DESIGN OF BEAM INJECTION AND EXTRACTION FOR HIRFL-CSR PROJECT *

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Abstract

The new national key project HIRFL-CSR[1-3] is an extending project of present HIRFL (Heavy Ion Research Facility of Lanzhou) project, which consists of two cooler storage rings (CSR). The beam accumulation, injection and extraction of the rings are described in this paper. For the beam accumulation two schemes will be adopted: multiple multiturn injection scheme and RF stacking scheme. Both fast and slow extraction from the rings will be arranged in the same channels. All the above requirements result in complicated ring structures.

1 OVERALL DESCRIPTION

As the upgrading project of existing HIRFL, CSR project evidently improve the research ability of heavy ions. CSR project will increase the energy and quality of heavy ion beams by an order of about ten. It consists of four parts: beam line from HIRFL to CSR, CSR accumulation ring and synchrotron (CSRm), radioactive ion beam production line(RIB), and experimental storage ring(CSRe).

The beam accumulated, cooled and accelerated in CSRm will be extracted to CSRe or external targets. Both fast and slow extractions are required.

For CSRe only single-turn injection is required. Both fast and slow extractions will be adopted in CSRe also for the future requirement.

2 ACCUMULATION AND EXTRACTION SCHEME OF CSRM

The layout of injection and extraction scheme of CSRm is shown in Figure 1.

2.1 Accumulation of Heavy Ions in CSRm

The beam lifetime in CSRm of beams extracted from HIRFL ranges from 15 seconds to several hours, so it's possible to accumulate beams in CSRm, where accumulation period is about 10 seconds[4].

In order to increase beam intensity, two methods will be adopted in CSRm. One is Multiple Multiturn Injection (MMI), which accumulates particles in horizontal phase space. Next is multiturn injection combined with RF Stacking (RFS), while particles are accumulated in momentum phase space. For both methods, electron-cooling time is a very important factor.

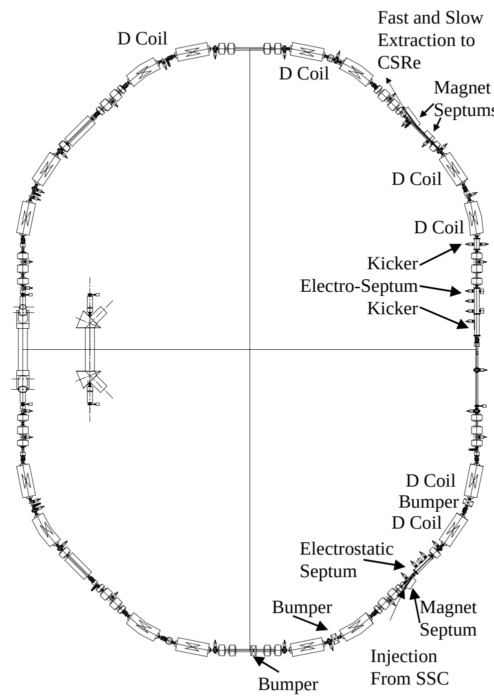

Figure 1: Layout of CSRm injection and extraction

- Multiple Multiturn Injection

In order to keep the closed orbit outside orbit bumping region unchanged, three bumpers are used.

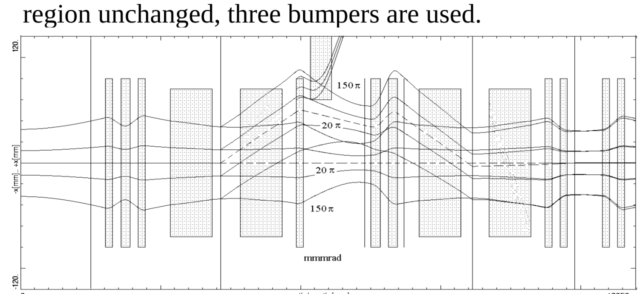

Figure 2: Injection orbit and beam envelope of MMI

The emittance of injection beam is $\varepsilon_{x,y}$=5-20π mm.mrad, momentum spread is ±0.15%. After multiturn injection the emittance is ε_x=150π mm.mrad. For multiple multiturn injection, horizontal acceptance of 20π mm.mrad is reserved as accumulation core, the rest is for subsequent multiturn injection. The horizontal beam

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emittance will be cooled down to 20π mm.mrad before next multiturn injection.

Simulations have been done on multiturn injection. Beam parameters of injection like α_x, β_x, direction, emittance and bumping orbit falling speed (or numbers of injection turns) will affect the gain factor of multiturn injection(Figure 3).

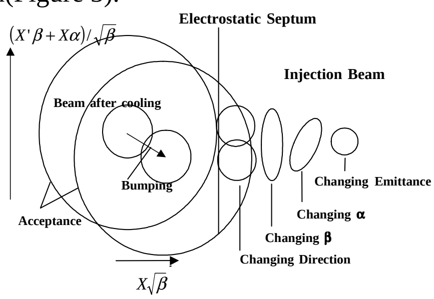

Figure 3: Factors affects gain factor of multiturn injection

We expect a gain factor of 4 to 8 for multiturn injection. The beam accumulation parameters of typical heavy ions for multiple multiturn injection are estimated in Table 1, where the striping efficiencies and beam lifetimes are taken into account.

Table 1: Beam accumulation parameters 10 seconds of typical heavy ions for MMI

Ion	E MeV/u	I_{in} (pps)	Z_1	η (%)	Lifetime (sec)	T_{cool} (ms)	MMI Gain	T (sec)	N	I_{acc} (euA)
$^{12}C^{6+}$	50	3.1×10^{12}			3198	2505	5	10	1.0×10^{8}	59.6
$^{16}O^{8+}$	50	2.3×10^{12}			1769	1964	5	10	1.0×10^{8}	75.7
$^{20}Ne^{10+}$	50	6.3×10^{11}			1107	1627	5	10	3.3×10^{7}	30.5
$^{40}Ar^{18+}$	30	6.9×10^{11}			340	681	5	10	1.1×10^{8}	145.6
$^{58}Ni^{24+}$	30	1.3×10^{11}	28	29.3	110	520	5	10	5.2×10^{6}	10.7
$^{84}Kr^{28+}$	25	2.2×10^{11}	33	24.0	76	409	5	10	1.2×10^{7}	26.7
$^{129}Xe^{36+}$	20	8.7×10^{10}	48	19.3	37	246	5	10	7.2×10^{6}	20.9
$^{181}Ta^{36+}$	15	8.7×10^{9}	59	16.9	24	118	5	10	1.2×10^{6}	3.6
$^{208}Pb^{37+}$	12	8.4×10^{9}	66	16.2	20	113	5	10	1.1×10^{6}	3.4
$^{238}U^{37+}$	10	8.4×10^{9}	72	15.4	15	106	5	10	1.1×10^{6}	3.4

- Multiturn Injection Combined with RFS

RF Stacking takes 50-100ms for each repetition period. The electron beam energy of cooler keeps the same as ion beam energy after RF stacking. The matching parameters of cavity for RF stacking are listed in Table 2. After simulation, the beam accumulation parameters of typical heavy ions for this method are estimated in Table 3.

2.2 *Fast and Slow Extraction of CSRm*

The fast extraction orbit and beam envelope for fast extraction is shown in Figure 5. The emittance of extraction beam is $\varepsilon_{x,y}$ = 10π mm.mrad, $\Delta p/p=\pm1\times10^{-4}$.

For slow extraction the same tunnel is used, but two additional dipole coils and fast quadruples are required for bumping and tune shift, two inflector is used instead of the kicker magnet. Third integer resonance with RF knock-out is adopt for slow extraction, with zero chromaticity condition. Final turns before extraction and extraction orbit is shown in Figure 6.

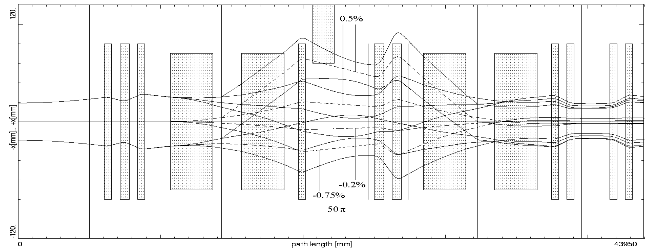

Figure 4: The horizontal beam orbit distribution for RFS

Table 2: The matching parameters of RF cavity for RFS

Injection Ions	E (MeV/u)	Δp/p (±%)	h	Z1	f (MHz)	f_{RF} (MHz)	V_{RF} (kV)
$^{12}C^{6+}$	25	0.15	32		0.422	13.52	10.10
$^{16}O^{8+}$	25	0.15	32		0.422	13.52	10.10
$^{20}Ne^{10+}$	25	0.15	32		0.422	13.52	10.10
$^{40}Ar^{18+}$	25	0.15	32		0.422	13.52	11.23
$^{58}Ni^{24+}$	25	0.15	32	28	0.422	13.52	10.47
$^{84}Kr^{28+}$	25	0.15	32	33	0.422	13.52	12.86
$^{129}Xe^{36+}$	20	0.15	32	48	0.379	12.13	11.01
$^{181}Ta^{36+}$	15	0.15	32	59	0.270	10.55	9.56
$^{208}Pb^{37+}$	12	0.15	32	66	0.270	9.46	7.92
$^{238}U^{37+}$	10	0.15	32	72	0.270	8.65	6.96

Table 3: Accumulation parameters of RFS

Ion	E	Injection Intensity (pps)	Single Turn Num.	Q	η (%)	Gain	RFS Period (ms)	Accu. Period (s)	Accu. Num.	$I_{accu.}$ (euA)
$^{12}C^{6+}$	25	3.1×10^{12}	7.4×10^{6}			2.8	100	10	2.0×10^{9}	840.0
$^{16}O^{8+}$	25	2.3×10^{12}	5.5×10^{6}			2.8	100	10	1.5×10^{9}	840.0
$^{20}Ne^{10+}$	25	6.2×10^{11}	1.5×10^{6}			2.8	80	10	5.1×10^{8}	350.0
$^{40}Ar^{18+}$	25	6.9×10^{11}	1.6×10^{6}			2.2	60	10	7.6×10^{8}	933.3
$^{58}Ni^{24+}$	25	1.3×10^{11}	3.1×10^{5}	28	29.3	2.2	60	10	4.2×10^{7}	79.7
$^{84}Kr^{28+}$	25	2.2×10^{11}	5.2×10^{5}	33	24.0	1.68	60	10	3.5×10^{7}	61.6
$^{129}Xe^{36}$	20	8.6×10^{10}	2.3×10^{5}	48	19.3	1.68	60	10	1.2×10^{6}	2.4
$^{181}Ta^{36}$	15	8.6×10^{9}	2.6×10^{4}	59	16.9	1.4	60	10	1.0×10^{6}	1.6
$^{208}Pb^{37}$	12	8.5×10^{9}	2.8×10^{4}	66	16.2	1.4	60	10	1.0×10^{6}	1.5
$^{238}U^{37+}$	10	8.5×10^{9}	2.9×10^{4}	72	15.4	1.4	60	10	1.1×10^{6}	1.4

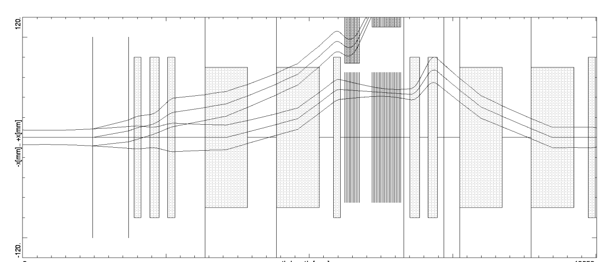

Figure 5: Fast extraction of CSRm

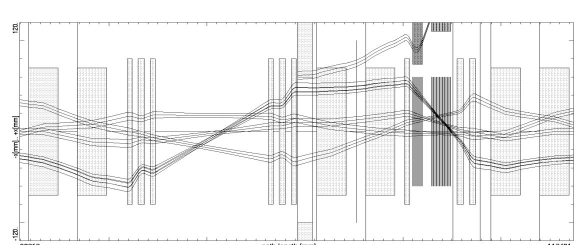

Figure 6: Slow extraction of CSRm

3 INJECTION AND EXTRACTION OF CSRE

The layout of injection and extraction scheme of CSRe is shown in Figure 7.

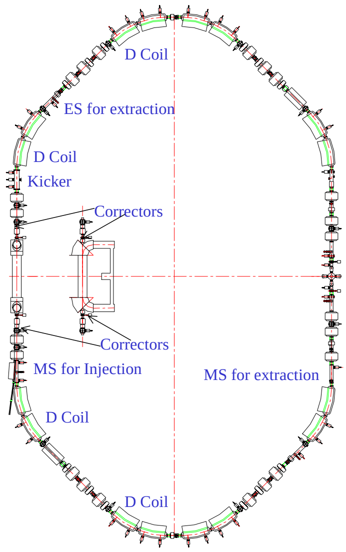

Figure 7: Layout of CSRe injection and extraction

3.1 Single Turn Injection of CSRe

There are two operation modes for CSRe: high-resolution mode and isochronous mode[1,2,3]. For CSRe only single-turn injection is required. The emittance of injection beam is $\varepsilon_x = \varepsilon_y = 20\pi$ mm.mrad. Momentum spread acceptance is ±1.0% for high-resolution mode, and ±0.4% for isochronous mode.

For injection into CSRe, beam transfer through edge field of quadruple and dipole. By numerical tracking through the field, the transfer matrix can be achieved. The beam envelope and direction are changed from ideal condition[5].

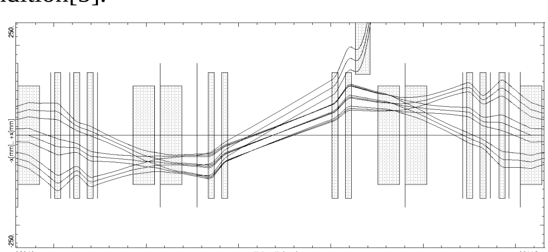

Figure 8: Single turn injection (high resolution mode)

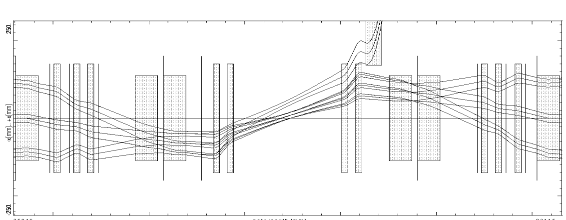

Figure 9: Single turn injection (isochronous mode)

3.2 Extraction of CSRe

Both fast and slow extractions will be adopted in CSRe for the future requirement. The extraction schemes are only used for high resolution mode.

The extraction orbit and beam envelope for fast extraction is shown in Figure 10. The emittance of extraction beam is $\varepsilon_{x,y}=20\pi$mm.mrad, $\Delta p/p=\pm0.2\%$.

For slow extraction the same tunnel is used, but two fast quadruples are required for tune shift and an inflector is used instead of the kicker magnet.

The same method of slow extraction as CSRm is adopt for CSRe, the final turns before extraction is shown in Figure 11.

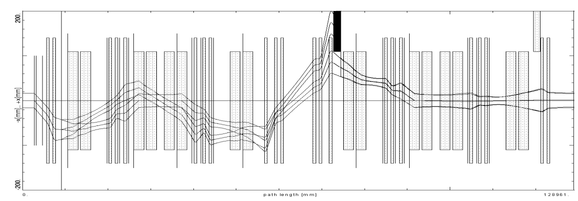

Figure 10: Fast extraction (High Resolution Mode)

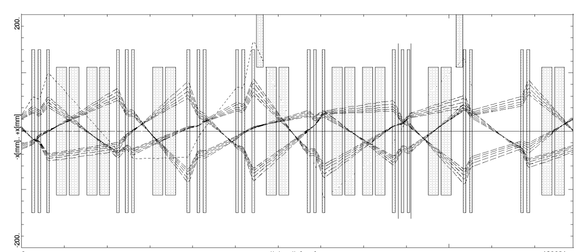

Figure 11: Slow extraction (high resolution mode)

4 ACKNOWLEGEMENTS

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REFERENCES

[1] J.W. Xia, et al., “HIRFL STATUS AND HIRFL-CSR PROJECT IN LANZHOU”, Proc. of the First Asian Part. Acc. Conf., KEK, Japan, 1998.

[2] J. W. Xia, Y. N. Rao, Y. J. Yuan, B. W. Wei. “HIRFL-CSR PLAN”, The 6th China-Japan Joint Symposium on Accelerators for Nuclear Science and Their Applications, Chengdu, China, 1996.

[3] J. W. Xia, Y. J. Yuan, M. T. Song, et al., “LATTICE OF THE CSR”, this conference.

[4] Y. N. Rao, J. W. Xia, Y. J. Yuan, B. W. Wei, “Lifetime of beam in heavy ion storage ring”, Trends of nuclear physics, Nuclear physics association of China, April 1995,in chinese.

[5] Y. J. Yuan, J. L. Wu, Y. G. Wang, X. Y. Xu, “The influence of edge field on beam injection”, High Energy Physics & Nuclear Physics, 2001,25(1):57-60, in Chinese