THE PHYSICAL PICTURES AND ENERGY CONVERSIONS OF RAREFIED DETERIUM PLASMA SHELL Z-PINCH UNDER ITS FLUID AND PARTICLE DESCRIPTIONS

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In the past two decades, although a number of studies have been carried out on the experiments and numerical simulations of Z-pinch, the researchers are not satisfied with the obtained knowledge and understanding about the Z-pinch physics. There is the trend that the convergence ratio of load radius used to becomes too large in the radiation magneto-hydrodynamics (RMHD) simulation of Z-pinch, which are based on the model of neutral single fluid. Whereas, the measured average radii of the current in Z-pinch plasmas are generally larger than that obtained in the RMHD simulations. Most experiments of Z-pinch have demonstrated that the radiated X-ray energies from Z-pinches can be much greater than the “kinetic” or “theoretical” magnetic energies coupled to the pinching plasmas during the implosions. Moreover, high energy particles and hard X-rays, which energies may be higher than the applied voltages between the cathode and anode, had been measured in axial direction in Z-pinch experiments. These experimental phenomena could not be well explained under the current RMHD model.

Actually, a Z-pinch plasma is consisted of a large amount of charged particles, i.e. electrons and ions with different charge state, and there are not sufficient conditions in physics to guarantee the plasma system to be in the electrically neutral state during the whole Z-pinch process. However, it is well known that to keep the electrically neutral state is the fundament of accurate RMHD simulation of Z-pinch. Therefore, it is necessary to explore the microscopic picture and energy conversion in Z-pinch process under the particle description, and to compare them with that under its fluid description for better understanding of the physical mechanism of Z-pinch. In this paper, a current-carrying rarefied deuterium plasma shell were simulated by a particle-in-cell code in 2D and a one dimensional RMHD code.[1]

The microscopic picture of the Z-pinch process is deducted from the PIC simulated results. In the Z-pinch process, the electrons are firstly accelerated in Z direction and get higher velocities, then they are driven inwards to the axis at the same time by the radial magnetic forces (i.e. Lorentz forces) of them. That causes the separations between the electrons and ions because the ion mass is much larger than the electron’s, and in turn a strong electrostatic field is produced. The produced electrostatic field attracts the ions to move towards the electrons. The magnetic field diffusion and the energy conversion in these two kinds of simulation are particularly compared and analyzed. In the PIC simulation, the magnetic field exists in the most of the plasma shell. However, it diffuses just into a part of the plasma shell in the RMHD simulation. So the plasma was highly compressed in RMHD simulation, even to “death”. In the PIC simulation, the kinetic energy of ion is mainly the radial component, its axial one is almost neglected. Whereas, the kinetic energy of electron is mainly the axial component, its radial one is small, about 3% of the axial component. The radial component of energy can be thermalized during the stagnation to contribute to the plasma temperature, and the axial component of energy may be possibly carried by the beams.

[1] Cheng Ning, Zhixing Feng, Chuang Xue, and Baiwen Li. Phys. Plasmas 22, 022710 (2015).