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SINGLE HEAVY ION BUNCH GENERATION SCHEME IN BRING AT HIAF*

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Abstract

As the Booster Ring of the High Intensity Heavy-ion Accelerator Facility (HIAF), BRing is a synchrotron which can be able to accumulate and accelerate full ion species provided by iLinac to required energy with RF acceleration system. When accelerating uranium beam(e.g. $^{238}U^{35+}$), the variation range of the kinetic energy is 17MeV/u-830 MeV/u, and the corresponding revolution frequency f_{rev} range is 0.099MHz-0.447MHz. Because of the low frequency limit value of 0.099MHz, the RF frequency f_{RF} of RF cavity should be h(harmonic number) times of f_{rev} ,thus, there will have h(is equal to harmonic number) bunches after acceleration. To satisfy the extraction requirement, the accelerated multiple bunches should be recollected in one bunch by means of longitudinal manipulation.

The different single bunch generation method of debunching and bunch merging are investigated separately, and the beam parameters in different cases are obtained, meanwhile, the optimized RF program during the debunching and bunch merging are presented.

INTRODUCTION

In China, the Heavy Ion Research Facility at Lanzhou (HIRFL) [1] is one major national research facility focusing on nuclear physics, atomic physics, heavy ion applications and interdisciplinary researches. A series of remarkable results have been obtained at HIRFL. Based on the developments and experience with heavy ion beam accelerators, a new project HIAF [2] was proposed by IMP in 2009. The facility is being designed to provide intense primary and radioactive ion beams for nuclear physics, atomic physics, application research sciences and so on. The schematic layout of HIAF project is shown in Fig. 1.

The HIAF project consists of ion sources, linac accelerator, synchrotrons and several experimental terminals. The superconducting ion Linac accelerator (iLinac) is designed to accelerate ions with the charge-mass ratio Z/A=1/7 (e.g. $^{238}U^{35+}$) to the energy of 17 MeV/u. Ions provided by iLinac will be cooled, accumulated and accelerated to the required intensity and energy (up to 1×10^{11} and 830 MeV/u of $^{238}U^{35+}$) in the Booster Ring (BRing), then fast extracted and transferred either to the external targets or the Spectrometer Ring (SRing).

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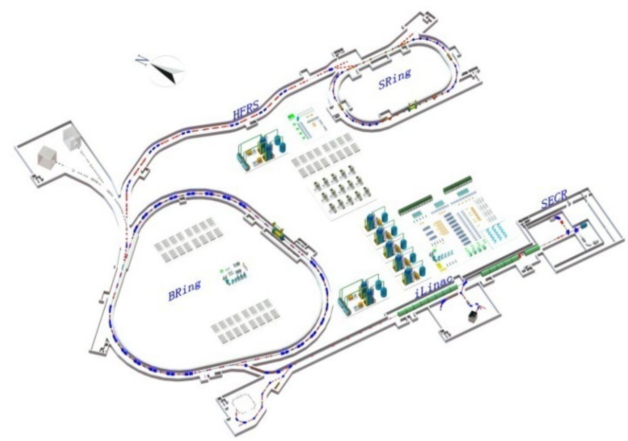

Figure 1: Layout of papers.

As a key part of the HIAF complex, BRing is a synchrotron which can be able to accumulate and accelerate full ion species with a circumference of 569 m and a maximum magnetic rigidity of 34 Tm, Table 1 shows the main configuration and parameters of the BRing.

Table 1: Main Parameters of BRing

Main parameters	Values
Circumference (m)	569
Maximum magnetic rigidity (Tm)	34
Accelerating rate (T/s)	12
Momentum acceptance (Δp/p)	$\pm5.0\times10^{-3}$
Injection	
Ion	$^{238}U^{35+}$
Energy (MeV/u)	17
Revolution frequency(MHz)	0.099
Momentum spread (Δp/p)	$\leq\pm2\times10^{-3}$
Extraction	
Maximum Energy (MeV/u)	830
Revolution frequency(MHz)	0.447
Particle number (ppp)	1.0×10^{11}

After two-plane painting injection and accumulation, the beam with the injection energy of 17 MeV/u is costing beam which will spread over 2π in rf phase and it has a momentum spread of $\Delta p/p = \pm2\times10^{-3}$ (see Fig. 2). Due to the evolution frequency of 0.099MHz at injection energy is beyond the working frequency range of the cavity, so the RF cavity will work at the harmonic number greater than 1, based on experience and dynamics results,

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the number will be selected as 3 or 4. Fig. 3a presents the bunch distribution at the end of acceleration at the harmonic number of 3, and Fig. 3b presents the bunch distribution at the end of acceleration at the harmonic number of 4.

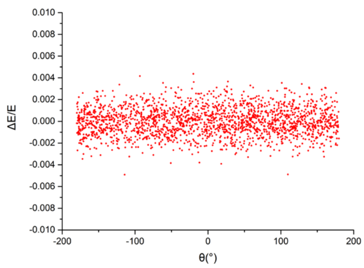

Figure 2: Initial distribution after accumulation.

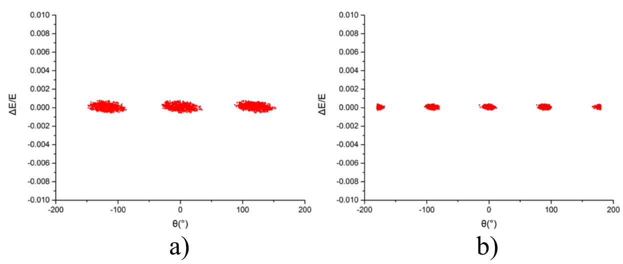

Figure 3: Beam distribution after acceleration. a) at the harmonic 3, and b) at the harmonic 4.

In order to meet the extraction requirement of the bunch number of one, multiple bunches which the number is equal to harmonic number of RF system should be converted to one. In general, there are two schemes to generate single bunch. The first one is firstly to debunch [3,4] multiple bunches to costing beam, then recapture the costing beam to one bunch, and the second one is to merge [5] the bunches through the RF manipulation.

DEBUNCHING

The conventional method for changing the longitudinal structure of the beam is to debunch by cancelling the voltage at the initial frequency, and then the beam will drift without longitudinal focusing, and then to rebunch with another RF frequency to one bunch. The voltage will be decreased adiabatically from the value which at the end of acceleration to that of cavity activation (close to 0v) within a period of time. Based on the beam parameters of $^{238}U^{35+}$ proposed by the BRing, the debunching process is simulated at the extraction energy of 830MeV/u. During the simulation process, we can know, the momentum spread decreasing with voltage decreasing. Fig. 4e-f show the longitudinal phase-space (azimuth – kinetic energy spread)distribution at the end of the beam debunching with different decreasing time(5ms, 10ms, 15ms, 20ms, 25ms and 30ms), and it is known from the figures, the multiple bunches can't be completely debunched if the debunching time is not enough. Figure 5 shows the momentum spread after debunching with different debunching time. From the results mentioned above, the debunching time of 30ms is enough, and the momentum spread is 0.00014 rms, the beam is costing beam in this case. After that the costing beam will be recaptured at the fundmental harmonic by turn on the rf voltage adiabatically. From the Fig. 6 we can see clearly that the single bunch is generated from 3 bunches successfully. And Fig. 7 shows the RF program during the whole process including capture, acceleration, debunch and recapture.

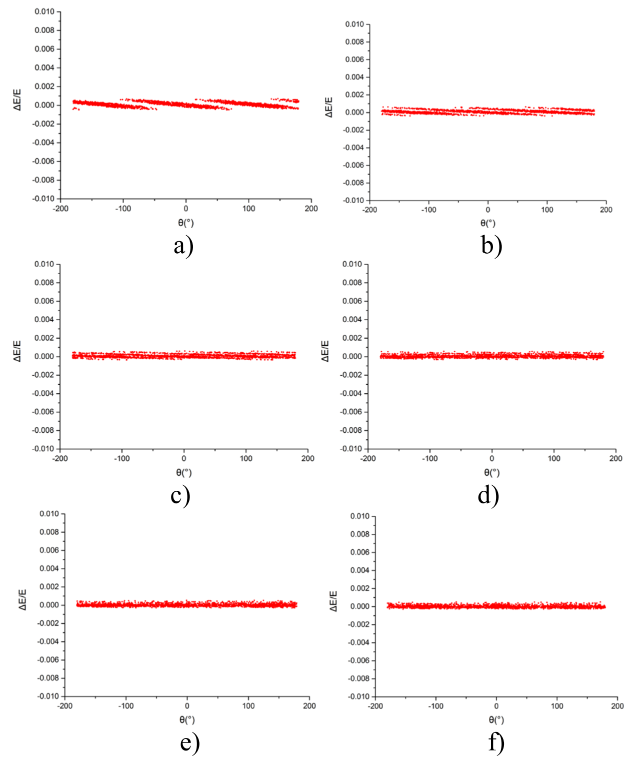

Figure 4: Beam distribution after debunching with different debunching time: a) 5ms, b) 10ms, c) 15ms, d) 20ms, e) 25ms, f) 30ms.

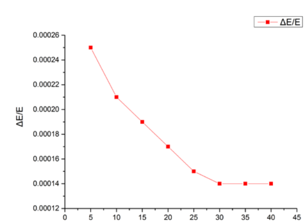

Figure 5: Momentum spread after debunching with different debunching time.

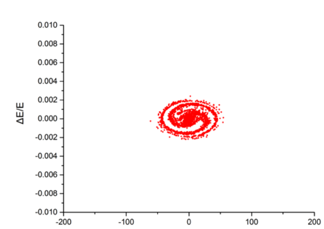

Figure 6: Beam distribution after recapture.

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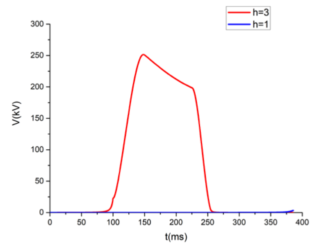


Figure 7: RF voltage program during the whole process. Red line is the RF voltage program with the harmonic 3, and the blue line is the RF voltage program with the harmonic 1.

There are two RF harmonics are used through this whole process, and the basic parameters of these RF system are listed in Table 2.

Table 2: Main Parameters of RF System of Debunching

Main parameters	Values
Ion species	U^{35+}
Energy (MeV/u)	830
Harmonic number h	4-1
Gap voltage(kV)	250-3.49

As the widely used way to generate single bunch, debunching can minimize emittance blow-up, however, this technique presents a number of drawbacks:

- RF voltages must be controlled down to small amplitudes in the presence of beam-loading,
- while drifting, the beam is left uncontrolled,
- the full circumference is filled with particles,
- the continuous beam has a very small $\Delta p/p$ which makes it prone to microwave instability.

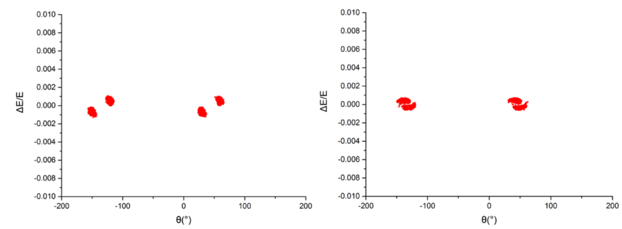
BUNCH MERGING

Another convenient alternative method of generating single bunch is bunch merging, and the bunch number of merging pairs must be divided by 2 (or a power of 2). In this article, the beam is accelerated with RF system at harmonic 4, so,4 bunches will be generated after acceleration, and the scheme of 4:2:1 bunch merging will be used to generate single bunch.

When the acceleration completed, there will 4 bunches held with an RF system on harmonic 4, RF voltage on harmonic 2 is slowly turned on while it is reduced on harmonic 4. With the correct phasing between both systems and sufficiently slow voltage changes, the 4 bunches merge into 2, and this process is shown in Fig. 8, after that, RF voltage on harmonic 1 is slowly turned on while it is reduced on harmonic 2, the 2 bunches merge into 1 this process is shown in Fig. 9. There are three RF harmonics are used through the whole process (see Fig. 10), and the basic parameters of these RF system are listed in Table 3.

Table 3: Main Parameters of RF System of Bunch Merging

Main parameters	Values
Ion species	U^{35+}
Energy (MeV/u)	830
Harmonic number h	4-2-1
Gap voltage(kV)	270-80-80



a) b)

Figure 8: Bunch distribution during the bunch merging. a)-during the merging from 4 to 2 and b)-at the end of merging from 4 to 2

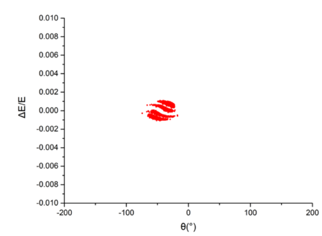


Figure 9: Bunch distribution after bunch merging.

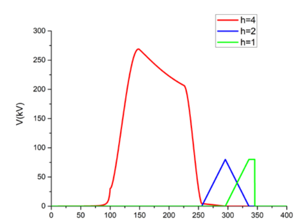


Figure 10: RF voltage program during the bunch merging process.

CONCLUSION AND OUTLOOK

Determination of single bunch generation scheme is a compromise of total operation cycle, RF system available, and so on. The study of this subject is just beginning, a more detail RF program and beam parameters will be presented in subsequent work.

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