Semi-empirical study on particle acceleration by interaction of fast plasma flow with perpendicular magnetic field

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Collisionless shocks, which occur due to an interaction between fast flow of collisionless plasma and background electromagnetic fields, are known as energy sources for high-energy particles in outer space, cosmic rays. In the relativistic region, first-order Fermi acceleration [1] has explained the energy distribution with the power-law for cosmic rays and the process how the particles gain the energy. However, particle acceleration mechanisms in the non-relativistic region to generate the relativistic particles have been not clarified. To understand particle acceleration mechanisms of collisionless shocks in the non-relativistic region, laboratory scale experiments are required for the experimental evaluation of the plasma behavior and the interaction of the fast plasma flow and the electromagnetic fields.

In this study, we investigate an interaction of a fast plasma flow driven by a tapered cone plasma focus device with a perpendicular magnetic field in a laboratory scale experiment. The tapered cone plasma focus device with a guiding acrylic tube with the length of 20 mm produces a quasi-one-dimensional plasma flow with the velocity of 30 km/s using a helium gas discharge at 0.1-0.5 Pa [2, 3]. The electron temperature and the ion number density have been respectively estimated to be $T_e \sim 3$ eV and $n_i \sim 10^{20}$ m^{-3}, and thus the mean free path of ion-ion collision becomes $\lambda_{ii} \sim 30$ mm, which is longer than the length of the acrylic tube as the system scale length. The plasma ion current was measured by an ion collector. We observed the variation of the current waveform with and without the perpendicular magnetic field with the peak of 25 mT. With the magnetic field, the ion current preceding the main plasma was observed [3].

Numerical simulations based on an electromagnetic hybrid particle-in-cell method [4] have been carried out to investigate the behavior of the plasma flow driven by the tapered cone plasma focus device in the perpendicular magnetic field. The numerical results showed that the acceleration of ions corresponds qualitatively to the experimental results. The magnetic field has been compressed with the propagation of the plasma flow. Some ions in the plasma flow have been accelerated by the induced electric field, due to the time evolution of the compressed magnetic field.

These results indicate the existence of a novel particle acceleration mechanism by the interaction of the fast plasma flow with the perpendicular magnetic field in the non-relativistic region.

References

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