Charge stripping accumulation of light heavy ions in HIRFL-CSR main ring*

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Abstract The charge stripping injection method has been adopted for the accumulation of light heavy ions in HIRFL-CSR. This method has some special requirements for the accelerating particles, and at the same time the structure of the injection orbit has to be changed. In this paper, the design of the orbit has been presented, as well as the calculation of the beam line matching. According to the result of commissioning, stripping injection can accumulate the beam to a higher current.

Key words heavy-ion accelerator, accumulation, stripping injection

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1 Introduction

Two methods, the multiple multi-turn injection and RF stacking methods, have been designed for the beam accumulation in HIRFL-CSR previously. They are. The RF stacking method is designed for light heavy ions. But it needs the beam to be injected to the centre of the RF bucket. By using the RF cavity in the ring, the energy deviation is suppressed and the beam moved to the accumulation orbit. This course has a very high requirement for the control of the RF and its phase, and requires that the ratio between the perimeters of the CSR injection orbit and the extraction orbit of injector to be integer. All these make it very difficult. In order to make sense easier, a new method, the charge stripping injection method for light heavy ions has been decided to be adopted. In this paper, the beam preparing and beam orbit design for the new method are studied.

2 The stripping injection

The acceptance for synchrotron is designed with a limit. According to Lowville's theorem, the phase space density keeps constant in the static magnet field. This limits the intensity of beam that can be injected in the ring. To overcome this limit for CSR, the main method we use is electron cooling[1], which condenses the phase space by energy exchange of ions and electrons.

For charge stripping injection[2], it can also condense the phase space, but in a different way. The beam is injected through a thin foil and its charge state is changed. The orbits of different charge state ions are separated when passing through magnet field. The fully stripped ions are designed to circulate near the closed orbit, so that they will come back and pass the foil again, most of the ions survive. At the same time, a new beam can be injected into the save phase space. By this way the phase space density can be condensed and one can get higher beam intensity.

By using electron cooling, the center momentum of the beam can be changed, so if there is dispersion at foil, the orbit is changed. When the beam is shifted away from the foil and another stripping injection procedure can begin. The beam is accumulated in both the transverse and longitudinal phase space. In this way one can reach even higher intensity.

3 Beam preparation

It's well known that light ions are suitable for stripping injection. The ion charge states, energy, foil

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thickness should be carefully chosen[3]. Beam energy and foil thickness are correlated. Stripping efficiency of fully stripped ions re-passing the foil (about 95%), relative energy loss (<0.2%) and foil lifetime (>0.5 a) are related to beam energy and foil thickness. For carbon beam case, the carbon foil is chosen at the thickness of about 15 μg/cm^2 with the dimension of 40 mm×20 mm.

Table 1. Changes of charge ratio selection.

$Z1$	C	N	O	F	Ne	Mg	Ar
12+							1.5
11+						1.09	1.64
10+						1.2	
9+					1.11	1.33	
8+				1.13	1.25	1.5	
7+			1.14	1.28	1.43	1.71	
6+		1.17	1.33	1.5	1.67	2	
5+	1.2	1.4	1.6	1.8	2		
4+	1.5	1.75	2				
3+	2						

The storage ring can accept limited range of beam with different changes of charge ratio ($Z/Z1$, Z is the element number; $Z1$ is the beam charge state before stripping). Selection of the injection beam charge states ($Z1$) is done in Table 1. We select $Z/Z1$=1.33—1.5, which means at least 2/3 up to 4/5 of the electrons of atom should be stripped before injection.

For ions lighter than Ne, we prefer to use the beam from SFC. The intensity of beam is higher from SFC, but the beam energy is relatively lower (For carbon, less than 8 MeV/u), which requires the ring dipole to work at 0.1 T.

4 Influence to CSR main ring

The overall structure of the ring will keep unchanged, except for some modifications of vacuum chambers for injection orbit, insertion of stripping foil and beam stopper and vacuum valves.

The electrostatic inflector is taken away for this accumulation mode, as it's difficult to move the anode and cathode with a distance of about 6 cm.

The layout of injection section of the CSR main ring can be seen in Fig. 1. The stripping foil and beam stopper are inserted in the first dipole of the injected beams. For the stripping foil, one ϕ60 hole is dug at 4.6° of the dipole magnet. The beam stopper and charge detector are located at the other end of the dipole.

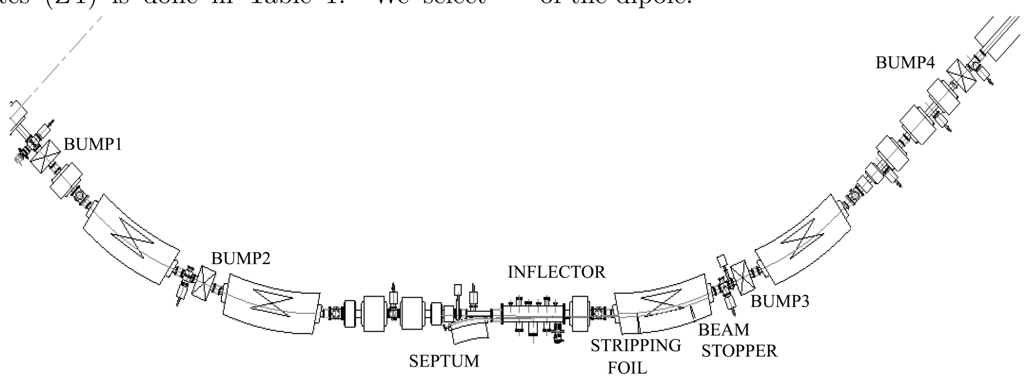

Fig. 1. Layout of injection section of CSR main ring.

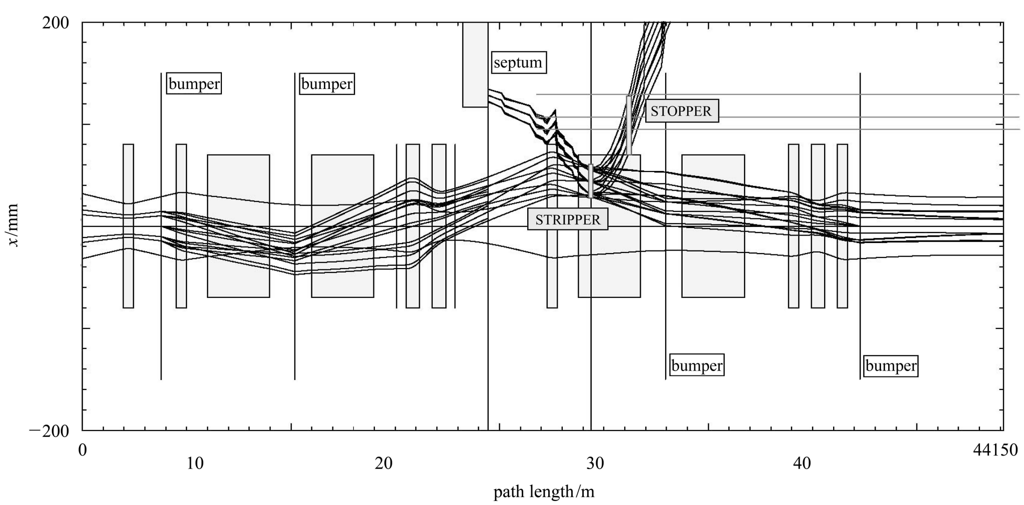

Fig. 2. Stripping injection orbits of C^{4+}, N^{5+} and O^{6+}.

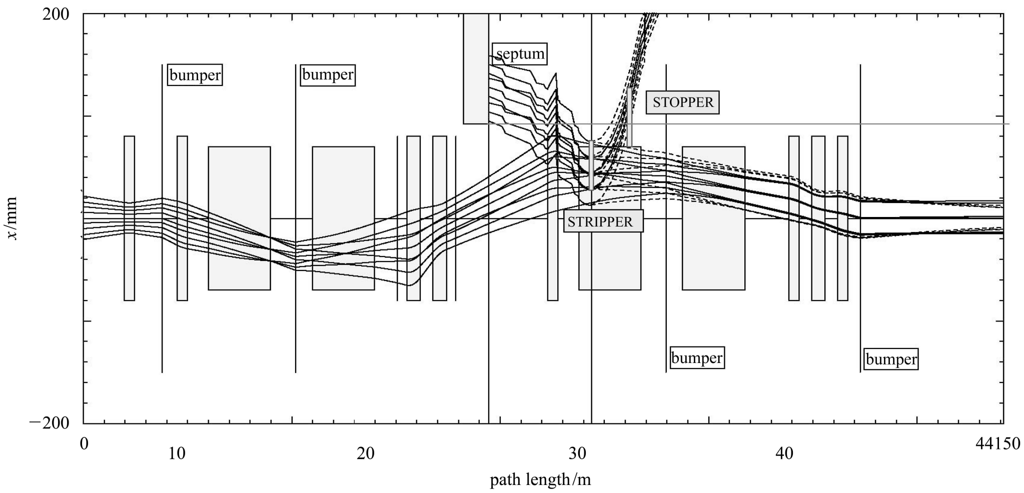

Fig. 3. Stripping injection orbits of carbon with the momentum spread of ±0.5%.

5 Orbit design

The stripping injection orbits of $^{12}C^{4+}$, $^{14}N^{5+}$ and $^{16}O^{6+}$ are designed and shown in Fig. 2. The positions of foil and stopper are fixed. The momentum spread of injected beam is not included. The horizontal emittance of injected beam is 20 πmm·mrad; and the accelerating beam acceptance is 80 πmm·mrad.

The stripping injection orbits of $^{12}C^{4+}$ with momentum spread of $\Delta p/p = \pm 0.5\%$ are shown in Fig. 3.

6 Matching of beam line

The matching of phase space and dispersion is important to get higher injection efficiency and smaller accelerating beam emittance that makes cooling time shorter. It's not easy to match the beam phase space, as the injection beam line is designed for multi-turn injection.

The matching is done roughly with the results listed in Table 2 and the beam envelope shown in Fig. 4. The beam emittance is 20 πmm·mrad in both planes, and $\Delta p/p = \pm 0.5\%$.

Table 2. Matching of phase space at stripping foil.

	β_x	α_x	β_y	α_y	D_x	$D_{x'}$
required	9.341	0.504	5.940	−0.469	3.0	−0.680
reached	9.342	0.506	5.941	−0.472	2.813	−0.348

The last component of the beam line is 4.6° part of the ring dipole, ahead of it are one of the ring quadruple with less focusing strength and the septum magnet. As one can see from Fig. 4, the acceptance of beam line is a bit less than the designed one.

7 Commission results

The commissioning is done in the CSR main ring with the charge stripping injection. The achieved intensity is shown in Fig. 5. The upper part shows

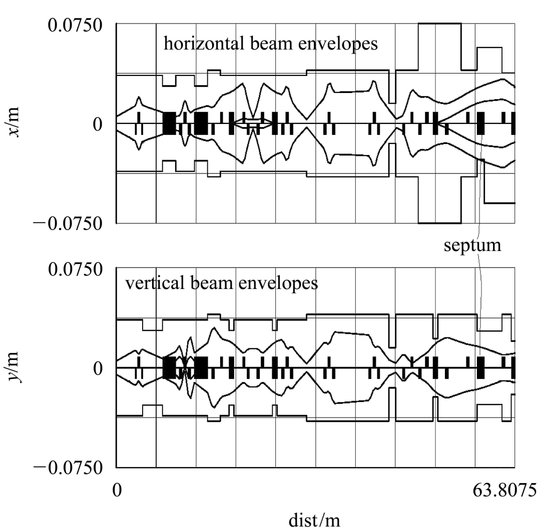

Fig. 4. Beam envelope of injection line.

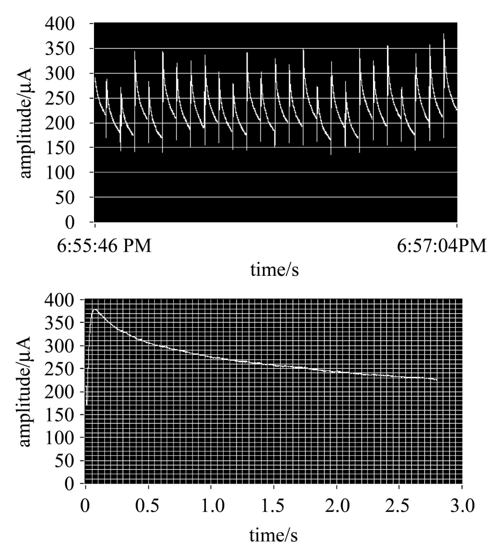

Fig. 5. Beam intensity achieved by stripping injection.

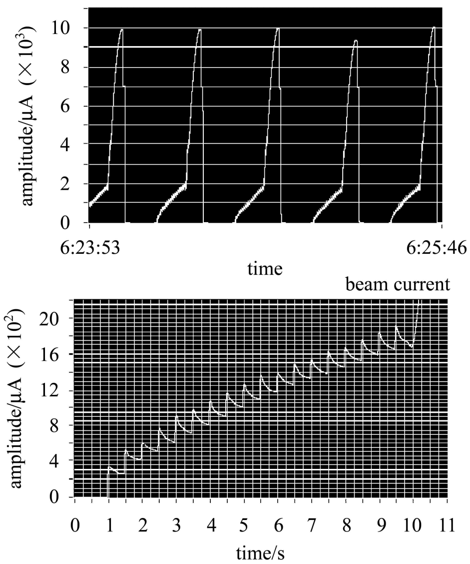

Fig. 6. Beam intensity achieved by stripping injection and electron cooling.

that the stripping injection is done repeatedly in every 3 s, and lower part is the last period.

With electron cooling, the accumulation is done with stripping injection. After ten seconds accumulation, the current can reach up to 1800 μA, and the number of particles is 7×10^9 (Fig. 6).

8 Conclusion

The stripping injection can overcome the limit of Lowville's theorem to inject the beam to a higher current in the ring without cooling system compared with the RF stacking method[4].

Using the cooling system, even higher current can be achieved. And we can make a conclusion that stripping injection is a better way for the accumulation of light heavy ions.

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