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Fokker-Planck Analysis of the Runaway Electron Generation in Tokamak Disruptions

トカマクプラズマでのディスラプション時における逃走電子生成のFokker-Planck解析

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Three-dimensional Fokker-Planck simulations investigate the runaway electron generation processes during tokamak disruptions. Full *f* Fokker-Planck simulation enables to include the hot-tail effect that has the possibility to enhance the runaway electron generation rate. In this paper, the results of the simulation with hot-tail effect are compared with those of without hot-tail effect. This comparison shows the importance of the hot-tail effect for the description of the runaway electron generation mechanism, especially for fast thermal quench disruption. In this poster, the comparison with experimental data in JT-60U also will be reported.

1. Introduction

Disruptive plasma termination is one of the crucial problems for plasma discharge, especially for a large-scale tokamak, such as ITER[1]. The disruption of tokamak plasmas causes rapid thermal and current quenches. The current quench induces the toroidal electric field that accelerates electrons. Owing to the low collisionality for high velocity particles, some of the electrons experience the electric force that is stronger than the collisional drag force and they become runaway electrons (REs). REs can damage to the first wall on impact. Since the RE generation rate is expected to be higher for a large-scale tokamak, RE generation during plasma disruption is potentially serious problem. In this reason, the estimation of the amount of the REs generated in disruption phase is required for the development of the operation scenarios, such as the mitigation method.

The inclusion of the non-thermal effect is required for the RE generation simulations. This is because, when the thermal quench time is enough short, the plasma cools down so quickly that high velocity electrons, which collision time is longer than the quench time, do not have enough time to thermalize. The rapid cooling forms the high velocity tail of the velocity distribution, and this high-energy tail is expected to enhance the primary RE generation rate. This effect of high-energy tail is called as “hot-tail effect”.

There are several previous researches [2-4] that simulate the RE generation during tokamak plasma disruption. Smith [5] and Feher [6] are one of the works that simulate the evolution of RE generation that includes the hot-tail effect and that of induced electric field, self-consistently. To our knowledge, however, the Fokker-Planck RE generation simulation that calculates the evolution of the velocity distribution function coupled with induced electric field has not been reported.

2. Equations

In our research, we have developed the Fokker-Planck code TASK/FP in order to calculate the evolution of the relativistic momentum distribution function and that of toroidal electric field self-consistently. It solves the Fokker-Planck equation as below;

$$\frac{\partial f}{\partial t} = -\nabla\cdot\vec{S}_{C,E} \tag{1}$$

where S_{C,E} denotes the flux due to the collision and electric field in momentum space[7]. The response of RE current to the electric field is described as following equations;

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial E}{\partial r}\right) = \mu_0\frac{\partial}{\partial t}j \tag{2}$$

$$j = \sigma_{sp}E + ecn_r \tag{3}$$

$$\frac{dn_{rp}}{dt} = \int\nabla\cdot\vec{S}_{C,E}d\vec{p} \tag{4}$$

$$\frac{dn_{rs}}{dt} = S_{avalanche}(n_r, E/E_C), \tag{5}$$

where RE density consists of two component "primary" and "secondary", $n_r = n_{rp} + n_{rs}$. The density of primary REs is defined as the electrons go out from the momentum calculation domain, $0 < p < p_{max}$ in eq. (4). In this poster, pmax has a value comparable to 1MeV. The secondary RE generation rate derived by Rosenbluth [8] is used in eq. (5). Ohm's law is adopted as the closure in the diffusion equation of electric field. In this equation, it assumes that the velocity of all REs equals to that of light and all of REs are collisionless. In this simulation, the thermal quench is described as;

$$T(t,\rho) = (T(0,\rho) - T_f(\rho))\exp(-t/\tau_q) + T_f(\rho)$$

where τ_q is a parameter of thermal quench time.

3. Benchmark of primary RE generation rate

The comparison of the primary RE generation rate between calculated by TASK/FP and by the expression, $dn_{rp}/dt = S_{conner}(E/E_D, T)$, derived by Conner [9], is shown in Fig. 1 for the steady electric field and temperature. It is found that they have good agreement.

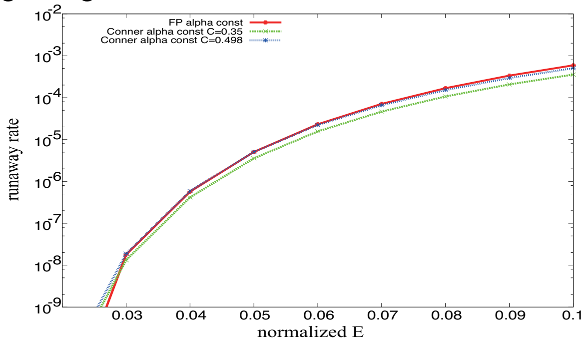

Fig. 1. The primary RE generation rate vs. electric field normalized by Dreicer field is shown. Red line denotes the value calculated by eq. (4). Green and blue are calculated by the expression derived by Conner and Hastie.

4. Simulations coupled with induced E field

We compare the RE generation simulation between two cases, A and B. In case A, the evolution of f and E are calculated by eqs. (1-3) and the primary RE generation rate is evaluated by eq. (4). In case B, the primary RE generation rate is calculated by Conner's expression used in Sec. 3 instead of eq. (4). Since the hot-tail effect is not considered in the expression, the differences of the simulation results between two cases will be caused by hot-rail effect. Figures 2 show the time evolution of net plasma current in each case. The whole plasma current which consist of ohmic one is replaced into RE current by t=30 msec in all lines. It is found that the fast thermal quench enhances the primary RE generation rate. The details will be explained in the poster.

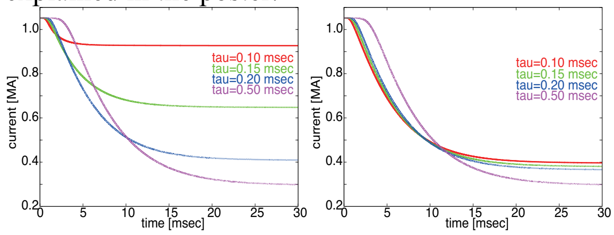

Fig. 2. The time evolutions of the plasma current for several values of quench time are shown. Left fig. is case A, Right fig. is case B.

5. Summary

The Fokker-Planck simulations coupled with the evolution of the induced electric field for tokamak disruption are reported. This simulation enables to include the hot-tail effect, and this effect enhances the primary RE generation rate, especially for fast thermal quench disruption.

The comparison of the simulations to the experimental data in JT-60U also will be reported in the poster.

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