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Numerical Analysis on Bunch Compression in Electron Trap Device as Compact Simulator of Energy Driver in Heavy Ion Fusion

重イオン慣性核融合のエネルギードライバーを模擬した電子トラップ装置のバンチ圧縮過程解析

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In inertial confinement fusion (ICF) driven by heavy ion beams (HIB), high-current HIBs are required as the energy driver. A compact simulator with electron beam compression using a Malmberg-Penning trap for understanding the beam behaviors with the scalable parameter in HIB-ICF have been proposed and developed. In this study, we have numerically investigated the beam dynamics for the compact simulator of high-current HIB by using Malmberg-Penning trap device to simulate the compression process. As a result, the transverse temperature increases with the increase of the trapped electrons due to the Coulomb interactions.

1. Introduction

Inertial confinement fusion (ICF), which irradiates energy drivers as the ion beam or the lasers to a fuel, is one of the methods of nuclear fusion. Therefore, the energy driver development is a key issue for inertial fusion energy. In ICF driven by heavy ion beams (HIB), high-current HIB, which is in the condition dominated by space charge effect, is required as the energy driver [1]. Because required parameters of the HIB for ICF are far from that of the conventional beams, the beam behaviors should be researched well for the energy driver development. Instead of the HIB, which is requires the large-scale accelerator, the equivalent beam dynamics can be simulated by a compact experimental apparatus using the electron beam which is one of the charged particle. Therefore the compact simulators with electron beam were proposed and developed [2]. In particular, the simulation of the pulse compression of the HIB has been demonstrated reproduced using the Malmberg-Penning trap device [3].

In this study, we numerically investigate the compression process in the Malmberg-Penning trap device [4] toward the compact simulator of high-current HIBs.

2. Compact simulator of Malmberg-Penning trap

Malmberg-Penning trap [3] is a confinement device of electron cloud, and investigates non-neutral plasmas on controlling the density distribution. The parameters of this device are 0.1 T of applied magnetic field and potential barrier of -100 V. The applied magnetic field and the potential barrier limit the electron behaviors in both radial and axial directions.

3. Numerical Simulation Model

Numerical simulations are performed under the experimental conditions as the HIB simulation by the Malmberg-Penning trap device. In this numerical simulation, the compression ratio of 10 from the initial condition was carried out using the molecular dynamics simulation code [5], which represents a particle-particle model.

Figure 1 shows the initial condition of particle distribution in the numerical simulation model. At the initial condition, electrons are arranged uniformly in cylindrical space with 10 mm of radius and 180 mm of length, and super particle number for 10000 and thermal equilibrium distribution for 1eV. As the boundary condition, the particles rebound from both ends. We have simulated with the compression time of 100 ns and the electron number from 1.6×10^{8} to 1.6×10^{9}

4. Calculation results

Figure 2 shows the particle distributions in longitudinal real space and transverse real space for the compression time of 100 ns with the electron number of 1.6×10^{8}. As shown in Fig. 2, the electron bunch is compressed in the longitudinal direction as a function of time, and the electrons are confined radial direction due to the external magnetic field.

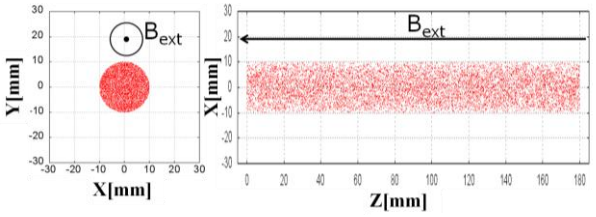

Fig. 1. Initial condition of particle distribution in real spaces and direction of applied magnetic flux density

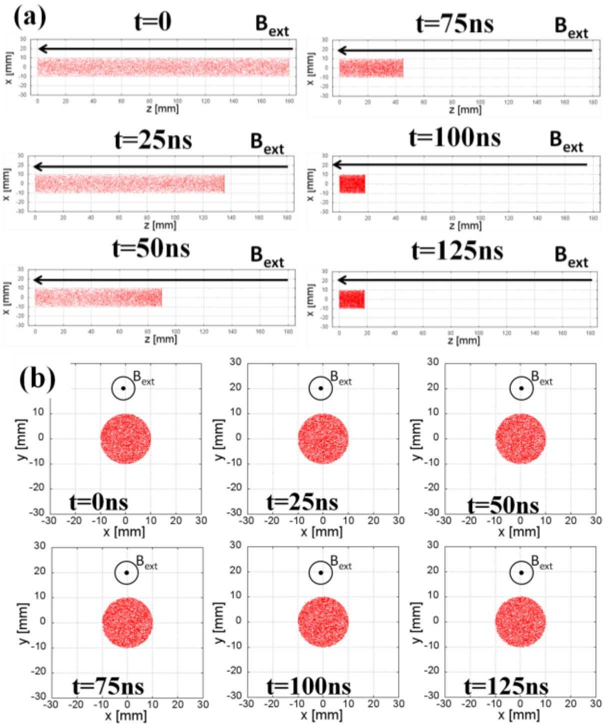

Fig. 2. Particle distribution for compression time of 100 ns with the electron number of 1.6×10^8 and the direction of the applied magnetic flux density in (a) longitudinal real spaces and (b) transverse real spaces

We have demonstrated a dependence on the electron number in the simulation box. Figure 3 shows the time evolution of transverse temperature, which is determined from the charge density distribution in the kinetic energy space, for each electron number from 1.6×10^8 to 1.6×10^9 for the compression time of 100 ns. These transverse temperatures show the degree of longitudinal transverse coupling due to the Coulomb interaction between particles. As shown in Fig. 3, the transverse temperature for 1.6×10^8 of electron number changed slightly. Therefore, it is estimated that the space charge effect is weak in experimental condition. In addition, the transverse temperature for 5 times and 10 times electron number increases due to the Coulomb interaction of particles.

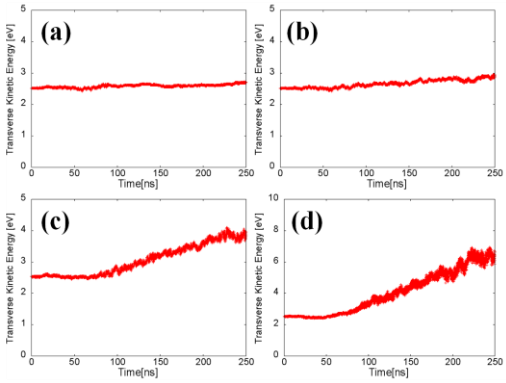

Fig. 3. Time evolution of transverse temperature for compression time of 100 ns in electron number for (a) 1.6×10^8,(b) 3.2×10^8,(c) 8.0×10^8 and (d) 1.6×10^9

5. Conclusion

We numerically investigate the compression process in the Malmberg-Penning trap device toward the compact simulator of high-current HIBs. From these results, the electron bunch during longitudinal compression can be confined in radial direction. In addition, with the increase of the number of electrons, the transverse temperature increases due to the Coulomb interaction of particles.

References

[1] S. Atzeni and J. Meyer-ter-vehn: *Physics of Inertial Fusion, Oxford Univ. Press, 2004*

[2] Y. Sakai, M. Nakajima, J. Hasegawa, T. Kikuchi, and K. Horioka: Nucl. Instrum. Methods Phys. Res. **A 733** (2014) 70.

[3] Y. Park, Y. Soga, Y. Mihara, M. Takeda, and K.Kamada: Res. Rep. NIFS PROC. **93** (2013) 84.

[4] Y. Soga, Y. Kiwamoto, and N. Hashizume: Phys. Plasma. **13** (2006) 052105.

[5] T. Kikuchi, K. Horioka, K. Takahashi, T. Sasaki, T. Aso, and Nob. Harada: Prog. Nucl. Energy. To be published (2014) 10.1016/j.pnucene.2014.07.023.