. Fusion **32** (1992) 633.
[2] F. Porcelli *et al.*, Plasma Phys. Control. Fusion **38** (1996) 2163.
[3] H. Natsume *et al.*, J. Plasma Fusion Res. **9** (2013) 3403048.
[4] A. Taroni *et al.*, Plasma Phys. Control. Fusion **36** (1994) 1629.
[5] M. Erba *et al.*, Plasma Phys. Control. Fusion **39** (1997) 261.
[6] I.T. Chapman *et al.*, Nucl. Fusion **50** (2010) 102001.