§32. Modelling of Breakdown Mechanism under Transient Electromagnetic Conditions

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A center solenoid (CS) coil is a key technology in tokamak systems and employed to initiate discharge, to start-up current, and to provide initial heating power into plasma. The initiation mechanism of torus discharge (breakdown) is usually analyzed based on ionization process by impact of electrons which are azimuthally accelerated at the "steady" null point region. In spherical tokamak (ST) experiment, however, shortage of central space requires removal or drastic reduction of the CS coil structure. Thus, alternative plasma start-up scheme is strongly needed in ST researches. Various CS-free ST start-up schemes such as ECW, EBW, LHW, Alfven wave, helicity injection, etc., are under investigation in world ST experiments.

In UTST experiment, novel plasma start-up scheme by outer poloidal field (PF) coils located outside of the vessel is developed. In this method, initial plasma current was driven at the null point formed transiently by the outer PF coils[1)]. In order to optimize this start-up scheme to increase plasma current and flux efficiency, analysis of the ionization process under "transient" electromagnetic field condition provided by the changing PF coil currents is required. In this study, 2-dimensional ionization calculation model is developed based on electron swarm model, a fluid picture of accelerated electrons.

First we calculated electron swarm parameters such as electron averaged velocity vector, diffusion coefficient tensor, and effective ionization rate by a Monte-Carlo calculation considering seven electron impact collision reactions: an elastic collision, an ionization collision, and five excitation collisions with helium atoms. In this calculation, these parameters gradually reach their final values in equilibrium state, as shown in Fig. 1. Different from common electron swarm calculations, the effect of magnetic field was included. The calculation results show that the parallel diffusivity (multiplied by the density N of background neutral particles), the parallel drift velocity, the averaged energy, and the reaction rate depended on the normalized electric field E/N and these final values were same as those obtained by the calculation without background magnetic field. On the other hand, the perpendicular diffusivity depended on the parallel electric field divided by the square of the magnetic field and the perpendicular drift velocity obtained in this calculation yielded same value as the theoretical value of ExB drift.

Here, we have to consider whether the calculation model is applicable to analyze the experimental situation. The convergence time of electron motion in this calculation was about 5 μs for the experimental situation, which is much shorter than the typical time constant ~ 0.1 ms of the electromagnetic field variation in the ST formation experiment. Therefore, we can conclude that the equilibrium state of the electrons obtained in this Monte-Carlo simulation will provide good picture of the initial breakdown process in the "transient" electromagnetic condition in ST formation scheme by outer PF coils.

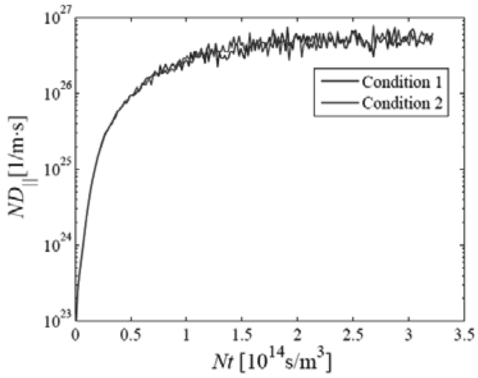

Fig. 1 Time evolution of electron parallel diffusivity.

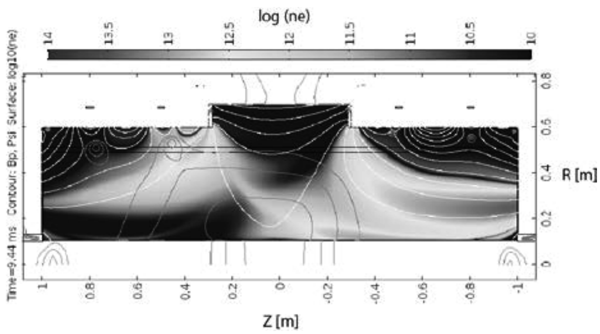

Fig.2 Electron density distribution in UTST device.

By using these swarm parameters, we carried out a fluid simulation to investigate dynamic ionization process in the 2-dimensional UTST model. The electromagnetic field inside the vessel was calculated from the experimental PF coil waveforms. Fig. 2 shows a snapshot of electron density profile. Although the null points were formed near the outboard wall ($Z \sim \pm 0.8$ m, $R \sim 0.55$ m), high electron density region in the simulation located middle ~ inboard area in the vacuum vessel. The simulation results indicate that the enhancement of the electron confinement by the mirror field has stronger impact on the electron density profile than the ionization process localized at the null point. Thus, the simulation model at this moment does not reproduce the experimental results well. Candidates of the problems in the simulation model are: inadequate initial electron density profile provided by the pre-ionization, inadequate boundary condition on the vessel wall. We also have to carry out further validation of the fluid treatment in the outboard region where toroidal magnetic field is much weaker than the inboard side.

1) Inomoto, M. et al.: Nucl. Fusion 55, 033013 (2015).