STUDY OF THE HEAVY ION BUNCH COMPRESSION IN CSRm

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Abstract

The feasibility of attaining nanosecond pulse length heavy ion beam is studied in the main ring(CSRm) of the Heavy Ion Research Facility in Lanzhou. Such heavy ion beam can be produced by non-adiabatic compression, and it is implemented by a fast rotation in the longitudinal phase space. In this paper, the possible beam parameters during longitudinal bunch compression are studied with the envelope model and Particle in Cell simulation, and the results are compared. The result shows that the short bunch $^{238}U^{28+}$ with the pulse duration of about 50ns at the energy of 200MeV/u can be obtained.

INTRODUCTION

High density plasma physics experiments based on heavy ion beams require high beam intensity with small focal spots and short pulse duration. In order to maximize the energy deposition of the heavy ion beam, the total number of particles has to be captured in a single bunch with a pulse length as short as possible, for the plasma physics experiments the most appropriate beam energy range is 100-300MeV/u, and the beam bunch should not exceed 50ns. At present, high intensity heavy ion beams with the required bunch duration of about 50ns are not available at the CSRm[1], some strategies[2][3][4] have to be developed to acquire such heavy ion beams. The most effective way to produce short ion bunches is the process of fast bunch compression by means of a 90°rotation of the longitudinal phase space ellipse whichis initiated by a fast jump of the RF-voltage amplitude, compared to the adiabatic capture process, the rise time of the voltage must be much shorter than the synchrotron period of longitudinal particle oscillations.

BEAM DYNAMICS CALCULATION AND SIMULATION DURING BUNCH COMPRESSION

In general, the performance of fast bunch compression can be proved by checking the validity of the relation [5],

$$\frac{\tau_{recap}}{\tau_{com}} = \sqrt{\frac{V_{com} + V_{recap}}{V_{recap}}},$$

where τ_{recap} and τ_{com} are the recaptured and compressed bunch lengths respectively, V_{recap} is the final recaptured amplitude and V_{com} is the amplitude provided by the compression cavity. The fast compression is done via 90^0 fast bunch rotation in the longitudinal phase space. The phase space rotation is induced by fast jump of RF voltage amplitude, in order to use the total available RF voltage effectively, the prebunching amplitude is taken as low as possible.

In CSRm, the initial beam parameters are assumed as Table 1, which are consistent with machine rigidity limits, can be compressed to be a length required by fast bunch rotation compression.

For simulation, the heavy ion beams are injected first into CSRm for the accumulation with e-cooling [6] and then the injected beams are accelerated. It is assumed that an initial momentum spread $\Delta p / p$ after accelerator is 5×10^{-4} and the bunch pulse length is about 472ns with 200MeV/u from table 1, which is too long for optimal target heating, and has to be shortened by a factor of 10 or more. According to theory we expect that the total voltage Vf of 160kV setting for mid-pulse] $\Delta p / p$ of 1% which is the acceptance of the CSRm at full compression is needed for getting heavy ion beam bunch of about 50ns length.

Table 1:Main Parameters for Bunch Compression in the CSRm

Ion species	$^{238}U^{28+}$
Particle energy/MeV/u	200
Initial pulse duration/ns	472
Horizontal emittance/πmm mrad	10
Vertical emittance/πmm mrad	10
Initial momentum spread	0.0005

At first, we calculate the variation of beam performance with the bunch compression using envelope model equation[7]. The envelope model equation is integrated from an initial bunch length to estimate the performance changes due to the fast bunch rotation induced by a sudden increase of RF voltage. The calculated results of the longitudinal beam dynamics during the bunch compression in CSRm are shown in Figure 1-3 as a function of revolution distance for CSRm parameters. In this case, a 90^0 rotation of the initial phase space ellipse takes place in 61.6 laps, the pulse duration decreases from 472ns to 24ns, and the momentum spread increases from 0.0005 to 0.01 during the bunch compression.

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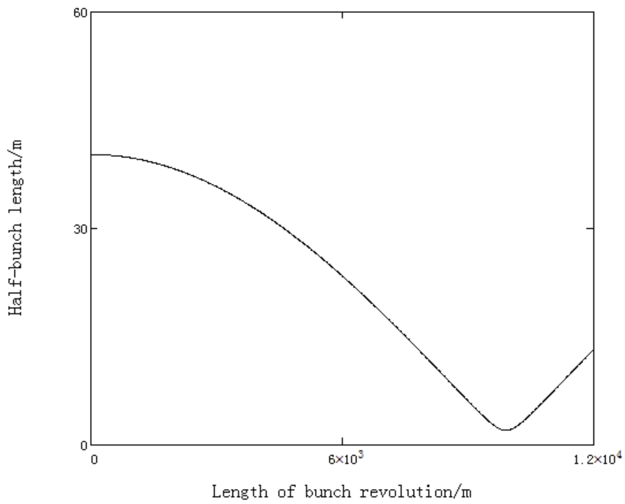

Figure 1: Half bunch length as a function of revolution length during bunch compression in CSRm.

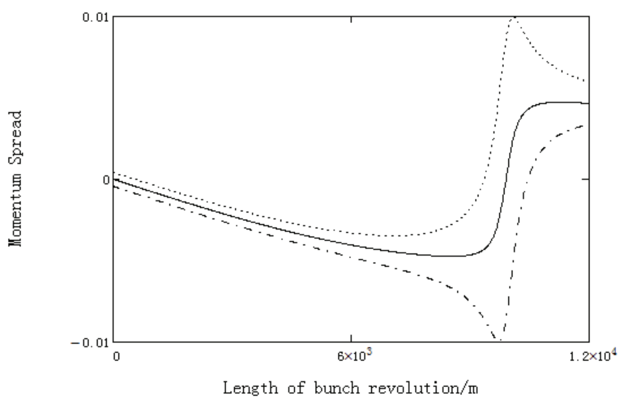

Figure 2: Momentum spread at 1/4 pulse as a function of revolution length during bunch compression in CSRm.

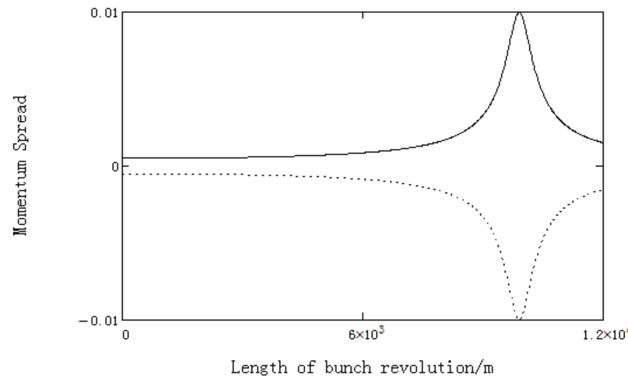

Figure 3: Momentum spread at mid-pulse as a function of revolution length during bunch compression in CSRm.

Also, the longitudinal beam dynamics was simulated using the more detailed PIC[8] method. Figure 4 shows the phase space distribution of the initial distribution (left), the one at some time in the process of the bunch compression (middle), and that at 1/4 synchrotron period (right). The phase space rotates while the high RF voltage amplitude jumps during the compression process, it is shown that the bunch length decreases while the momentum spread increases, and the shortest bunch length takes place in 59 laps when the momentum spread is 0.01. It can be seen from Figure 5 that the density of the heavy ions increases during the bunch compression.

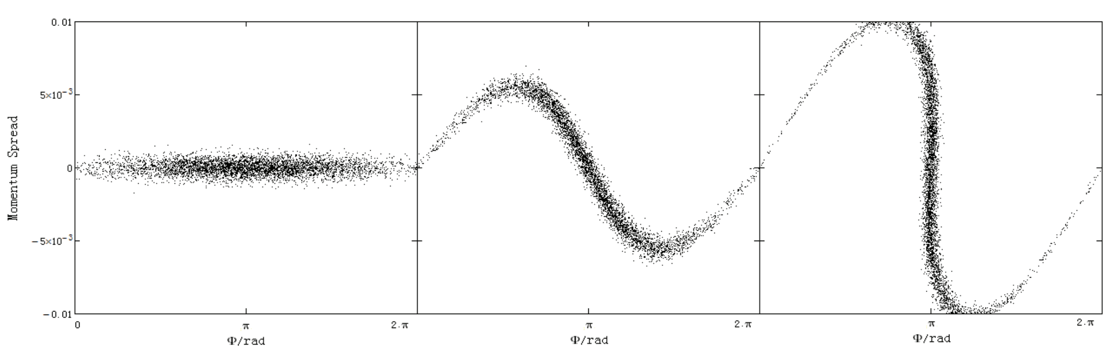

Figure 4: Phase space evolution during the bunch compression in CSRm. The initial phase space distribution(left), phase space distribution at a fixed time during the bunch compression(middle), and the phase space distribution at 1/4 synchrotron period(right).

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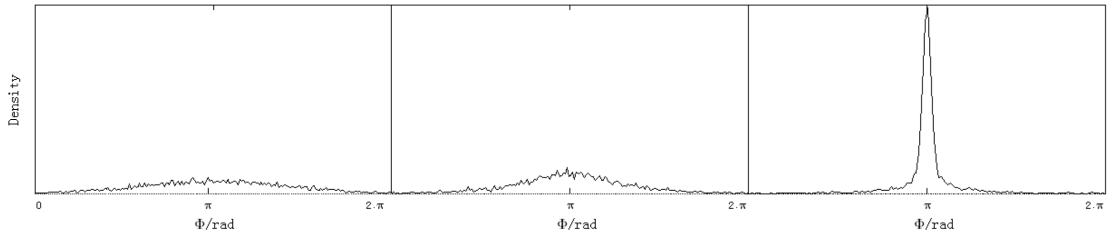

Figure 5 : Beam density evolution during the bunch compression in CSRm. The initial density of the heavy ions (left), the density at a fixed time during the bunch compression(middle), and the density at 1/4 synchrotron period(right).

The compression dynamics of typical heavy ion $^{238}U^{28+}$ was studied with two different methods, and the detail results are shown in Table 2. It can be concluded that it is possible to compress $^{238}U^{28+}$ ion bunch to a length of about 50ns.

Table 2: Comparison of the Results with Two Study Methods

Parameter	Envelope Model	PIC
Initial bunch length/ns	472	
Initial momentum spread	0.0005	
RF voltage/kV	610	
Final bunch length	24	26
Initial momentum spread	0.01	
Ratio of compression	19	18

CONCLUSION

Study of the bunch compression in the CSRm ring using the fast bunch rotation scheme was investigated by the envelope model and PIC simulations. The initial beam parameters were restricted by the magnetic rigidity and space-charge tune shift. The calculation results indicate that the short pulse bunch length of about 50ns can be expected by the bunch compression in the CSRm, and if the initial momentum spread is small enough, the bunch length will be shortened after the longitudinal rotation. The bunch is compressed longitudinally in the ring to about 1% momentum spread, and kicked out of the ring near peak compression into an extraction line for the final transport and focusing onto a target.

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