Rapid Communications

Beam Dynamics Simulation in Final Beam Bunching of Heavy Ion Inertial Fusion

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Bunching beam dynamics and emittance growth in a final buncher of heavy ion fusion accelerator system are studied using a particle-in-cell simulation. The results indicate that while the beam current is increased by longitudinal compression, the beam particles dilute in phase space depending on the bunching history.

Keywords:
beam bunching, emittance growth, particle-in-cell method, heavy ion inertial fusion.

In the final stage of an energy driver system for heavy ion inertial fusion (HIF), an intense-heavy-ion beam should be longitudinally compressed for effective fuel pellet implosion. The beam has extreme parameters of ~10 GeV particle energy, a beam current of kA level, and ~10 ns pulse duration. Longitudinal bunch compression is indispensable in all of the suggested HIF accelerator systems [1,2]. For this reason, the beam dynamics in the final beam buncher is a crucial issue in the design of the HIF accelerator system [3,4].

An induction beam buncher applies bunching voltage so as to make a considerable velocity tilt between the head and the tail of the beam bunch for the beam compression [3,4]. The induction buncher consists of acceleration gaps and FODO configuration quadrupole lattices for beam transport [4,5]. The transverse confinement force and the lattice structure should be carefully designed for beam envelope matching [4]. However, the beam current rapidly increases with the longitudinal beam compression, and this increase causes beam envelope mismatch and resonance effects [6]. These unfavorable factors are the sources of emittance growth which is particle distribution dilution in phase space.

Beam length is estimated using the longitudinal envelope equation [3] as shown in Fig. 1. The beam parameters were assumed as the final stage of Ref. [2]. We assume that an induction buncher length of 230 m is a “Slow” compression schedule, and “Rapid” compression is assumed if the whole transport line consists of the induction buncher [7]. In addition, when the beam bunch is linearly compressed we call it as “Linear” compression case as Fig. 1 shows.

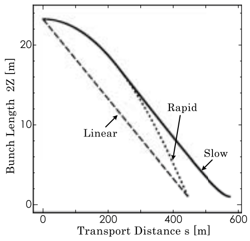

Fig. 1 Behaviors of bunch length for three different beam bunching schedules.

We investigate the transverse particle behavior with the beam current increase using the transverse two-dimensional particle-in-cell simulation [8] with the longitudinal behavior which was estimated in Fig. 1. The calculations are carried out assuming fourfold symmetry for the sake of saving calculation time and memory [6]. Figure 2 shows the initial particle distributions and beam envelope estimated by the K-V distribution model [5] in the real ($x - y$) and phase ($x - x'$) spaces ($x' = dx/ds$). As shown in Figs. 3 and 4, the beam envelopes expand due to the current increase

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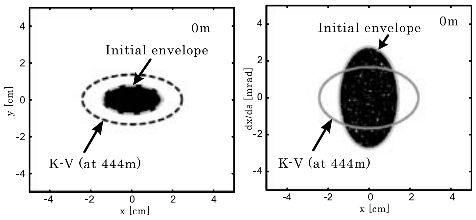

Fig. 2 Initial distribution of beam particles in physical ($x - y$) space and phase ($x - x'$) space.

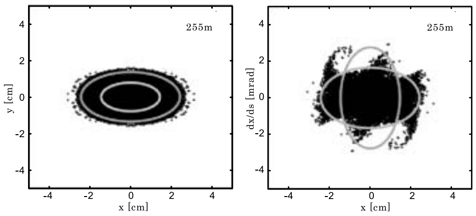

Fig. 3 Beam particle maps in physical ($x - y$) space and phase ($x - x'$) space at $s = 255$ m in a “Linear” compression schedule.

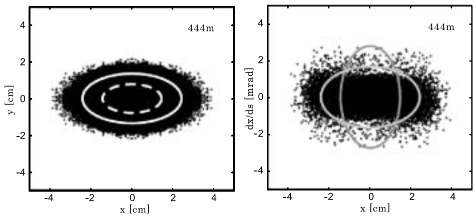

Fig. 4 Beam particle maps in physical ($x - y$) space and phase ($x - x'$) space at $s = 444$ m (last lattice) in a “Linear” compression schedule.

during the transport and bunching. The real and phase space areas of beam particles expanded to a greater extent than the estimated result based on the K-V envelope model shown in Fig. 4. It is known that the transverse instabilities in space charge dominated beams cause emittance growth [5]. An inspection of Fig. 3 reveals that the instabilities triggered by resonant particles, cause the emittance growth shown in Fig. 4.

In the case of a “Rapid” compression schedule, the real and phase space maps of the beam particles are shown in Fig. 5. We also show the beam particle maps in the case of a “Slow” compression schedule as shown in Fig. 6. Comparisons of Figs. 4, 5, and 6 show that the different bunching schedules cause different final emittance values during the longitudinal bunch compression. It is considered that the amount of emittance growth depends on the transport history after passage through the resonance conditions [6].

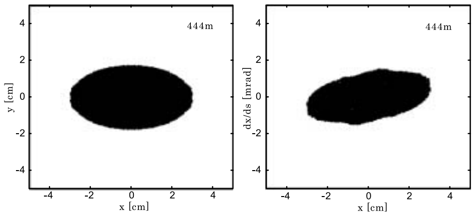

Fig. 5 Beam particle maps at the last lattice in a “Rapid” compression case. Left figure shows real ($x - y$) space, right figure shows phase ($x - x'$) space.

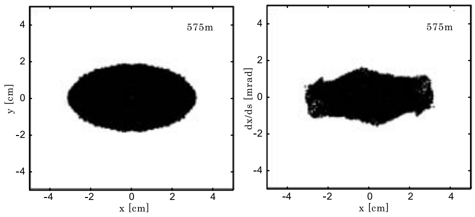

Fig. 6 Beam particle maps at last lattice in a “Slow” compression case. Left and right figures show real ($x - y$) and phase ($x - x'$) spaces, respectively.

The bunching beam dynamics and emittance growth in a final stage of HIF were numerically described in this study. The transverse particle simulation showed that the behavior of emittance evolution depends on the bunching history: the resonance effect is the trigger source and the transport distance after the resonance region of the final buncher determines the amount of emittance growth.

[1] J.J. Barnard *et al.*, Nucl. Instrum. Methods in Phys. Res. **A415**, 218 (1998).

[2] J.J. Barnard *et al.*, Phys. Fluids **B5**, 2698 (1993).

[3] E.P. Lee and J.J. Barnard, *Proc. of 2001 Particle Accelerator Conf.*, Chicago, (IEEE, Piscataway, NJ, 2001), Vol.4, p. 2929.

[4] H. Qin *et al.*, *Proc. of 2001 Particle Accelerator Conf.*, Chicago, (IEEE, Piscataway, NJ, 2001), Vol.3, p. 1761.

[5] R.C. Davidson, *Physics of Nonneutral Plasmas* (World Scientific, Singapore, 2001).

[6] A. Friedman *et al.*, Nucl. Instrum. Methods Phys. Res. **A415**, 455 (1998).

[7] T. Kikuchi, M. Nakajima and K. Horioka, “Bunching Beam Dynamics in Final Stage of Heavy Ion Fusion Driver”, *Proc. RPIA2002*, KEK, Tsukuba, *in print by* KEK report.

[8] R.W. Hockney and J.W. Eastwood, *Computer Simulation Using Particles* (McGraw-Hill, New York, 1981).