23P040-P

Transport Analysis Study of Oscillation Phenomena for the Electric Field in Helical Plasmas

ヘリカルプラズマでの電場振動現象に関する輸送解析研究

Shinichiro Toda, Kimitaka Itoh
登田慎一郎, 伊藤公孝

National Institute for Fusion Science, 322-6 Oroshi, Toki, Gifu, 509-5292, Japan
核融合科学研究所　〒509-5292　土岐市下石町322-6

A model for the experimental results of the periodic oscillation of the electric field, so-called the electric field pulsation, observed in helical plasmas is presented. A self-generated oscillation of the radial electric field is shown as the simulation result in helical plasmas. Two different time scales are found in the self-generated oscillation, which are the transport time scale and the fast time scale at the transition of the radial electric field. This oscillation because of the hysteresis characteristic is attributed to the electric field pulsation observed in helical plasmas. The parameter region of the condition for the self-generated oscillation is derived.

1. Introduction

The turbulence-driven transport and the formation mechanism of transport barriers are critical issues to realize improved confinement modes in toroidal plasmas. One possible mechanism to explain the transport barriers is the structural transition in the profile of the radial electric field E_r and the suppression of turbulence by its shear. In tokamaks, the model of L/H transition and the edge localized modes (ELMs) which is based on the bifurcation of the radial electric field was presented [1]. A self-generated oscillation of the edge density and temperature takes place. In helical plasmas, the neoclassical helical-ripple transport plays a dominant role in the process of forming the profile of E_r. The bifurcation of E_r in helical plasmas takes place and the resultant strong shear of E_r was predicted to induce the transport barrier. At the state of the positive E_r in the core region, the electron internal transport barrier (e-ITB) is observed when the Electron Cyclotron Resonance Heating (ECRH) is applied which is localized around the plasma center. The temporal evolution equation for the radial electric field is solved in helical plasmas. The cyclic phenomena in the temporal evolution of the radial electric field, namely the electric field pulsations, have been observed in the core region of Compact Helical System (CHS) [2] and Large Helical Device (LHD) [3]. The periodic oscillation of the electric potential which includes the intermittency characteristic is shown in LHD. In our previous work for the analysis of the temporal evolutions of the radial electric field, the stationary solutions of the radial electric field were obtained. The temporally oscillating solutions of E_r in the core region have not been shown yet.

2. Transport Analysis Results

The temporal evolution in the time interval $0.66 \leq t \leq 0.70$s of E_r in Fig. 1, T_e, T_i and n is studied. The solid line, the dotted-dashed line, the dotted line and the dashed line show the temporal evolutions of the physical quantities at ρ= 0.1, ρ = 0.3, ρ = 0.5 and ρ=1.0, respectively. The state A at t=0.6721s indicates the one at ρ = 0.3 just before the transition from the negative E_r to the positive E_r. Just after the transition from the state A, the state changes to the one B at t=0.6734s. From the state B, the plasma profile changes with t->he transport time scale and reaches the state C at t= 0.6793s. Just after the state C, the transition from the positive E_r to the negative E_r takes place at ρ = 0.3 and the state changes to the one D at t = 0.6801s. From the state D, the plasma state changes to the state A at t= 0. 6833s with the transport time scale. At the time t= 0.6833s, plasma parameters come back to the values at the state A, and the transition occurs again from the negative E_r to the positive E_r. The temporal evolutions in the core region (at ρ = 0.1, ρ = 0.3 and ρ = 0.5) clearly show the characteristic of the limit cycle. In the core region at ρ = 0.3, the transitions occur from the negative E_r to the positive E_r at t= 0.6721s and from the positive E_r to the negative E_r at t= 0.6801s. The time period of the limit cycle is about 10ms, which is determined by the typical transport time scale. The self-generated oscillation of the radial electric field is shown to have two time scales: a slow time scale of the transport time scale (about 10ms) and a fast time scale at the transition (about 1ms). The temporal change of the E_r profile causes the temporal change of the radial profile of the neoclassical and anomalous diffusivities. Owing to the influence of E_r on transport coefficients, the temporal evolution of the radial T_e, T_i and n profiles takes place as the limit cycle in the core region.

We study the conditions in the parameter space, where the self-generated oscillation occurs. When the intensity of source is varied, the mean values of the temperatures and the density change, and the temporal evolution of calculations reaches either the stationary state or the self-generated oscillation. Furthermore, the profile of the stationary electric field takes different types of roots. At first, stationary electric fields in the entire radial region become the electron root (E_r>0) in the region labeled 'e-root' in Fig. 2 on the $\bar{T}_e / \bar{T}_i - \bar{n}$ plane. In the regime of the low density $\bar{n} \approx (1-3)\times 10^{18}\,\mathrm{m}^{-3}$ and the high electron temperature $\bar{T}_e / \bar{T}_i > 3$, the positive and stationary solutions of E_r are found. Secondly, if the density gets larger, the electric field in the core plasma takes the electron root, and the electric field in the outer plasma takes the ion root ($E_r < 0$) in the region labeled 'e-i root'. In the region labeled 'e-i root', the type of the transition is classified to the hard or soft one. The multiple solutions of E_r are shown in the enclosed region inside the 'e-i region': $1 < \bar{T}_e / \bar{T}_i < 2$ and $\bar{n} \approx (0.2-1.4)\times 10^{19}\,\mathrm{m}^{-3}$. In this region, the so-called 'hard' transition occurs between the multiple ambipolar E_r and the reduction of the anomalous heat diffusivity is shown due to the strong shear of the radial electric field. In the region labeled 'e-i region' outside this enclosed region, the slow (and namely, the soft) transition takes place spatially and temporally since there are no multiple solutions of the ambipolar E_r. In the enclosed region, the shaded region is shown for the self-generated oscillation: $1 < \bar{T}_e / \bar{T}_i < 2$ and $\bar{n} \approx 1\times 10^{19}\,\mathrm{m}^{-3}$. In the enclosed region outside the shaded region, the stationary profile of the radial electric field is obtained even if there are multiple solutions of the ambipolar E_r at some radial locations. When the value of the density increases further: $\bar{n} \approx 2\times 10^{19}\,\mathrm{m}^{-3}$, all radial stationary electric fields changes to the ion root in the parameter region labeled 'i root'. The parameter region of the two patterns for the temporal evolutions: the stationary state and the self-generated oscillation are examined on the $\bar{T}_e / \bar{T}_i - \bar{n}$ plane. The physical mechanism to realize

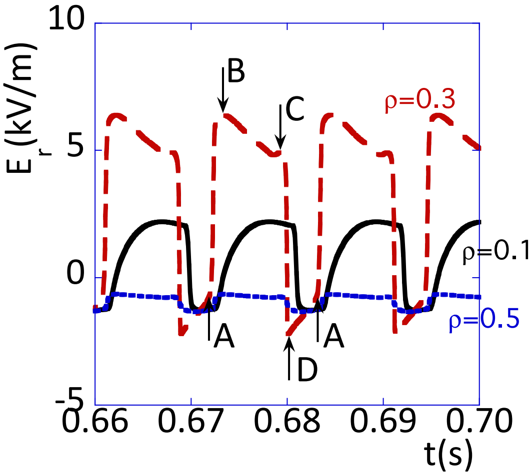

Fig.1 Temporal evolution of the radial electric field

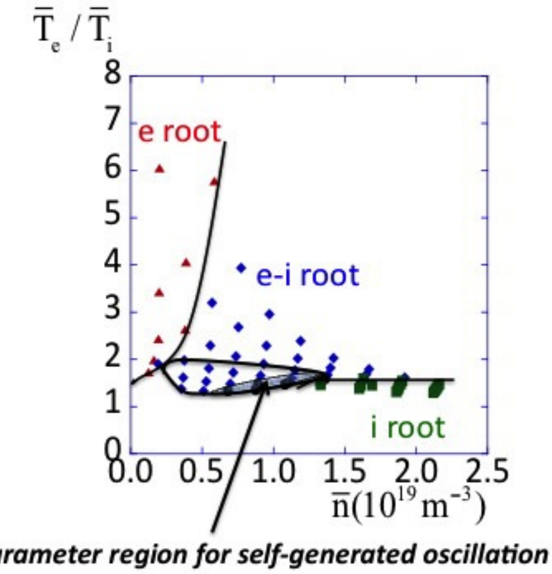

Fig.2 Parameter space for the self-generated oscillation

a self-generated oscillation is also studied, concerning the flux-gradient relation which includes the hysteresis characteristic [4].

Acknowledgments

This work is partly supported by the Grant- in-Aid for Scientific Research of JSPS (19360148, 21224014 and 23561002) and by the NIFS Collaborative Research Program (NIFS10KNXN180 and NIFS11KNST023).

References

[1] S. -I. Itoh, K. Itoh and A. Fukuyama, Nucl. Fusion **33** (1993) 1445.
[2] A. Fujisawa et al., Phys. Rev. Lett. **81** (1998) 2256.
[3] A. Shimizu et al., Plasma Fusion Research **5** (2010) S1015.
[4] S. Toda and K. Itoh, Plasma Phys. Contr. Fusion **53** (2011) 115011.