Beam Dynamics Simulation During Longitudinal Bunch Compression with Focusing Field Errors

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In heavy ion inertial fusion (HIF), the intense heavy-ion beam (HIB) is one of the influential candidates as the energy driver, and the physics of space-charge-dominated beams is crucial in the HIF and High Energy Density Physics studies. Required parameter values of HIB are several GeV particle energy, ~100 kA total current, and ~10 ns short pulse duration, and the beam parameters are far from those of conventional particle accelerator system. Therefore the beam dynamics and control are important research issues in HIF. At the final stage, the beam pulse must be longitudinally compressed from ~100 to ~10 ns.

In our studies [1, 2, 3], the beam instability excited by the strong space charge effect was observed using multi-particle numerical simulations during the final beam bunching. The final beam bunching was carried out by the beam transport using the continuous and alternating focusing lattice system. We also investigate the beam dynamics during the bunch compression with the focusing error field.

Transverse particle-in-cell simulation with a longitudinal bunch compression model is carried out to investigate transverse particle behaviors. For the particle positions x_p and y_p of index p, the equations of motion along the transport distance s are written as[1]

$$\frac{d^2 x_p}{ds^2} = -k_x\, x_p - \frac{q}{\gamma^3\, m_0\, v_z^2}\frac{\partial \phi}{\partial x}, \qquad (1)$$

$$\frac{d^2 y_p}{ds^2} = -k_y\, y_p - \frac{q}{\gamma^3\, m_0\, v_z^2}\frac{\partial \phi}{\partial y}, \qquad (2)$$

where q is the charge of the beam ion, m_0 is the rest mass of the beam ion, γ is the relativistic factor at the center of longitudinal beam position, v_z is the longitudinal beam velocity, and ϕ is the self-electrostatic potential of the beam, respectively. The transverse focusing coefficients k_x and k_y are constant for the continuous focusing (CF) model, and are given as the alternate values for the alternating gradient (AG) focusing model. Studying the effect of the focusing field error, we introduce the error δk, which has the normal distribution. As a result, the focusing forces including the field error are given by $k_x + \delta k$ and $k_y + \delta k$.

The evolutions of the emittance growth, which indicates the ratio of the average emittance to the initial one at each lattice period, are shown in Figs. 1 and 2. Figure 1 shows the calculation result with the field error in the case of the beam transport with the CF lattice. The relative rms value $(\delta k/k)_{rms}$ of the field errors applied by the pseudo random numbers of the normal distribution is 0.1. As shown in Fig. 1, the additional emittance growth after the longitudinal bunch compression is observed by only 2 %. Figure 2 shows emittance growth history during the final beam bunching with the focusing field error in the AG field lattice. To change the focusing field error ratio $(\delta k/k)_{rms} = 0 \sim 0.1$, we can compare the emittance growth due to the longitudinal compression with the field error. In the case of $(\delta k/k)_{rms} = 0.01$, the emittance growth is almost same level in the comparison with the result in no-field error case. However, the emittance growth of 2.4 times is indicated in the longitudinal bunch compression with the 10% focusing field error. The results show the quite difference between the beam transport in the CF and AG field lattices with the focusing field error.

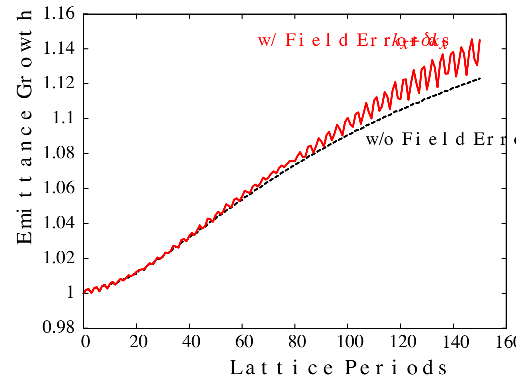

Figure 1: Evolution of the rms emittance during the final beam bunching with CF lattice.

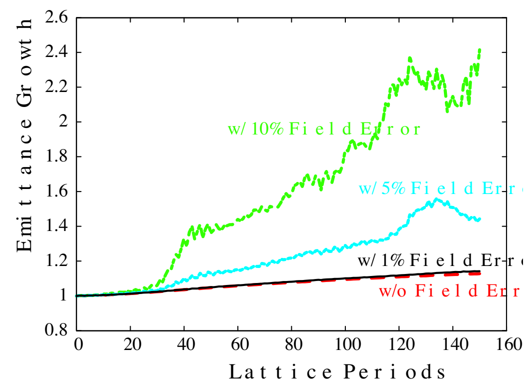

Figure 2: Evolution of the rms emittance during the final beam bunching with AG focusing lattice.

References

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