§3. Simulation Studies on Effective Ion Heating through Magnetic Reconnection

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The ST attracts the attention as a candidate of future fusion reactors, since STs enable us the confinement of a higher-beta plasma compared to standard tokamaks. In plasma merging experiments of STs, two torus plasmas are merged together to form single torus plasma under magnetic compression. At the contacting point of initial two ST plasmas, magnetic reconnection takes place and single ST plasma with high temperature is formed [1].

In plasma merging experiments, it is observed that electrons are heated in the vicinity of the reconnection point; the contacting point, while ions are heated in the downstream. The mechanism of such particle heating is considered to be important to a complete understanding of high-beta plasma formation. An understanding of the heating mechanism can lead to higher-performance of STs for realizing economical ST reactors in the future. In past works, for instance shock heating [1] was suggested for the ion heating mechanism. In this paper, we report the new different mechanism of the ion effective heating.

By means of particle simulations, we investigate the ion heating mechanism in the downstream of magnetic reconnection. Microscopic kinetic effects originating from stochastic particle motions play essential roles in energy transfer process in the vicinity of the reconnection point [2]. Figure 1 shows the schematic diagram of our simulation model. The two torus plasmas in a ST device are drawn in the left part of Fig. 1 and the right part displays the area simulated by our PIC code named PASMO [3]. This PIC area covers from the central reconnection point to the ion dissipation region and mimics the region near the contacting point of merging plasmas. The initial condition is one-dimensional equilibrium with a uniform guide magnetic field in the z direction.

In Fig. 2, we show the spatial profiles of the magnetic field lines and the x-component of the ion bulk velocity as color contours in the (x, y) plane in the case of B_{z0}=B_{x0} = 2.0 and m_i=m_e=100. By plasmas and magnetic fluxes supplied from the upstream, magnetic reconnection is driven, where the reconnection point lies at the almost center and bipolar outflows emanate from the reconnection point.

In order to investigate the ion heating mechanism, we have examined the change in velocity distributions at some local points of the simulation domain. We have analyzed ion velocity distributions integrated over regions (A)-(C) designated in Fig. 2. It has been found at the region (A) that there are two peaks in the distribution because nongyrotropic ions in the region (A) move back and forth across the reconnection point. This behavior is called meandering motion. In contrast, the velocity distribution at the region (B) spreads mainly in the v_x direction, that is, ions are effectively thermalized in the downstream.

It suggests that the pickup mechanism [4, 5] plays a major role in the ion heating, since characteristic features of the velocity distribution at the region (B) fit well in that of picked-up particles. According to the theory of the pickup mechanism, nonadiabatic particles which enter the downstream across the separatrix become magnetized due to a strong guide field in the downstream and gain a convective velocity equal to the outflow velocity v_0, forming a ring velocity distribution with v_0 [5]. From the analysis of the ring-like structure in the velocity distribution of the region (B), it has been found that the center is located at $(v_x, v_y) \simeq$ (0.02, 0.0) and its radius is nearly equal to 0.02. From Fig. 2, the velocity of outflow is estimated to be about 0.02 in the region (B).

In the near future, we plan to compare simulation results obtained by PASMO with experimental results such as TS-3 and TS-4 at University of Tokyo and MRX at Princeton Plasma Physics Laboratory.

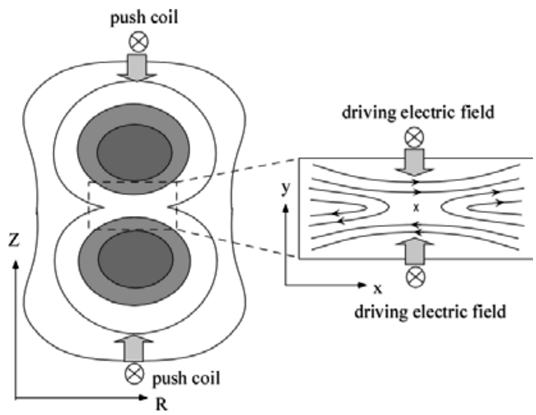

Fig. 1: Schematic diagram of our particle simulation model.

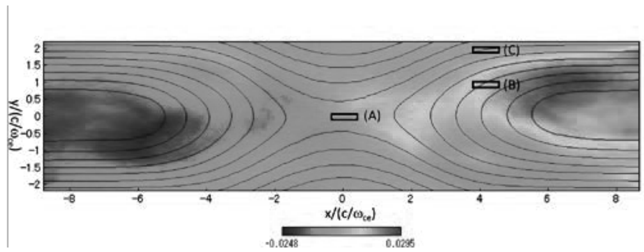

Fig.2: Spatial profiles of the magnetic field lines and the ion bulk velocity v_{ix} (color contours). Velocities are normalized to c. The small rectangles represent regions where ions are sampled.

1) Y. Ono et al., Plasma Phys. Control. Fusion **54** (2012) 124039.
2) R. Horiuchi and T. Sato, Phys. Plasmas **1** (1997) 3587.
3) W. Pei, R. Horiuchi, and T. Sato, Phys. Plasmas **8** (2001) 3251.
4) E. Mobius et al., Nature **318** (1985) 426.
5) J. F. Drake et al., Astrophys. J. Lett. **700** (2009) L16.