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Study on effect of magnetic field gradient for hypersonic plasma flow by numerical analysis
数値解析による極超音速プラズマ流に対する磁場勾配の影響の検討

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To simulate a collisionless shock in a laboratory scale, control of plasma flow velocity in external applied magnetic field is required. The relation between the magnetic field and the plasma flow generated by a taper-cone-shaped plasma focus device is unclear. The plasma behavior in the applied magnetic field is studied by a hybrid particle-in-cell method. The results indicated that the magnetic field gradient affects to the shock velocity.

1. Introduction

A collisionless shock, which has occurred in collisionless plasma, has unclear mechanisms such as energy dissipation process and generation of highly energetic particles. To understand these unclear processes, laboratory scale experiments with well-defined shock structures are required to compare its behaviors and a validity of numerical modeling [1-2]. In order to generate the collisionless shock in laboratory scale, Drake [1] has considered the required conditions as the hypersonic plasma flow and the magnetic flux density. We have considered generating the collisionless shock by using a taper-cone-shaped plasma focus device [3]. The experimental results showed decreasing of the shock velocity at the region of the applied magnetic field. Furthermore, the deceleration degree of the shock velocity varied by changing of the shape of the magnetic field distribution. However, the relation between magnetic field and the plasma flow the magnetic field is unclear.

In this study, to clarify the effect of the applied magnetic field on the hypersonic plasma flow generated by the taper-cone-shaped plasma focus device, the plasma behavior is simulated with numerical calculations. We focus on the effect of the magnetic field gradient on the plasma velocity.

2. Experimental Setup and Results

To obtain the one-dimensional plasma flow, we have proposed the taper-cone-shaped plasma focus device [3-4]. The taper-cone-shaped plasma focus device generates the hypersonic plasma flow of which velocity is about 10 km/s in helium gas discharge [3].

The applied magnetic field distributions in the experiment were shown in Fig. 1. The magnetic field distribution in the case (1) has a gradient. On the other hand, the magnetic flux density in the case (2) is almost constant. The generated plasma flows were observed by a streak camera as shown in Fig. 2. Figure 2 showed the deceleration of the plasma flow in each magnetic field distribution.

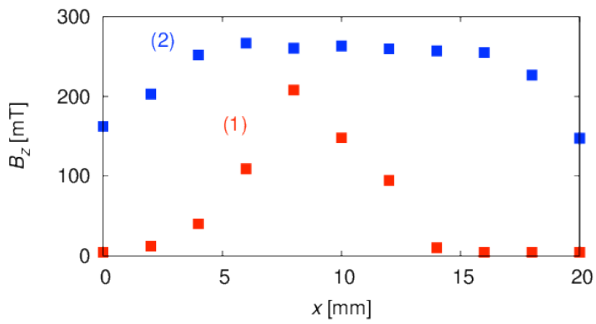

Fig. 1. Applied magnetic field distribution in the experiment.

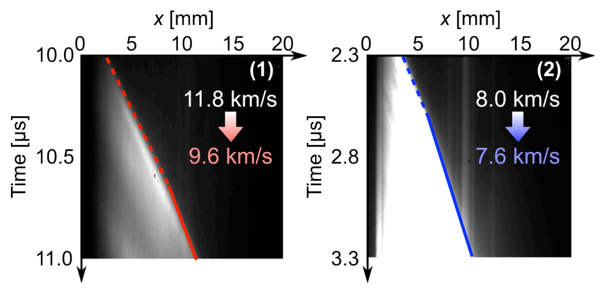

Fig. 2. Streak images of the plasma flow generated by the taper-cone-shaped plasma focus device.

3. Numerical Simulation Conditions

A hybrid particle-in-cell (PIC) method was employed to study the plasma behavior in the region of the applied magnetic field. In the hybrid PIC method, ions are treated as particles, and electrons are treated as a fluid that satisfies charge neutrality immediately [5]. Therefore the hybrid PIC method is able to adopt thermodynamic non-equilibrium of ions easily.

The numerical simulation analyzed as one-dimensional space and three-dimensional phase space. In initial conditions as shown in Fig. 3, the temperature and the pressure in front of the shock were respectively 300 K and 0.01 Pa. On the other hand, the temperature and the average velocity of ions in the shock were respectively 9000 K and 10km/s. To study the ion behavior affected by magnetic field distributions, two types of the magnetic field distribution as shown in Fig. 3, were calculated. In the case (A), magnetic flux density B increases with the x-direction, which propagates the shockwave. On the other hand, in the case (B), B decreases with the x-direction. This means that both magnetic field distributions have respectively the adverse magnetic field gradient. The applied magnetic field is a constant at 2 mT in the case (C), which does not have the gradient.

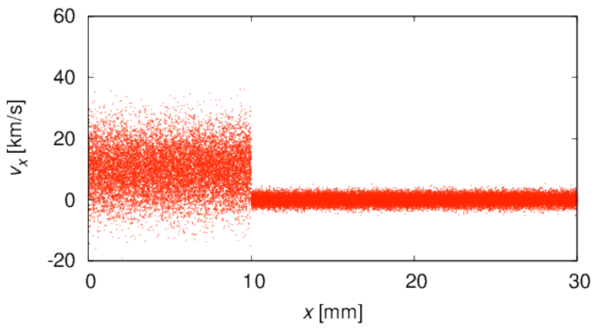

Fig. 3. Initial conditions of the numerical simulations.

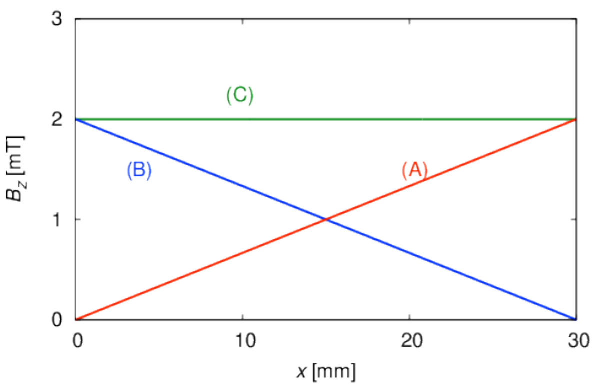

Fig. 4. Applied magnetic field distributions in the numerical simulation.

4. Numerical Simulation Results

Figure 5 shows the time evolution of the shock position calculated by the numerical simulation. In the case (C), the propagation velocity of the shock v_s was a constant. This means that the flat magnetic field distribution does not affects to the shock velocity. On the other hand, v_s in the case (A) and (B) varied with the time evolution. Furthermore, Fig. 5 showed that v_s was decelerated in the case (A), and was accelerated in the case (B). These results indicate that the magnetic field gradient affects the shock velocity.

5. Conclusion

To clarify the effect of the magnetic field gradient for the hypersonic plasma flow generated by the taper-cone-shaped plasma focus device, the plasma behavior in the magnetic field was simulated by the hybrid PIC method. The numerical simulation results showed that the shock velocity was varied with the distribution of applied magnetic field. It indicates that the magnetic field gradient affects the shock velocity.

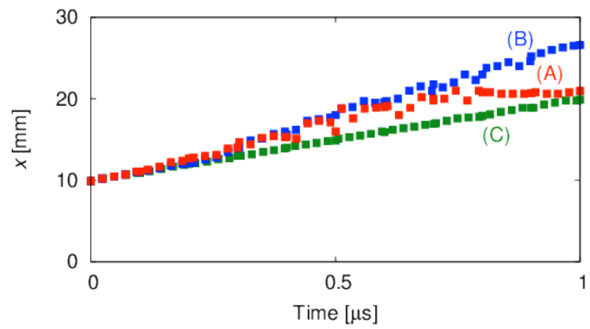

Fig. 5. Time evolution of the shock position calculated by the Hybrid PIC method.

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