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Investigation of high guide field reconnection in UTST merging experiment using floating potential measurement
浮遊電位計測を用いたUTST合体実験の高ガイド磁場リコネクションの機構解明

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Electrostatic potential structure around the X-point was investigated for magnetic reconnection with strong guide field (typically $B_g/B_{rec}>10$) in the UTST merging experiment. In the upstream region more than 5cm away from the X-point, field-aligned electrostatic electric field ($E_{\|es}$) and inductive electric field ($E_{\|ind}$) almost cancel each other out, while in the current sheet within 5cm from the X-point, $E_{\|ind}$ dominate $E_{\|es}$. This result denotes that ideal MHD condition is broken in the region with thickness of half of the ion skin depth (*di*) and the residual electric field could provoke parallel electron acceleration during magnetic reconnection in strong guide field. Numerical analysis shows that electrons are accelerated in less than 1μsec within the diffusion region by parallel electric field and travel along the separatrix. Also, the analysis denotes that electrons' kinetic energy become higher in magnetic reconnection with stronger guide field.

1. Introduction

Merging startup is one of the center-solenoid-coil-free startup methods firstly used in TS-3 [1] (the University of Tokyo), then in START [2], MAST [3] (UKAEA) and regularly performed in TS-4 and UTST. In UTST, external poloidal field coils are used to form initial tokamaks in upper and lower region of the vacuum vessel. These two tokamaks are merged to form one spherical tokamak (ST). During the merging of two tokamaks, magnetic field of each tokamaks causes magnetic reconnection, an energy conversion phenomenon commonly observed in space and laboratory plasmas. Most of the past theoretical and numerical studies of magnetic reconnection treated the simplest configuration of 2-dimentional reconnection without guide field, the magnetic field component orthogonal to reconnecting magnetic field. However, many of the magnetic reconnection events in space and laboratory plasmas include nontrivial guide field component, especially during ST merging startup experiment, the toroidal magnetic field is typically 0.1~0.3T and the poloidal magnetic field is 0.01~0.02T, which indicate that guide field (B_g) is more than 10 times stronger than reconnecting magnetic field (B_{rec}). Recently, guide field effect on collisionless reconnection attracted attention and many numerical studies on magnetic reconnection with guide field have been conducted. However, most of them treats the case with weak guide field case, $B_g/B_{rec} < 0.8$, and a few of them treat the moderate guide field case, $B_g/B_{rec} = 2\sim5$ [4,5]. Therefore, simulation studies on magnetic reconnection with strong guide field have not yet reproduced the situation in ST merging experiment.

Magnetic reconnection generally causes heating or acceleration of ions and electrons, which will determine the performance of the STs formed by merging technique. In this paper, electron acceleration mechanism caused by field-aligned electric field ($E_{\|}$) was experimentally verified in high guide field magnetic reconnection with $B_g/B_{rec} > 10$ case.

2. Measurement

In order to understand the magnetic reconnection event during ST merging experiment, information of all three components of magnetic field and electric field is necessary. In UTST, 2D magnetic probe measurement is installed to obtain the three components of magnetic field and inductive electric field in toroidal direction under the assumption of axisymmetry. Poloidal electric field components are derived from floating potential profile measured by Langmuir probe array.

3. Results

Potential profile around the X-point abruptly shows quadrupole structure when the reconnection speed is growing up. Also, around this phase, $E_{||}$ become strong around the X-point, possibly corresponding to the dissipation region. $E_{||ind}$ and $E_{||es}$ are compared in figure 1. This figure shows that, away

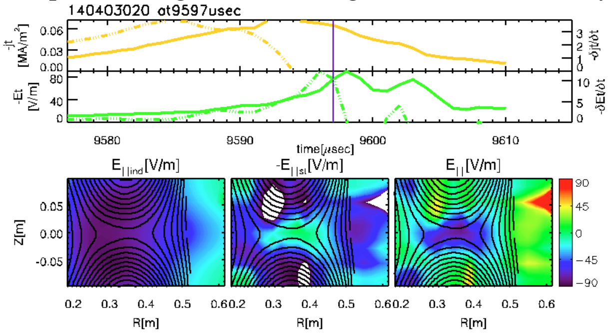

fig 1 $E_{||ind}$ (left), $E_{||em}$ (middle) and $E_{||}$ at fast reconnection phase.

from the X-point, $E_{||ind}$ and $E_{||es}$ are almost comparable and cancel out as expected in the ideal MHD condition, while around the X-point, $E_{||ind}$ dominate $E_{||es}$. The width of this diffusion region is about 5cm, corresponding to 0.5*di*, and the length is 10cm, almost equal to *di*. Note that the shape of diffusion region is observed in UTST experiment was symmetric about the neutral line, while the numerical study of guide field reconnection predicted asymmetric diffusion region localized on a pair of separatrices, as reported in VTF experiment [6]. The reason of this discrepancy is not clear but large difference in density and boundary condition might change the local structure around the X-point.

Using the measured magnetic field and electric field profile, trajectory of electrons around the X-point with different initial position and velocity is calculated. In figure 2, circle markers show the locations of test electron particles with the kinetic energy indicated by color. It was found that some electrons are accelerated up to more than 300eV in short duration less than 1μsec. Also, these electrons are localized along the upper left and lower right

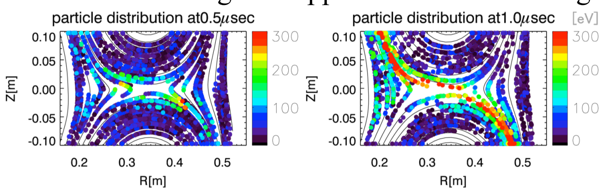

fig 2 Test particle location and their kinetic energy at 0.5 and 1.0 μsec from calculation start.

separatrices, as observed in simulation studies of guide field reconnection. These energetic electrons are most efficiently accelerated when they come close to the X-point. This calculation is applied to 3 cases with same B_{rec} (~0.01T) but different B_g (0.13, 0.20 and 0.23T). The energy distribution of all the test electron particles is shown in figure 3. From

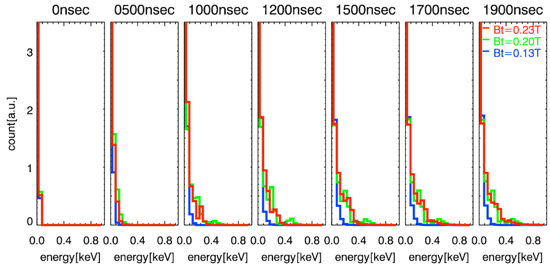

fig 3 Kinetic energy histogram of test particles with different guide field case

this figure, it is observed that more energetic electrons are generated in the reconnection with stronger guide field, suggesting higher conversion efficiency from magnetic to electron kinetic/thermal energy.

4. Summary

$E_{||}$ profile around the X-point is experimentally obtained using magnetic field and electric field profile during the magnetic reconnection with high guide field in UTST merging experiment. The width and length of the diffusion region during high guide field reconnection is estimated to be 5cm (0.5*di*) and 10cm (~*di*), respectively. Due to this parallel electric field, electrons are expected to be efficiently accelerated around the X-point and these energetic electrons will localize along the upper left and lower right separatrices. Also, more energetic electrons are generated with stronger guide field, suggesting the higher energy conversion efficiency with stronger guide field.

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