General Design of the CSR Project in IMP

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Abstract CSR, a new accelerator project under the construction to upgrade the existing heavy ion cyclotron system in Lanzhou, is a double cooling-storage-ring system. It consists of a main ring and an experimental ring. The heavy ion beams from the cyclotron system will be accumulated and accelerated first in the main ring, then extracted to produce radioactive ion beams or high-Z beams, and finally to be send to the second ring for internal-target experiments.

Key words heavy ion, beam accumulation, electron cooling, storage ring, lattice

1 Introduction

Since December of 1999, a new cooling-storage ring (CSR) project[1, 2] has been started to upgrade the heavy-ion research facility (HIRFL)[3] of the Institute of Modern Physics (IMP) in Lanzhou, shown in Fig. 1. Based on this new storage ring system, many high-precision physical experiments can be done by providing the all ion beams from proton to Uranium with wide energy range. CSR will be a multi-subject research flattop and will greatly enhance the performances of HIRFL for those frontier researches by using radioactive ion beams (RIBs) and highly charged heavy ions (high-Z beams) in the fields of nuclear physics, RIB physics, hadron physics, nuclear astrophysics, atomic physics, cancer therapy and other related applications. The initial conception of CSR was started in 1993 and the plan was proposed in 1996. After two-years discussing, it was approved by the government. The period from the beginning of 2000 to the summer of 2001 is the stage of the building construction, design optimization and prototype experiments. The machine fabrication and installation are from 2001 to 2005, and the sub-system tests and the preliminary storage-ring commissioning is in 2005 and 2006.

2 General descriptions

2.1 Outline

CSR is a multipurpose cooling storage ring system that consists of a main ring (CSRm), an experimental ring (CSRe), and a radioactive beam line (RIBLL2) to connect the two rings, shown in Fig. 1. The two existing cyclotrons SFC (energy constant $K = 69$) and SSC ($K = 450$) of the HIRFL respectively will be used as its injector system. The heavy ion beams with the energy range of 7—30MeV/u from the HIRFL will be accumulated, cooled and accelerated to the high-energy range of 100—500MeV/u in the main ring, and then extracted fast to produce RIBs or high-Z beams. Those secondary beams will be accepted and stored or decelerated by the experimental ring for many internal-target experiments or high precision spectroscopy with beam cooling. On the other hand, the beams with the energy range of 100—1000MeV/u will also be extracted from CSRm by using slow extraction or fast extraction for many external-target experiments, and for the future development, the possibility of internal-target mode in CSRm will be reserved for those high-energy proton experiments with the energy range of 2—2.8GeV.

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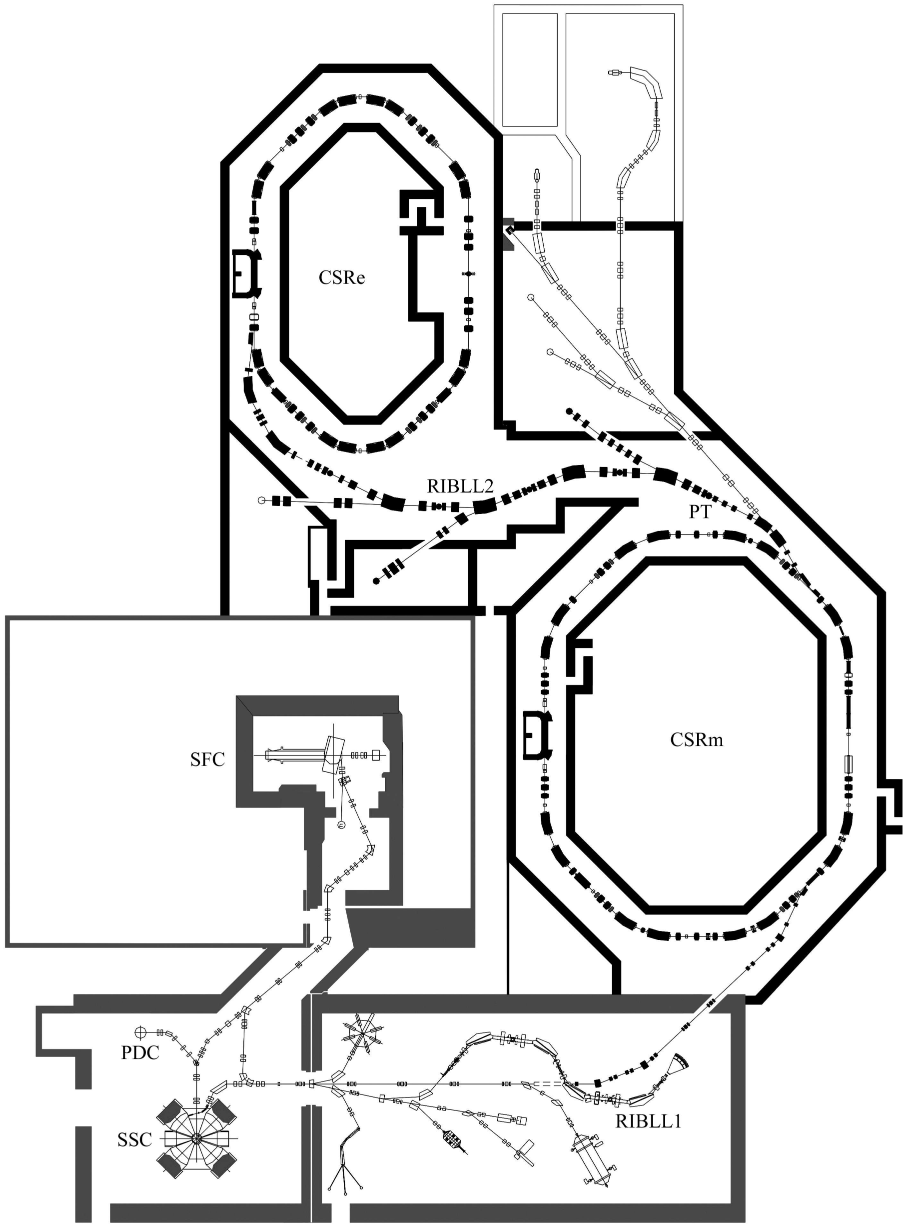

Fig. 1. The overall layout of the HIRFL-CSR complex.

Two electron coolers located in the long straight sections of CSRm and CSRe, respectively, will be used for beam accumulation and cooling.

CSR intends to provide internal and external target beams for many physics experiments. One gas internal-target in the long straight section of CSRe will be used for nuclear physics and highly charged state atomic physics. Another thin solid internal-target in the long straight section of CSRm will be used for particle physics. Several external targets of CSRm will be used for nuclear physics, cancer therapy study and other researches.

2.2 Major parameters

The beam parameters and the major machine parameters of CSR are listed in Table 1.

3 Operation scheme

3.1 Normal operation mode

CSR is a double ring system. In every operation cycle, the stable-nucleus beams from the injectors are accumulated, cooled and accelerated in the main ring, then extracted fast to produce RIBs or high-Z beams.

The experimental ring can obtain the secondary beams once for every operation cycle. The accumulation duration of CSRm is about 10s. Considering the ramping rate of magnetic field in the dipole magnets is 0.1—0.4T/s, the acceleration time of CSRm will be nearly 3s. Thus, the operation cycle is about 17s.

Table 1.　Major parameters of the CSR.

	CSRm		CSRe
circumference/m	161.00		128.80
ion species	stable nuclei: p—U, RIBs: $A<238$		stable nuclei: p—U, RIBs: $A<238$
max. energy/(MeV·u^{-1})	2800(p), 1100(C^{6+}), 500(U^{72+})		2000(p), 750(C^{6+}), 500(U^{90+})
intensity/particles	10^5—10^9(stable nuclei)		10^3—10^9(stable nuclei, RIBs)
$B\rho_{\max}$/Tm	12.05		9.40
$B_{\max}$/T	1.6		1.6
ramping rate/(T·s^{-1})	0.1—0.4		0.1—0.2
repeating circle/s	∼17(∼10s for accumulation)		
acceptance	fast extraction mode		normal mode
$A_{\rm h}$/(πmm·mrad)	200($\Delta P/P=\pm0.15\%$)		150($\Delta P/P=\pm0.5\%$)
$A_{\rm v}$/(πmm·mrad)	40		75
$\Delta P/P(\%)$	1.4($\varepsilon_{\rm h}=50\pi$mm·mrad)		2.6($\varepsilon_{\rm h}=10\pi$mm·mrad)
E-cooler			
ion energy/(MeV·u^{-1})	7—50		10—500
length/m	4.0		4.0
RF system	acceleration	accumulation	capture
harmonic number	1, 2	16, 32, 64	1, 2
$f_{\min}/f_{\max}$/MHz	0.24/1.81	6.0/14.0	0.4/2.0
voltages/$n\times$kV	1×7.0	1×20.0	2×10.0
vacuum pressure/mb	3.0×10^{-11}		3.0×10^{-11}

In CSRe, two operation modes will be adopted. One is the storage mode used for internal-target experiments or high precision spectroscopy with electron cooling. Another one is the deceleration-storage mode used for atomic-physics experiments. In the second mode those high-Z beams can be decelerated to ∼10MeV/u. Fig. 2 shows the magnetic field exciting procedure of the two rings.

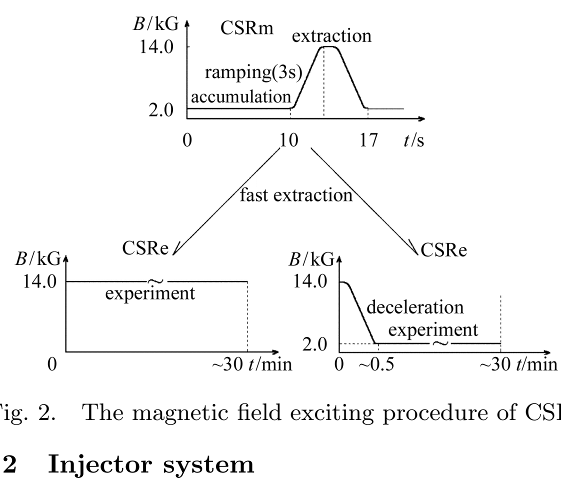

Fig. 2.　The magnetic field exciting procedure of CSR.

3.2　Injector system

The existing HIRFL facility[3] will be used as the injector system of CSR. It consists of two cyclotrons, the main accelerator SSC (Separated Sector Cyclotron, $K=450$) and the pre-accelerator SFC (Sector-Focusing Cyclotron, $K=69$). The light heavy ions, for example C, N, O etc., can be injected into CSRm directly from SFC without the acceleration of SSC, but the heavy ions of $A>40$ should be accelerated by the combination of SFC and SSC before the injection. The mean extraction radius of SFC and SSC are 0.75m and 3.20m respectively.

3.3　Beam accumulation

While heavy ion beams from HIRFL are injected into CSRm, the beam lifetime should be long enough for the beam accumulation in CSRm. Referring to the actually measured spectra of residual gases, in the case that the average vacuum pressure of CSR is assumed to be 3.0×10^{-11} mbar, the residual gas composition will be 85% of H_2 and 15% of N_2 and CO. According to the calculation[4], the REC (radiative electron capture) process in the electron cooler restricts the lifetime of light heavy ions (C—Kr) in CSRm. The electron capture from the residual gas molecule dominates the lifetime of heavy ions (Xe—U), and the beam loss caused by Coulomb scattering can be negligible. As conclusion, the beam lifetime (>15s) is longer than the time of the beam accumulation (~10s) in CSRm.

Three methods will be used in CSRm to accumulate the heavy ions up to 10^6—10^9 in a short duration of 10s. The first is the stripping injection (STI) for the light-heavy ions of $A \leqslant 20$. The second is the multiple multi-turn injection (MMI) in the horizontal phase space with the acceptance of 150πmm·mrad. This method will be fitting for the heavy ions of $A > 40$, because the e-cooling time of the very heavy ions is faster than that of the light-heavy ions. The third one is the combination of the horizontal multi-turn injection plus the RF stacking[5] (RFS) in the momentum phase space for those light heavy ions of $A \leqslant 40$. In the third method, the horizontal acceptance is 50πmm·mrad used for the multi-turn injection and the momentum acceptance is 1.25% for the RF stacking. During the accumulation, electron cooling will be used to cool the beam in order to increase the accumulation ratio and efficiency. Table 2 is the calculated accumulation parameters for several typical ions. Comparing the three methods, the STI is the most fast one and the technique is simple, but it is only fitting to the light-heavy ions owing to the injection orbit. For those very heavy ions, only the MMI can be used, because of the reasons of the cooling time and the life-time of ions. The technique of the MMI+RF is more difficult than others, but it is necessary for the light-heavy ions of $20 < A < 40$, because the accumulation rate of MMI+RF is more fast than MMI for those ions.

Table 2. Parameters of the beam accumulation in CSRm.

	C^{4+}	O^{7+}	O^{7+}	Xe^{48+}	U^{72+}
injector	SFC	SFC	SFC	SSC	SSC
energy/ (MeV·u^{-1})	7	10	10	20	10
current/pμA	2	0.5	0.5	0.01	0.01
current/ particles s^{-1}	1.2×10^{13}	3×10^{12}	3×10^{12}	6×10^{10}	6×10^{9}
particles of one turn	5×10^{7}	1×10^{7}	1×10^{7}	1.5×10^{5}	2×10^{4}
efficiency of stripping	68%			19%	15%
method	STI	MMI+RFS	MMI	MMI	MMI
injection pulse/ms	1—5	0.1	0.1	0.1	0.1
cycle/ms	2500	100	1000	250	100
period/s	2.5	10	10	10	10
gain factor of MMI		2.8	5	5	5
total gain factor	30	280	50	40	75
particles	1.5×10^{9}	2.8×10^{9}	5×10^{8}	6.0×10^{6}	1.5×10^{6}

4 Lattice

4.1 CSRm lattice

CSRm is a racetrack shape, as shown in Fig. 3, and consists of four arc sections. Each arc section consists of four dipoles, five focus quadruples and three defocus quadruples. The lattice of each arc section is given as follows,

$$—L_1—FDF—B—B—F—L_2—DF—B—B—F\frac{1}{2}D$$

where, L_1 is a long-straight section with dispersion free for e-cooler or extraction kicker and internal target. L_2 is a dispersion drift for beam injection, extraction and RF cavity.

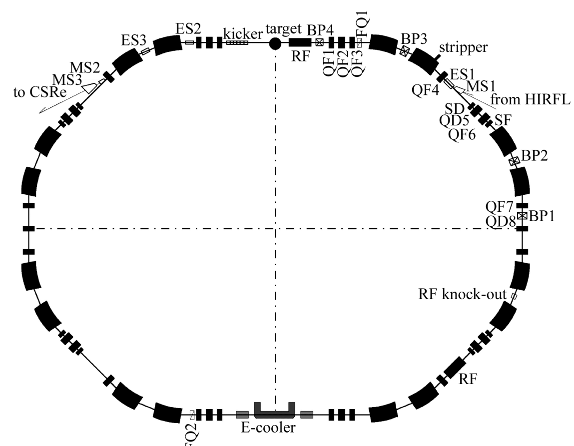

Fig. 3. The lattice layout of CSRm.

In CSRm, three lattice modes will be adopted for different functions. The first one is the fast-extraction mode for the beam extracted from the ring during one turn. The second one is the slow-extraction mode for the beam extracted continuously from CSRm in the period of 1—5 seconds. The third one is the internal-target mode with small β-amplitude in the target point without beam extraction. For the first and second modes, CSRm is symmetrical along the short and long axes, and 8 independent variables for quadruple are adopted for these two lattices. But in the internal-target mode, the ring is only symmetrical along the short axis, and 15 independent variables for quadruple are used for the lattice.

Figs. 4 (a, b, c) are the distributions of the β-functions and the dispersion for the three modes, and Table 3 is the lattice parameters of CSRm.

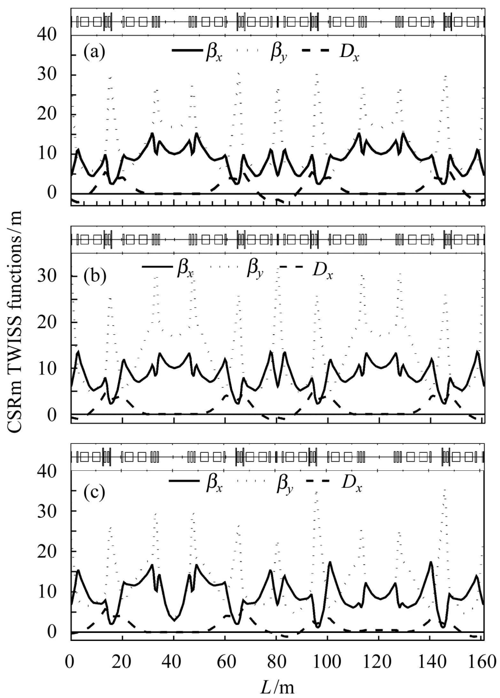

Fig. 4. The distributions of the β and dispersion for the fast-extraction mode (a), the slow-extraction mode (b) and the internal-target mode (c).

In the injection section, 4 bump magnets (BP1, BP2, BP3, BP4) will be used to move the closed orbit from center to the injection orbit in the horizontal plane, then injection beam will be deflected into the closed orbit by one static-electric septum (ES1) and one magnetic septum (MS1). During the multi-turn injection, the field of the 4 bumps will be reduced to zero isochronously, the closed orbit will be moved back to the center. The machine with the horizontal acceptance of 150πmm·mrad for MMI or 50πmm·mrad for MMI+RFS will be filled by injected beam simultaneously. Fig. 5 (a, b) are the orbits of the MMI and MMI+RFS respectively. For the beam stripping injection (STI), a stripper of Carbon foil is located in the first dipole just after the injection point. While doing the STI, the injection static-electric septum (ES1) will be removed and replaced by an empty vacuum chamber. Fig. 5 (c) is the orbits of the STI.

For CSRm, fast and slow beam extractions should be done. In the extraction section, six kicker modes will be used for the fast extraction, and two static-electric septa (ES2, ES3), two fast quadruples (FQ1, FQ2), one RF knock-out, two families of sextuple and six in-dipole coils will be used for the slow extraction with 1/3 order resonance. The two extractions will use one channel, and the final elements of the extraction are two magnetic septa (MS2, MS3). Fig. 5 (d, e) are the orbits of the two extraction modes.

In CSRm, 16 auxiliary coils in dipoles, five combined vertical and horizontal correctors and six vertical correctors will be used for the global closed-orbit correction.

Table 3. Lattice parameters CSRm.

	fast extraction mode	slow extraction mode	internal target mode
transition gamma	γ_{tr}=5.418	γ_{tr}=5.168	γ_{tr}=5.119
tune values	Q_x/Q_y=3.64/2.61	Q_x/Q_y=3.63/2.61	Q_x/Q_y=3.695/2.73
natural chromaticity	$Q'_x/Q'_y=-3.17/-5.37$	$Q'_x/Q'_y=-3.05/-5.34$	$Q'_x/Q'_y=-3.73/-5.77$
Max.β-amplitude	β_x/β_y=12.1/13.5m (dipole)	β_x/β_y=11.1/17.5m (dipole)	β_x/β_y=14.9/17.5m (dipole)
	β_x/β_y=15.3/30.5m (quadruple)	β_x/β_y=13.5/32.2m (quadruple)	β_x/β_y=17.5/35.6m (quadruple)
Max. dispersion	$D_{\max}(x)$=3.1m(dipole, β_x=9.0m)	$D_{\max}(x)$=3.2m(dipole, β_x=10.4m)	$D_{\max}(x)$=4.3m (dipole, β_x=7.0m)
	$D_{\max}(x)$=5.4m(Quad., β_x=9.9m)	$D_{\max}(x)$=4.6m(Quad., β_x=8.0m)	$D_{\max}(x)$=5.8m(Quad., β_x=7.9m)
injection section	β_x= 8.0m, D_x= 4.1m (septum)	β_x= 10.0m, D_x= 4.0m (septum)	β_x= 10.0m, D_x= 4.1m (septum)
	β_x= 9.7m, D_x=3.9m (quadruple)	β_x=11.9m, D_x=3.9m (quadruple)	β_x= 12.4m, D_x=3.9m (quadruple)
E-cooler section	β_x/β_y= 10.0/16.7m, D_x= 0	β_x/β_y= 10.0/17.0m, D_x= 0	β_x/β_y= 8.2/8.3m, D_x= 0
target	β_x/β_y= 10.0/16.7m, D_x= 0	β_x/β_y= 10.0/17.0m , D_x= 0	β_x/β_y= 2.9/3.5m, D_x= 0
RF station section	β_x/β_y= 8.0/22.5m, D_x= 4.1m	β_x/β_y= 10.0/19.1m, D_x= 4.0m	β_x/β_y= 14.0/25.9m, D_x= 3.4m

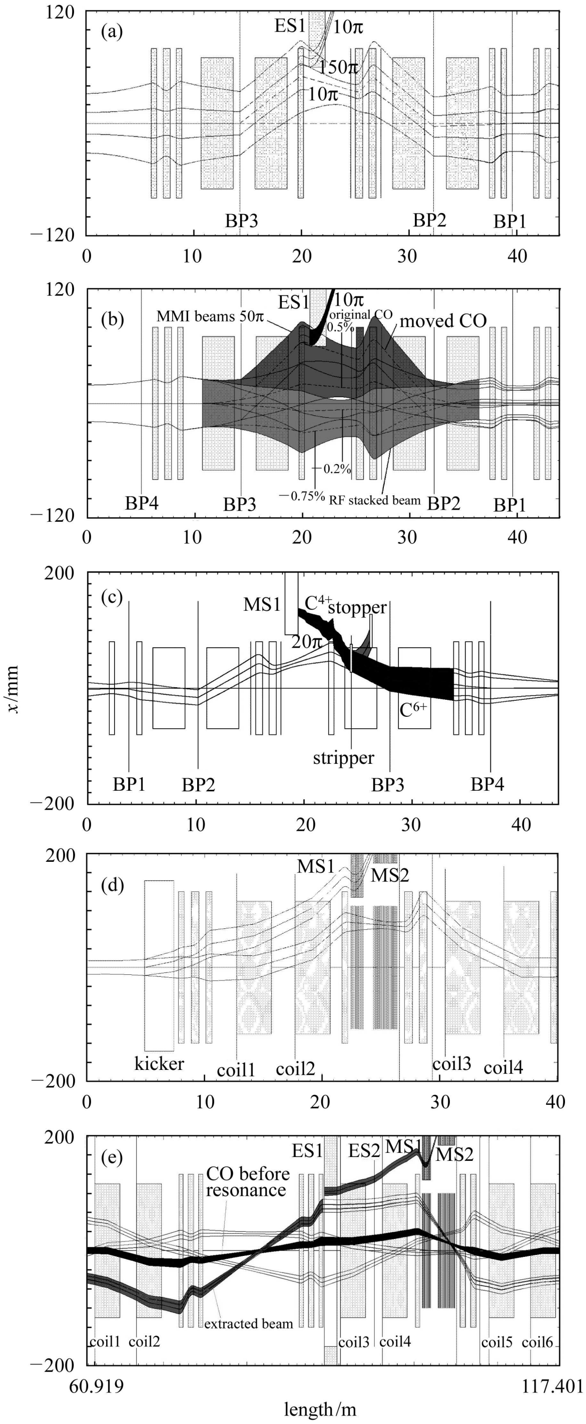

Fig. 5. The orbits of the MMI (a), MMI+RFS (b), STI (c), fast-extraction (d) and slow-extraction (e) in CSRm.

4.2 CSRe lattice

The layout of CSRe is shown in Fig. 6. It has a race track shape and consists of two quasi-symmetric parts. One is the internal-target part and another is the e-cooler part. Each part is a symmetric system and consists of two identical arc sections. Each arc section consists of four dipoles, two triplets or one triplet and one doublet. 11 independent variables for quadruple are used in CSRe. The lattice of the half ring is given as follows,

$$—\mathrm{L_T}—\mathrm{FD}—\mathrm{F}—\mathrm{B}—\mathrm{B}—\mathrm{L_R}—\mathrm{FD}—\mathrm{F}—\mathrm{B}—\mathrm{B}—\mathrm{B}—$$
$$\mathrm{B}—\mathrm{F}—\mathrm{DF}—\mathrm{L_R}—\mathrm{B}—\mathrm{B}—\mathrm{FD}—\mathrm{L_C}—$$

where, $\mathrm{L_T}$ and $\mathrm{L_C}$ are the long-straight sections with dispersion free for internal target and e-cooler, $\mathrm{L_R}$ is the dispersion drift for RF cavities.

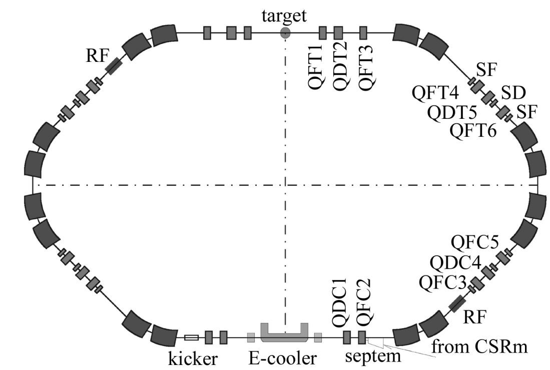

Fig. 6. Lattice layout of CSRe.

In CSRe three lattice modes will be adopted for different requirements. The first one is the internal-target mode with small β-amplitude in target point and the large transverse acceptance (A_h=150πmm·mrad, A_v=75πmm·mrad) for internal-target experiments. The second one is the normal mode with a large momentum acceptance of $\Delta P/P$=2.6% for high-precision mass spectroscopy[6]. The third one is the isochronous mode with a small transition γ_{tr} that equals the energy γ of beam in order to measure the mass of the short-life-time RIBs.

Table 4 shows the lattice parameters of CSRe for the three lattice modes, and Fig. 7 denotes the distributions of the β-functions and the dispersions for the three modes.

The injection of CSRe is located in the zero-dispersion section of the e-cooler in order to accept the large momentum spread (±1%) beams from RIBLL2 shown in Fig. 1. The single-turn injection will be adopted by using one magnetic septum and four kicker modes. During the injection, four auxiliary coils in four main dipoles will be used to create a bump orbit for the injection, and the injection channel will pass through the fringe field of a dipole and

Table 4. Lattice parameters of CSRe.

	internal-target mode	normal mode	isochronous mode
transition gamma	γ_{tr}=2.457	γ_{tr}=2.629	γ_{tr}=1.395
betatron tune values	Q_x/Q_y=2.53/2.57	Q_x/Q_y=2.53/2.57	Q_x/Q_y=1.695/2.72
natural chromaticity	$Q'_x/Q'_y=-3.70/-3.55$	$Q'_x/Q'_y=-3.10/-3.74$	$Q'_x/Q'_y=-1.57/-3.25$
Max. β-amplitude	β_x/β_y=25.7/8.7m(dipole)	β_x/β_y=17.6/8.2m(dipole)	β_x/β_y=28.1/12.2m(dipole)
	β_x/β_y=43.0/20.4m(quadruple)	β_x/β_y=30.9/22.3m(quadruple)	β_x/β_y=41.2/36.4m(quadruple)
Max. dispersion	$D_{\max}(x)$=7.9m(dipole, β_x=14m)	$D_{\max}(x)$=6.5m(dipole, β_x=13m)	$D_{\max}(x)$=18.5m(dipole, β_x=28m)
	$D_{\max}(x)$=9.4m(Quad., β_x=16m)	$D_{\max}(x)$=7.8m(Quad., β_x=16m)	$D_{\max}(x)$=21.2m(Quad., β_x=34m)
injection section	β_x= 30.8m, D_x=0m(septum)	β_x= 30.4m, D_x=0m(septum)	β_x=40.8m, D_x=0m(septum)
	β_x=31.4m, D_x=0m(quadruple)	β_x=30.9m, D_x=0m(quadruple)	β_x=41.2m, D_x=0m(quadruple)
E-cooler section	β_x/β_y=12.9/16.5m, D_x=0	β_x/β_y=12.5/16.0m, D_x=0	β_x/β_y= 2.6/10.5m, D_x=0
target	β_x/β_y=3.0/1.7m, D_x=0	β_x/β_y=5.4/1.5m, D_x=0	β_x/β_y=20.8/1.0m, D_x=17.7m
RF station section	β_x/β_y=4.0/8.3m, D_x=4.6	β_x/β_y=4.0/8.4m, D_x=4.5	β_x/β_y=19.0/11.5m, D_x=15.0m

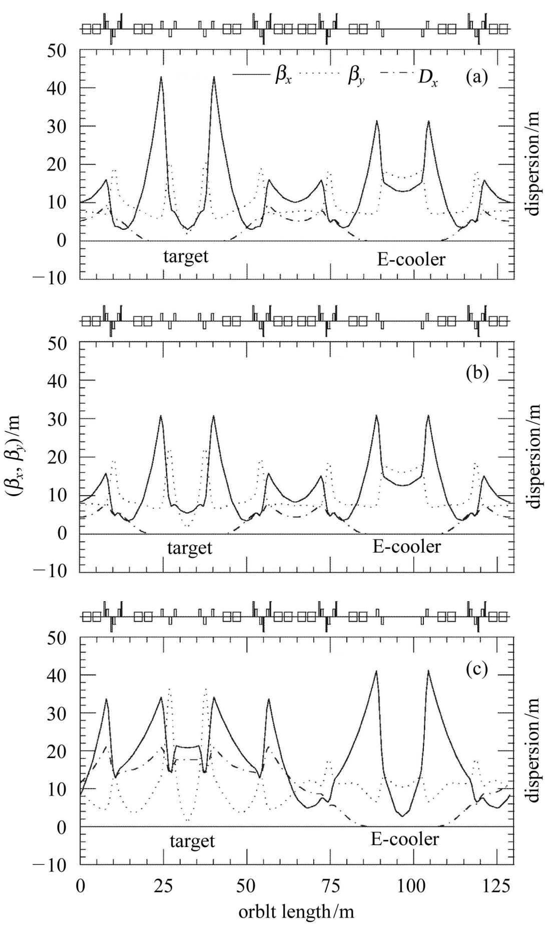

Fig. 7. The distributions of the β and dispersion for the internal-target mode (a), normal mode (b) and isochronous mode (c).

two quadruples. For the three lattice modes, the gradient of the doublet quadruple nearby the injection septum should be maintained at the same value in order to obtain the same injection orbit. Fig. 8 shows the single-turn injection orbit of CSRe.

In CSRe, two families of sextuple will be used to correct the chromaticity, and 16 in-dipole coils, four double-direction correctors, six vertical correctors will be used for the global closed orbit correction.

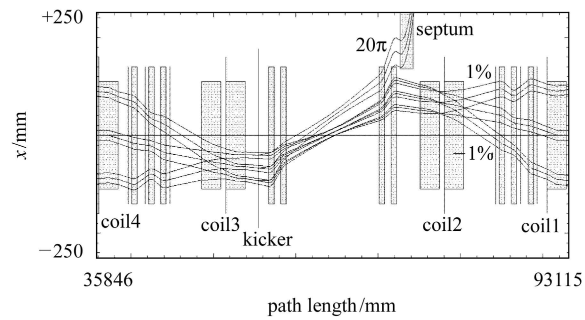

Fig. 8. The single-turn injection orbit of CSRe.

5 Subsystems

5.1 Magnets and correlative subsystems

All the magnetic cores of CSR will be laminated of 0.5mm-thick sheets of electro-technical steel with high induction and cold-rolled isotropy. Coils will be made of T2 copper conductor with hollow and insulated with polyimide stick tape and vacuum epoxy resin impregnating. In order to reach the necessary field uniformity at the different levels of the range of 0.1—1.6T, an air hole will be punched at the center of the pole to control the magnetic field flux flow at high magnetic fields[7]. The magnetic field distribution on the median plane will be improved and a good field distribution in a wide field range can be obtained. In CSRm the H-type frame was designed for the dipole, but in CSRe the C-type dipole with a large useful aperture was adopted for physics experiments.

Table 5. Major correlative parameters of the magnets.

dipole			quadruple		
	CSRm	CSRe		CSRm	CSRe
number×angle/(°)	17×22.5	16×22.5	number	30	22
bending radius/m	7.6	6.0	gradient range/(T/m)	0.3—11.0	0.3—7.0
field range/T	0.1—1.6	0.08—1.6	bore diameter/mm	170	240
ramping rate/(T/s)	0.1—0.4	0.1—0.2	useful aperture/mm^2	160×100	280×140
air gap/mm	80	84	$\Delta K/K$	$\pm1.5\times10^{-3}$	$\pm1.5\times10^{-3}$
useful aperture/mm^2	140×60	220×70	ideal length/m	0.5, 0.65	0.65, 0.75
homogeneity($\Delta B/B$)	$\pm1.5\times10^{-4}$	$\pm1.5\times10^{-4}$			
vacuum. chamber			vacuum. chamber		
aperture/mm^2	156×61	236×72	aperture/mm^2	180×110	285×150
cross section	rectangular	rectangular	cross section	octagonal	octagonal
power supply			power supply		
number	1	1	number	30	22
feeding mode	series	series	feeding mode	independent	independent
stability (at low cur.)	$\pm1\times10^{-4}$/8h	$\pm1\times10^{-4}$/8h	stability (at low cur.)	$\pm5\times10^{-4}$/8h	$\pm5\times10^{-4}$/8h
ripple (at low cur.)	5×10^{-5}	5×10^{-5}	ripple (at Max. cur.)	3×10^{-6}	5×10^{-6}
tracking precision	$\pm3\times10^{-4}$	$\pm3\times10^{-4}$	tracking precision	$\pm5\times10^{-4}$	$\pm5\times10^{-4}$

All power supplies of the ring magnets will need DC and pulse operation modes, while high current stability, low current ripple, good dynamic characteristic are necessary. Two types of power supply, a traditional multi-phase thyristor rectifier for dipoles and a switching mode convertor for quadruples, will be adopted. Table 5 displays the major parameters of magnets, its correlative power supplies and vacuum chambers.

5.2 Electron-cooler system

Table 6. Major parameters of the two e-coolers.

parameters	CSRm	CSRe
ion energy/(MeV·u^{-1})	7—50	10—500
electron energy/keV	3.8—35	5—300
Max. electron beam current/A	3	3
cathode radius/cm	1.25	1.25
magnetic expansion factor	1—4	1—10
Max. field of gun region/KG	2.4	5
magnetic field of collector region/KG	1.2	1.2
magnetic field of cooling section/KG	0.6—1.5	0.5—1.5
length of cooling section/m	4.0 effective length=3.4m	4.0 effective length=3.4m
installation length/m	7.2	7.2
deflection angle of toroid	90°	90°
deflection radius of toroid/m	1.0	1.0

Two electron coolers will be equipped in CSRm and CSRe, respectively, for heavy ion beam cooling. In CSRm, e-cooling will be used for the beam accumulation at the injection energy range of 7—30MeV/u to increase the beam intensity. In CSRe, e-cooling will be used to compensate the growth of beam emittance during internal-target experiments or to provide high quality beams for the high-resolution mass measurements[6] of nuclei. Table 6 denotes the major parameters of the two e-coolers. The two coolers are the same but different in the high voltage unit only, in order to reduce the time of development and the production cost of the devices.

6 Conclusions

The general design of CSR is a combination design of accelerator and experimental instrument. The double ring complex is not only a synchrotron-storage-ring system, but also a circular spectrometer system. The first ring CSRm is a multi-function synchrotron with beam accumulation, cooling and internal or external target experiment. The second ring CSRe is not only a cooling-storage-ring with deceleration function, but also a circular spectrometer with internal-target experiment.

For CSR project, the first-turn tuning of CSRm was finished without any adjusting at February 3 of 2005, and the 13 turns beam in CSRm was obtained at October 21 of 2005. In the end of 2006 the whole initial commissioning of CSR will be finished.

References

1 WEI B W et al. HIRFL Heavy Ion Cooler-Storage Ring Proposal. Proc. of the Fifth China-Japan Joint Sym. on Acc. for Nuclear Sc. and Their App. Osaka, Japan, 1993. 162

2 XIA J W et al. HIRFL-CSR Plan. Proc. of the 6th China-Japan Joint Symposium on Accelerators for Nuclear Science and Their App. Chengdu, China, Oct. 1996. 24

3 WEI B W. Results from Lanzhou K450 Heavy Ion Cyclotron. Proc. of 1989 Particle Acc. Conf., IEEE

4 RAO Y N et al. Lifetime of Ion Beam Stored in HIRFL-CSR. Proc. of the 14th Inter. Conf. on Cyclotrons and Their App. South Africa, 1995. 358

5 YUAN Y J et al. Simulation of RF Stacking and Multiple Single-Turn Injection and Multi-turn Injection. Proc. of the 14th Inter. Conf. on Cyclotrons and Their App. South Africa, 1995. 479

6 Schlitt B. Schottky Mass Spectrometry at the Heavy Ion Storage Ring ESR. GSI Reports, DISS. 97-01, Sep. 1997

7 Umezawa M. A New Dipole Bending Magnet with Improved Magnetic Field Distribution. Proc. of the 11th Sym. on Accelerator Science and Tech. Harima Science Garden City, 1999

兰州冷却环总体设计

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摘要　兰州重离子冷却环CSR是兰州重离子加速器研究装置HRRFL的一项升级工程，是一个双冷却储存环系统，由主环CSRm和实验环CSRe构成．从HIRFL回旋加速器系统来的重离子束，首先注入到主环CSRm中进行累积冷却，然后加速到较高的能量引出打初级靶产生放射线次级束RIBs或高离化重离子束，这些次级束再被送到验环CSRe储存起来以开展内靶实验．

关键词　重离子束　累积　电子冷却　储存环　磁聚焦结构

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