HIRFL-CSR PROJECT

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Abstract

HIRFL-CSR, the project that was proposed to upgrade the HIRFL facility, is a multifunctional Cooling Storage Ring (CSR) system, consisting of a main ring (CSRm) and an experimental ring (CSRe). The heavy ion beams from the HIRFL will be injected, accumulated, cooled and accelerated to high energy in the CSRm, then fast-extracted to produce radioactive ion beams (RIB), highly-charged stage ions, or slow-extracted to do experiment. The secondary beams will be accepted by CSRe and used for internal-target experiments of the high sensitive and high precision spectroscopy with cool beam. CSR project was started in end of 1999 and finish in the end of 2004. The period from beginning of 2000 to the summer of 2001 is the time for the building construction, fabrication design, prototype experiments. In this paper, the outline and status of the project will be reported.

1 INTRODUCTION

From May of 1993 to Nov. of 1996, an upgrade HIRFL plan was proposed [1] with the multi-functional Cooling Storage Ring (CSR) forming a HIRFL-CSR accelerator system shown in Fig. 1. It will greatly enhance the performances of HIRFL for the researches by using Radioactive Ion Beams (RIB) and high-charged state heavy ion beams in the fields of nuclear physics and atomic physics. This plan was approved by Chinese government in July of 1998, and the project was started in Dec. of 1999. It is the stage that is mainly for the building construction, the prototype experiments, system optimization and the components fabrication design from Jan. 1999 ~July 2001. The installation and tuning is plan in last 1.5 year. The whole desired construction time is about 5 years, and the total budget is about 300 million Chinese yuan.

2 GENERAL DESCRIPTIONS

2.1 Outline

HIRFL-CSR [2] is a multipurpose Cooling Storage Ring system that consists of a main ring (CSRm), an experimental ring (CSRe), and a radioactive beam line separator (RIBLL2) to between the two rings, shown in Fig.1. The two existing cyclotrons SFC (K=69) and SSC (K=450) of the HIRFL will be used as its injector system. The heavy ion beams with the energy range of 8~30 MeV/u from the HIRFL will be injected, accumulated, cooled and accelerated to the energy range of 100~400 MeV/u in the main ring (CSRm), and then fast extracted to produce radioactive ion beams (RIB), Highly-Charged stage Ions (HCI). The secondary beams (RIB or HCI) can be accepted and stored in the experimental ring (CSRe) for the nuclear physics and highly-charged-state atomic physics researches. On the other hand, the beams with the energy range of 100~900MeV/u can also be extracted from CSRm by using slow or fast extraction modes for nuclear physics, cancer therapy, high density, temperature plasma study and other researches.

Two electron coolers, located in the long straight sections of CSRm and CSRe respectively, will be used for beam accumulation and providing high quality beams for internal-target experiments.

The whole complex of CSR will be setup under the ground about – 3 meter.

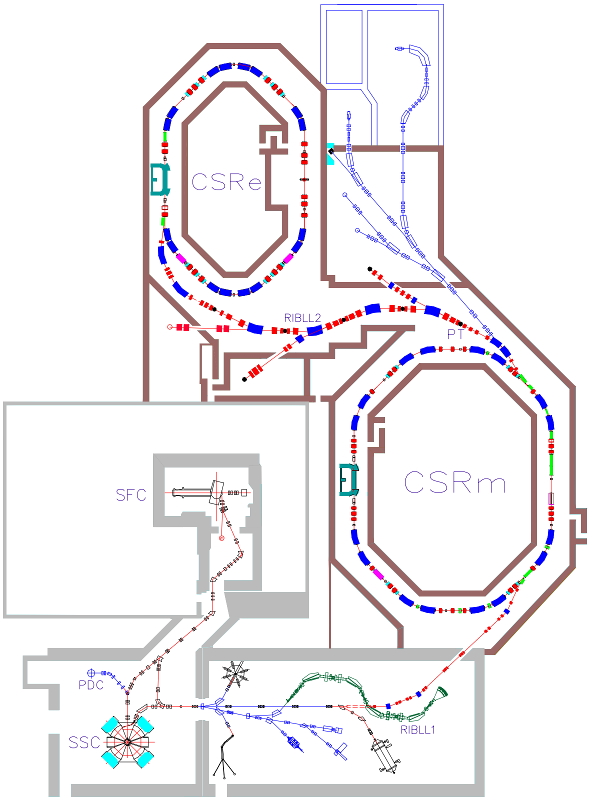

Fig. 1. Overall layout of the HIRFL-CSR complex.

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2.2 Main Parameters

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

Table 1 Major parameters of the CSR

	CSRm	**CSRe**
Circumference (m)	161.00	128.80
Ion species	Stable nuclei: C -- U,	Stable nuclei: C -- U,
Max. energy (MeV/u)	900 (C^{6+}) , 400 (U^{72+})	600 (C^{6+}), 400 (U^{90+})
Intensity (Particles)	10^5—10^9 (stable nuclei)	$10^{3\text{--}9}$
$B\rho_{max}$ (Tm)	10.64	8.40
B_{max} (T)	1.4	1.4
Ramping rate (T/s)	0.1--0.4	0.1--0.4
Repeating circle (s)	17 (10s for accumulation)	
Acceptance		Normal mode
A_h (π mm-mrad)	200 (ΔP/P = ±0.15 %)	150 (ΔP/P =±0.5%)
A_v (π mm-mrad)	30	75
ΔP/P (%)	1.25 (ε_h= 50 π mm-mrad)	2.6 (ε_h= 10 π mm-mrad)
E-cooler		
Ion energy (MeV/u)	8---50	25---400
length (m)	4.0	4.0
RF system	Acceleration Accumulation	Capture
Harmonic number	1 16, 32	1
f_{min}/f_{max} (MHz)	0.24 / 1.7 6.0 / 14.0	0.5 / 2.0
Voltages (n × kV)	1 × 7.0 1 × 20.0	2 × 10.0
Vacuum pressure (mbar)	6.0×10^{-11}	6.0×10^{-11}

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 CSRm, then extracted fast to produce RIB or HCI. CSRe can obtain the secondary beams once of every operation cycle. The typical accumulation duration of CSRm is less than 10 seconds. Considering the ramping rate of magnetic field in the dipole magnets to be 0.1~0.4 T/s, the acceleration time of CSRm will be nearly 3 seconds. Thus the operation cycle is about 17 seconds.

For 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 some atomic physics experiments. Fig. 2 shows the magnetic field exciting procedure of the two rings.

In every cycle the circulating beams in CSRe can be used for bombarding the internal target continuously. The maximum beam life time (few hours) could be obtained depending the experiment configuration and the vacuum. Therefore, the quasi-continuous beams at the internal target of CSRe could be obtained. In fact CSRe is the beam stretcher of CSRm as Fig. 3.

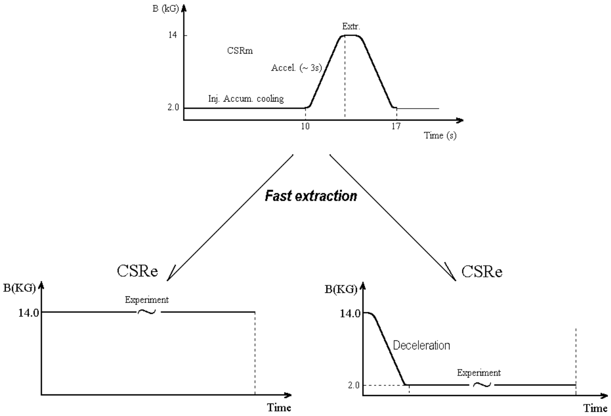

Fig. 2. Magnetic field exciting procedure of CSR

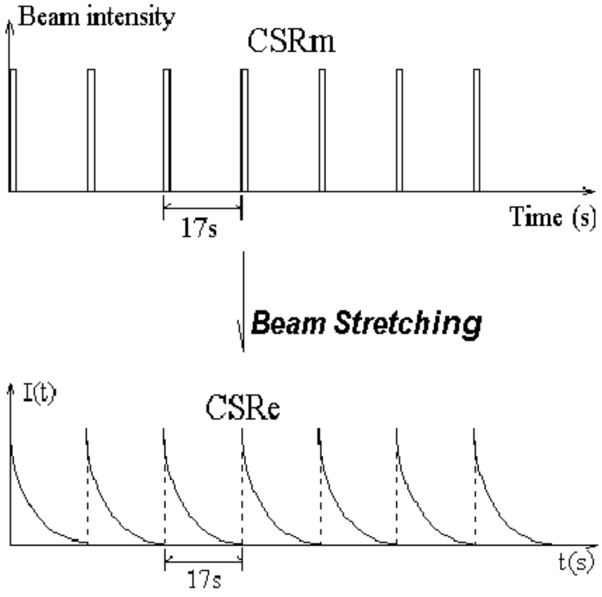

Fig. 3. Time structures of the CSR beams

3.2 Injector system

The existing HIRFL facility will be used as the injector system of CSR. It consists of two cyclotrons [3], the main accelerator SSC (Separated Sector Cyclotron, K=450) and the pre-accelerator SFC (Sector-Focusing Cyclotron, K=69). The light heavy ions, example C, N, O etc., can be injected into CSRm directly from SFC without the acceleration of SSC. However, the heavy ions (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. The beam parameters of HIRFL as the injector system of CSRm are shown in table 2.

Table 2 Beam parameters from the injectors

Ions	Energy MeV/u	$F_{Rev.}$ MHz	Harmonic number	Intensity pps
SFC injection				
$^{12}C^{5+}$	10	9.248	1	3×10^{12}
$^{16}O^{7+}$	10	9.248	1	2×10^{12}
$^{20}Ne^{8+}$	10	9.248	1	1×10^{12}
$^{40}Ar^{14+}$	8	8.284	1	8×10^{11}
$^{40}Ca^{14+}$	8	8.284	1	4×10^{11}
Emittance<10π mm-mrad			$\delta P / P < \pm 0.15\%$	
SSC injection (before stripping)				
$^{58}Ni^{14+}$	25	3.380	4	2×10^{11}
$^{84}Kr^{21+}$	25	3.378	4	2×10^{11}
$^{129}Xe^{28+}$	20	3.033	4	1×10^{11}
$^{181}Ta^{35+}$	15	2.162	4	8×10^{9}
$^{208}Pb^{36+}$	12	2.162	4	8×10^{9}
$^{238}U^{37+}$	10	2.162	4	8×10^{9}
Emittance < 10π mm-mrad			$\delta P / P < \pm 0.15\%$	
Phase width ~ ± 5°			Phase stability~±0.5°	

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 [4], in the case that the average pressure of CSR is assumed to be 6.0×10^{-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 lifetimes of light heavy ions (C--Kr) in CSRm, the electron capture from the residual gas molecule dominates the lifetimes of heavy ions (Xe--U), and the beam loss caused by Coulomb scattering can be negligible. In conclusion the beam lifetimes (>15s) are longer than the time of the beam accumulation (~10s) in CSRm.

Two method will be used for CSRm to accumulate the heavy ions up to $10^{6\sim9}$ in a short duration of 10 seconds. One is the Multiple Multi-turn Injection (MMI) in the horizontal phase space with the acceptance of 150π mm mrad. Another is the combination of the horizontal multi-turn injection and the RF Stacking [5] (RFS) in the momentum phase space. In the second method the horizontal acceptance is 50π mm 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 for the cooling of beam phase space in order to increase the accumulation ratio and efficiency. Table 3 is the accumulation parameters of several typical ions.

Table 3 Parameters of the accumulation in CSRm

	O^{7+}	O^{7+}	Xe^{48+}	U^{72+}
Injector	SFC	SFC	SSC	SSC
Energy (MeV/u)	10	10	20	10
Current (eμA)	3	3	0.5	0.05
Current (pps)	3×10^{12}	3×10^{12}	1×10^{11}	8×10^{9}
Particles/Turn	3×10^{7}	3×10^{7}	2×10^{5}	3×10^{4}
Efficiency of stripping			19%	15%
Method	RFS	MMI	MMI	MMI
Cycle(ms)	100	2500	250	100
Period (s)	10	10	10	10
Gain factor of MMI	2.8	5	5	5
Particles	6×10^{9}	6×10^{8}	8×10^{6}	2×10^{6}

3.4 Production of secondary beams

RIB (Radioactive Ion Beams) will be produced by the in flight method [6]. The heavy ions from present HIRFL system will be injected into CSRm for accumulating, cooling and accelerating to higher energies (200—400 MeV/u), and then extracted to bombard a primary target in order to produce radioactive beams. Finally those RIB produced will be accepted by CSRe for physical experiments with beam cooling.

Highly-charged ions fully stripped heavy ions or H-like and He-like heavy ions are demanded for atomic physics researches. HIRFL-CSR will provide those heavy ion beams by multiple stripping shown in below figure. In the energy range of CSRe fully stripped ion as heavy as Golden could be obtained, and the highest charged state for Uranium is 91+.

SFC(K=69)--|→SSC(k=450)--|-→CSRm--|---→CSRe
(Strip.) Strip. Strip.
$^{238}U^{37+}$ $^{238}U^{37+}$ $^{238}U^{72+}$ $^{238}U^{91+}$
0.96MeV/u 10MeV/u 400MeV/u 400MeV/u

4 LATTICE

4.1 CSRm lattice

The CSRm layout is a racetrack shape shown in Fig. 4, and consists of four identical arc sections. Each arc section consists of four dipoles, two triplets and one doublet. 8 independent variables for quadruple are used. The lattice of each arc section is given as follows,

$$\overset{L_1}{\text{----------FDF--B--B--F}}\overset{L_2}{\text{-------DF--B--B--F}}\,\frac{1}{2}\,\text{D}$$

Where $2L_1$ is a long-straight section with dispersion free for e-cooler or RF cavity. L_2 is a dispersion drift for beam injection or extraction. Fig. 5 is the distribution of the β-functions and the dispersion in CSRm, Table 4 is the lattice parameters of CSRm.

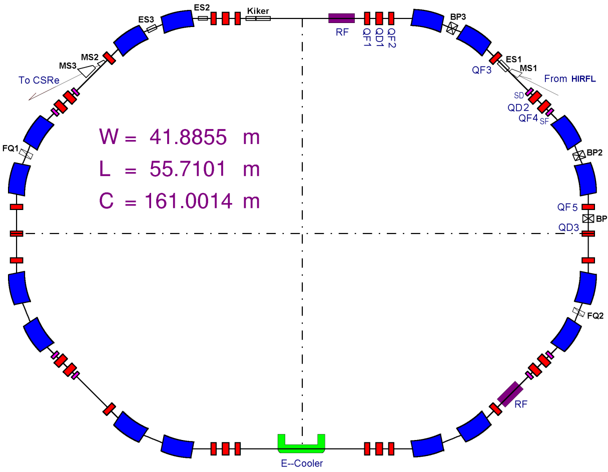

Fig. 4. Lattice layout of CSRm

In the injection arc-section 3 bump magnets (BP1, BP2, BP3) 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 3 bumps will be reduced to zero isochronously, the closed orbit will go back to the center, and the horizontal acceptance (150π or 50π mm-mrad) will be filled by injection beam simultaneously. Fig. 6 is the injection orbit of the MMI.

For CSRm fast and slow beam extractions should be done. In the extraction arc-section 5 kicker modes will be used for the fast extraction, and two static-electric septum, two fast quadruples, two families of sextuple and 6 in-dipole coils used for the slow extraction of 1/3 order resonance. The two extractions will use one channel, and the final elements of the extraction are two magnetic septum.

For beam injection and extraction the special vacuum chambers will be adopt to get large horizontal space.

In CSRm 16 in-dipole coils, 2 double-direction correctors, 9 vertical correctors will be used for the global closed orbit correction.

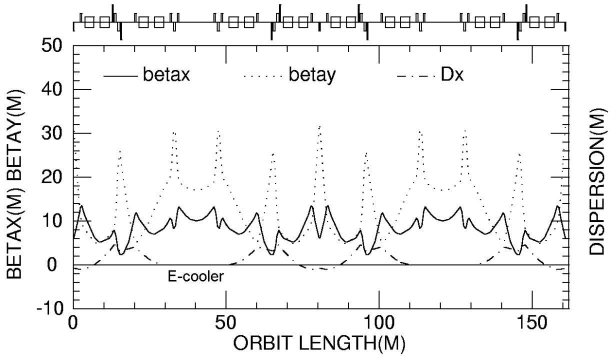

Fig. 5. Distribution of the β and dispersion of CSRm

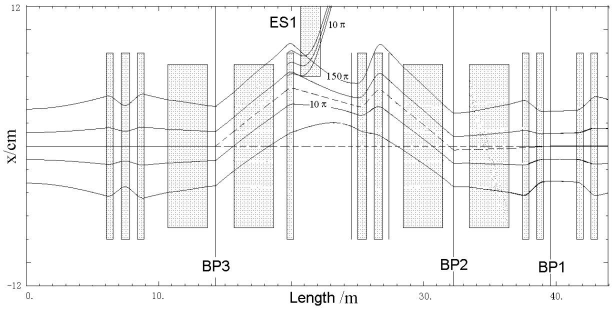

Fig. 6. Injection orbit of the MMI in CSRm

Table 4 Lattice parameters CSRm

Transition gamma	$\gamma_{tr} = 5.168$
Betatron tune values	Qx / Qy = 2.63 / 2.61
Natural chromaticity	Q'_x / Q'_y = -3.05 / -5.34
Max. β-amplitude	β_x/β_y=10.4/17.5 m (Dipole)
	β_x/β_y=13.5/32.2m (Quadruple)
Max. dispersion	$D_{max}(x)$=3.2 m (Dipole, β_x=10.4m)
	$D_{max}(x)$ = 4.6m (Quad., β_x=8.0 m)
Injection section	β_x=10.0 m, D_x = 4.0 m (Septum)
	β_x=11.9 m, D_x = 3.9 m (Quadruple)
E-cooler section	β_x/β_y = 10.0/17.0 m , D_x = 0
RF station section	β_x/β_y = 10.0/6.4 m , D_x = 4.0

4.2 *CSRe Lattice*

The layout of CSRe is shown in Fig.7. It is 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,

L_T L_R L_R L_C
-----FD-F--B-B---FD-F-B-B--B-B-F-DF---B-B--FD-----

Where $2L_T$ and $2L_C$ are the long straight sections with dispersion free for internal target and e-cooler. L_R is the dispersion drift for RF cavities.

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 Δ P/P = 2.6% used for high-precision mass spectroscopy. 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 those short-life-time RIB[7].

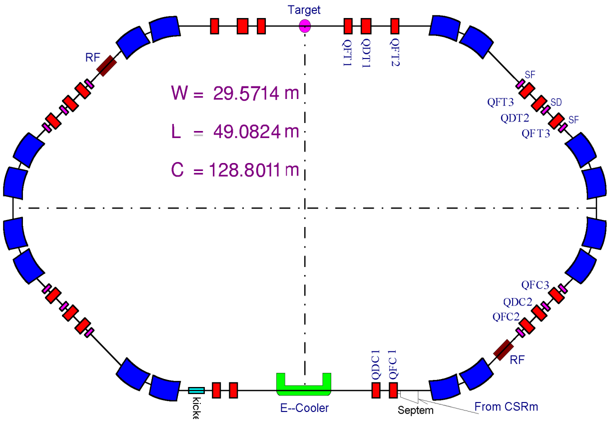

Fig. 7. Lattice layout of CSRe

Table 5 is the lattice parameters of the CSRe for the three lattice modes, and Fig.8, Fig.9, Fig.10 are the distribution of the β-functions and the dispersions for those modes.

Table 5 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	Qx / Qy = 2.53 / 2.57	Qx / Qy = 2.53 / 2.57	Qx / Qy = 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=25.7/8.7 m (Dipole) β_x/β_y=43.0/20.4 m (Quadruple)	β_x/β_y=17.6/8.2 m (Dipole) β_x/β_y=30.9/22.3 m (Quadruple)	β_x/β_y=28.1/12.2 m (Dipole) β_x/β_y=41.2/36.4 m (Quadruple)
Max. dispersion	D_{max}(x)=7.9m(Dipole, β_x=14m) D_{max}(x)=9.4m (Quad. , β_x=16m)	D_{max}(x)=6.5 m (Dipole, β_x=13m) D_{max}(x)=7.8m (Quad. , β_x=16m)	D_{max}(x)=18.5m (Dipole, β_x=28m) D_{max}(x)=21.2m(Quad. , β_x=34m)
Injection section	β_x= 30.8 m , D_x = 0 m (Septum) β_x= 31.4 m, D_x =0 m (Quadruple)	β_x= 30.4 m, D_x = 0 m (Septum) β_x= 30.9 m, D_x = 0 m (Quadruple)	β_x= 40.8 m , D_x = 0 m (Septum) β_x= 41.2m, D_x = 0 m (Quadruple)
E-cooler section	β_x/β_y = 12.9/16.5 m , D_x = 0	β_x/β_y = 12.5/16.0 m , D_x = 0	β_x/β_y = 2.6/10.5 m , D_x = 0
Target	β_x/β_y = 3.0/1.7 m , D_x = 0	β_x/β_y = 5.4/1.5 m , D_x = 0	β_x/β_y = 20.8/1.0 m , D_x = 17.7m
RF station section	β_x/β_y = 4.0/8.3 m , D_x = 4.6	β_x/β_y = 4.0/8.4 m , D_x = 4.5	β_x/β_y = 19.0/11.5m , D_x = 15.0m

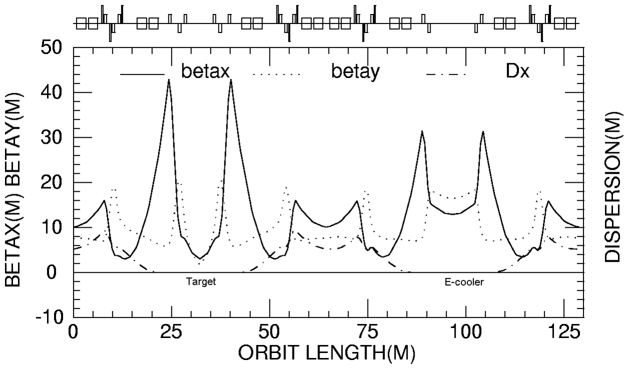

Fig. 8. Distribution of the β-functions and the dispersion for the internal-target mode

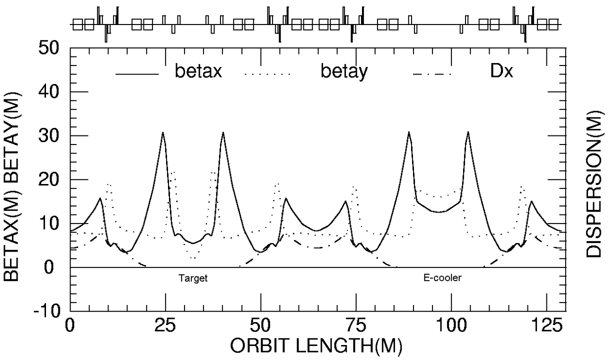

Fig. 9. Distribution of the β-functions and the dispersion for the normal mode

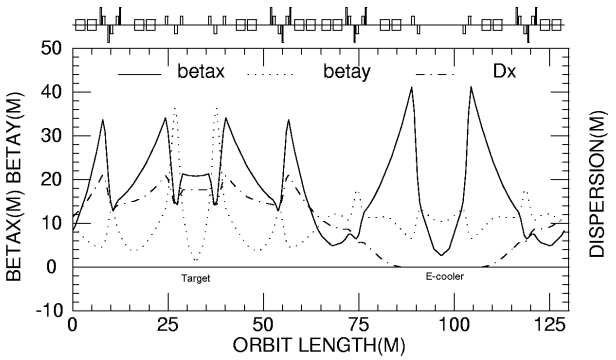

Fig. 10. Distribution of the β-functions and the dispersion for the isochronous mode

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 adopt by using 4 in-dipole coils, one magnetic septum and 4 modes of kicker, and the injection channel will pass through the fringe field of a dipole and two quadruples. For the three lattice modes the gradient of the doublet quadruple nearly the injection septum should be kept at the same value in order to get the same injection orbit. Fig. 11 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, 4 double direction correctors, 6 vertical correctors used for the global closed orbit correction.

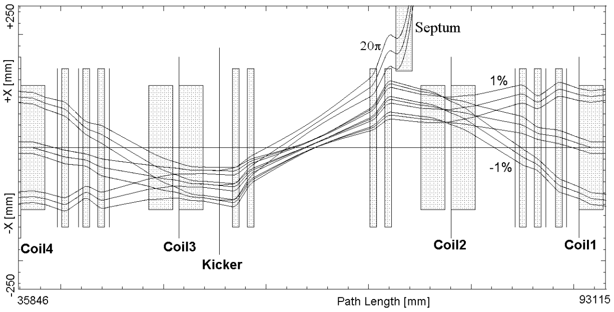

Fig. 11. Single-turn injection orbit of CSRe

5 SUB-SYSTEM

5.1 Magnets and correlative sub-systems

All magnet 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 different field levels in the range of 1000Gs to 14000Gs, a so-called modified H-type dipole was designed for CSRm. An air hole will be punched at the center of the pole to control the magnetic field flux flow at high magnetic fields [8], 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 CSRe the C-type dipole with large useful aperture will be adopted for physics experiments.

All power supplies of the ring magnets will need DC and pulse operation modes, and high current stability, low current ripple; good dynamic characteristic should be required. Two types of supply, traditional multi-phase thyristor rectifier for dipoles and switching mode converter for quadruples, will be adopted.

Table 6 is the major parameters of magnets and its correlative power supplies and vacuum chambers.

Table 6 Major correlative parameters of the magnets

	CSRm	CSRe
Dipole		
Number×angle (deg.)	16×22.5	16×22.5
Bending radius (m)	7.6	6.0
Field range (T)	0.1--1.4	0.1--1.4
Ramping rate (T/s)	0.1--0.4	0.1--0.4
Air gap (mm)	80	96
Useful aperture (mm^2)	140×60	220×70
Homogeneity (ΔB/B)	$\pm1.5\times10^{-4}$	$\pm1.5\times10^{-4}$
Vacuum. Chamber		
Aperture (mm^2)	150×60	220×70
Cross section	Rectangular	Rectangular
Supply of dipole		
Number	1	1
Feeding mode	Series	Series
Stability (at low cur.)	$\pm1\times10^{-4}$/8h	$\pm1\times10^{-4}$/8h
Ripple (at low cur.)	5×10^{-5}	5×10^{-5}
Tracking precision	$\pm3\times10^{-4}$	$\pm3\times10^{-4}$
Quadruple		
Number	30	22
Gradient range (T/m)	0.3—9.0	0.3—6.5
Bore diameter (mm)	170	240
Useful aperture (mm^2)	160×100	280×140
ΔK/K	$\pm1.5\times10^{-3}$	$\pm1.5\times10^{-3}$
Ideal length (m)	0.65, 0.5	0.65, 0.75
Vacuum. Chamber		
Aperture (mm^2)	188×116	280×140
Cross section	Octagonal	Octagonal
Supply of quadruple		
Number	30	22
Feeding mode	Independent	Independent
Stability (at low cur.)	$\pm1\times10^{-4}$/8h	$\pm1\times10^{-4}$/8h
Ripple (at low cur.)	5×10^{-5}	5×10^{-5}
Tracking precision	$\pm5\times10^{-4}$	$\pm5\times10^{-4}$

5.2 *Electron-cooler system*

Two electron coolers will be equipped in CSRm and CSRe respectively for heavy ion beam cooling. In CSRm the e-cooling will be used for the beam accumulation at the injection energy range of 8~30 MeV/u to increase the beam intensity. In CSRe the e-cooling will be used to compensate the growth of beam emittance during internal target experiments or provide high quality beams for the high resolution mass measurements [9] of nuclei. Table 7 is the major parameters of the two e-coolers, and Fig.12, Fig.13 are the general view of them. The two coolers are the same with the only difference of the high voltage unit in order to reduce the time of development and the production cost of the devices.

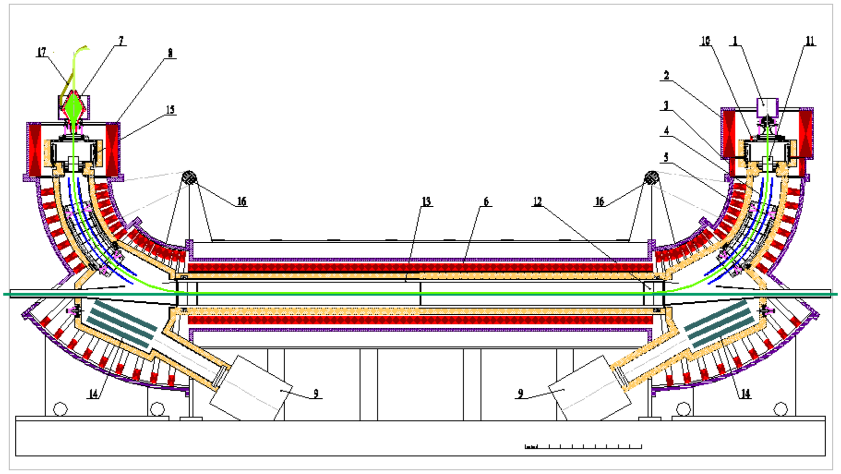

Fig. 12. Layout of the CSRm e-cooler

1- electron gun,
2- the main solenoid of the gun,
3- an additional solenoid of the gun,
4- the electrostatic deflector,
5- toroid, 6-the main solenoid,
7- collector,
8- the main solenoid of the collector,
9- ion pumps, 10-compensation coil,
11- titan sputter, 12-pickup electrodes,
13- vacuum chamber, 14-getter pumps,
15- heating jackets, 16 –hinge,
17-cooling system of the collector.

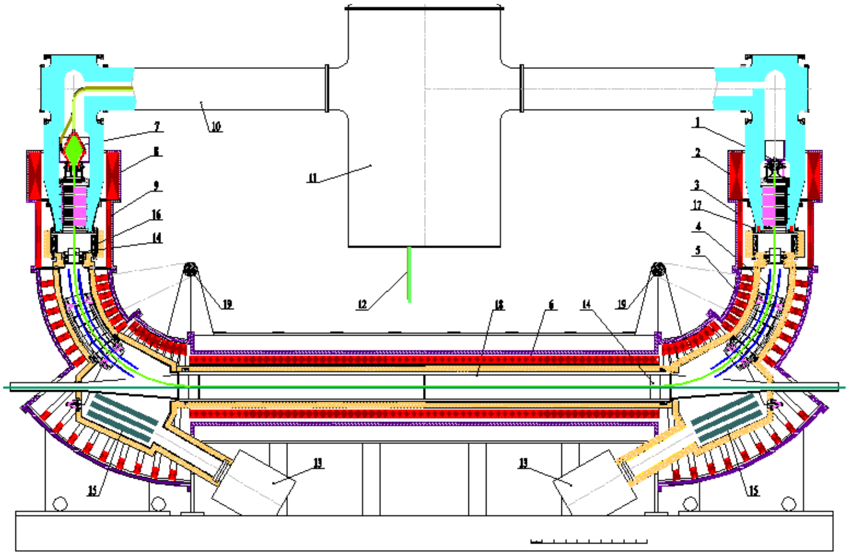

Fig. 13. Layout of the CSRe e-cooler

1- electron gun,
2- the main solenoid of the gun,
3- an additional solenoid of the gun,
4- the electrostatic deflector, 5-toroid,
6- the main solenoid, 7-collector,
8- the main solenoid of the collector,
9- additional solenoid of the collector,
10- SF_6-gas feeder,
11- HV power supply,
12- cooling system of the collector,
13- ion pumps, 14- pickup electrodes,
15- getter pumps, 16- heating jackets,
17- compensation coil,
18- vacuum chamber,
19- hinge.

Table 7 Major parameters of the two e-coolers

Parameters	CSRm	CSRe
Ion Energy [MeV/u]	8-50	25-400
Electron Energy [keV]	4-35	10-300
Electron beam current [A]	3 (1.0A@5.5keV)	
Cathode radius [cm]	1.25	1.25
Magnetic expansion factor	1- 4	1- 10
Max. field in gun region [kG]	2.4	5
Magnetic field in collector region [kG]	1.2	1.2
Magnetic field at 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)
Deflection angle of toroid [Deg.]	90˚	90˚
Deflection radius of toroid [m]	1.0	1.0

5.3 RF system

Two RF cavities will be used for beam accelerating and RF stacking in CSRm respectively. The stacking cavity with the frequency range of 6.0-14.0 MHz will be used to catch the SSC or SFC beam bunches with harmonic number h=16, h=32 or h=64 during the beam accumulation in the momentum acceptance with RF stacking. After beam accumulation the heavy ion beams will be accelerated by the accelerating cavity from the low energy range of 8-30MeV/u to the high energy range of 100-900MeV/u with harmonic number h=1.

In CSRe two identical RF cavities will be installed in two drift sections and used for beam capture, bunching, de-bunching and deceleration with harmonic number h=1 or 2. Table 8 is the general parameters of the CSR RF system.

Table 8 General parameters of the CSR RF systems

	Acc. In CSRm	Stacking In CSRm	CSRe
Number of cavity	1	1	2
Freq. range [MHz]	0.24~1.7	6.0 ~14.0	0.5~2.0
Harmonic number	1	16, 32, 64	1, 2
Peak RF voltage [kV]	7.0	20	20
Peak RF power [kW]	18	20	30
Installation length [m]	2.5	2.3	2.0
Aperture ϕ [mm]	200	200	200
Gap capacitance [pf]	6800	190~1300	2000

5.4 Ultra-high vacuum system

The CSR vacuum system is divided into four parts, the two storage rings of CSRm and CSRe, and the two beam lines of the injection line from HIRFL, and RIBLL2. The pressure of less than 3.5×10^{-9} Pa (N_2 equivalent) will be required in CSRm and CSRe, and 1×10^{-7} Pa will be necessary for the two beam lines.

For CSR UHV system Titanium sublimation pump and sputter ion pump are chosen as the main pumps, about 160 titanium pumps and 85 ion pumps will be equipped in CSR. For each part two or three movable oil-free turbo-molecular pumping stations will be equipped for pre-pumping, leak detecting and back-out. Many all-metal gate valves will be used to divide each part to several sections, and fast-closed valves will also be installed in injection and extraction positions for protecting two rings from some accidents. A lot of bellows with the length of 0.2~0.28m will be installed at those possible positions, specially the two sides of the dipole chambers, in order to correct installation error and absorb the heat expansion during the bake-out process.

The vacuum bake-out temperature will be 300°C. And all components of the two rings will be equipped with permanent back-out jackets. The dipole and quadruple chambers will be heated by coaxial heaters with an out-diameter of 2 mm. A special insulation material (Microtherm) will be used for these chambers to avoid thermal lost and protect the magnet coils from damage. This insulation will keep the outside temperature lower than 80°C with the thickness of 3~5 mm. Other chambers are baked by heating tapes which are made of glass fibre with the thickness of 10~25 mm.

5.5 Beam diagnosis system

In each ring there are many beam diagnosis devices for the future machine tuning and operation. 2 or 3 viewing screens and one Faraday-cup will be used for the fist turn tuning. One Schottky noise diagnostic device, one phase pick-up and 2 beam transformers will be used for the machine operation. One magnesium jet monitor used to detect the beam profile. 10 or 14 position pick-ups will be equipped for the global closed-orbit correction in the two transverse planes.

5.6 Internal-target system

The CSRe internal target is designed to provide both polarized and unpolarized atomic beams for physics experiments. The target will operate in the polarized mode with H and D gases. This mode will permit the researches of the spin structure of hadrons and allow measurements of nuclear form factor and so on. The polarized target will use the state selection in multiple magnets to get the polarized atomic beams with a density about 5×10^{11}atoms/cm^2. In the normal unpolarized mode the beam is a cluster jet and can achieve the desired density about 1×10^{12} atoms/cm^2 by cooling the nozzle to the given temperature.

5.7 Survey and alignment

One permanent standard point near the ring centre and many normal control-network points in each ring will be used for the ring survey and alignment. The control networks of CSR have been designed. According to the design the maximum point-position error of the horizontal control-network should be less than 0.06mm, and the vertical one should be less than 0.05mm.

For the CSR alignment the installation errors of magnets should be less than the desired values. According to the error simulation results the desired misalignments of dipole and quadruple is shown in the Table 9, where the 6 misalignments are three position errors, Δx (horizontal), Δy (vertical), Δz (beam direction) and three angle errors, $\Delta\phi$, $\Delta\theta$, $\Delta\psi$ around x-axis, y-axis, z-axis respectively.

Assuming that the distribution of every error is a $\pm2\sigma$ Gauss distribution, and according to the simulation calculating of closed orbit distortion (COD) with the misalignment values of Table. 9, and a dipole field error of $\Delta B/B \sim 5\times10^{-4}$, the maximum random COD values in dipoles and quadruples of CSRm and CSRe are shown in the followings.

For CSRm, $x_{COD}(D)$=15mm, $y_{COD}(D)$=10mm,
$x_{COD}(Q)$=18mm, $y_{COD}(Q)$=17mm.
For CSRe, $x_{COD}(D)$=10mm, $y_{COD}(D)$=7mm,
$x_{COD}(Q)$=15mm, $y_{COD}(Q)$=10mm.

Table 9 Misalignments of dipole and quadruple

Error	Dipole	Quadruple
ΔX (mm)	0.5	0.15
ΔY (mm)	0.5	0.15
ΔZ (mm)	2.0	0.5
Δϕ (mrad)	0.5	0.5
Δθ (mrad)	0.5	0.5
Δψ (mrad)	0.5	0.5

In order to meet the requirements of survey and alignment, the traditional optical instruments will be used for the pre-installations, and one laser tracker, a digital levelling device used for the final survey and alignment adjustment.

6 RIBLL2 DESCRIPTION

RIBLL2, the second Radioactive Ion Beam Line at Lanzhou, is one of the parts of the beam transport line between CSRm and CSRe, shown in Fig.1. It is designed to operate at higher energy with the maximum magnetic rigidity of 10.64 Tm. The separator of RIBLL2, which consists of 2 dipoles and 10 quadruples, is a mirror-symmetric system, achieving a point-point and parallel-parallel image at its intermediate focal plane with maximum position dispersion. The double achromatic of $D = D' = 0$ is automatically realized at the final focal plane. Its resolving power of magnetic rigidity is 1200 at the momentum deviation of ΔP/P = ±1% and the divergence of ±25mrad. Fig. 14 is the envelopes in x plane of the separator.

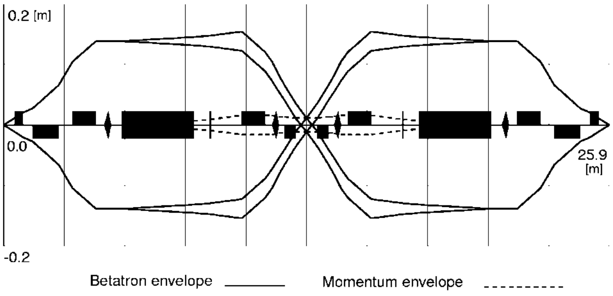

Fig. 14. Horizontal envelope of the RIBLL2 separator with the ΔP/P of ±1% and emittance of 25π mm-mrad

The following part is almost a copy of the separator to further purify RIB. The total length of RIBLL2 is about 55 meters. And the ion optics of it is optimized to third order in order to obtain high realistic resolving power and minimize the emittance growth. Table 10 is the major parameters of the RIBLL2 magnets.

Table 10 Major parameters of the RIBLL2 magnets

Dipole:

Number	4
Arc length (mm)	3054
Bending radius (mm)	7000
Bending angle (degree)	25
Magnet field (Tesla)	1.52
Useful aperture (mm^2)	320×56

Quadruple:

Number	4	4	4	8
Length (mm)	400	500	1100	1000
Strength (T/m)	19.02	7.77	12.05	7.58
Aperture (mm^2)	80×80	150×150	150×150	320×110

7 PROJECT STATUS

7.1 Building construction

The building construction of CSR was start at December of 1999 and will be finished in the summer of 2001. The construction includes the two storage ring main halls, an experiment hall, an experiment building with 6 floors, and other auxiliary systems.

7.2 Magnet prototypes

The magnets of the injection beam line from HIRFL to CSRm were selected as the R&D items of the CSR magnet fabrication. The selected magnets are the C-type dipole with the bending radius of 2m and the bending angle of 60^0, and the quadruple with the effective length of 0.4m and the bore diameter of 100mm. Fig.15 and Fig.16 are the prototypes of dipole and quadruple.

Fig. 15. 60° C-type dipole prototype of CSR

Fig.16. Quadruple prototype of CSR

The preliminary mapping shows homogeneity about $\pm 3.5\times 10^{-4}$ for design aperture in the maximum field to 1.55T, the homogeneity $\Delta Bl/Bl$ is less than $\pm 1.5\times 10^{-3}$ in the useful aperture of 100×55 mm^2. And the pole tip field of the quadruple can reach to 0.95T. The integral and harmonic measurements of the prototype magnets by coils are on going.

7.3 Power supply prototypes

The power supplies for the prototype magnets were selected as the prototype. Switching converter and thyristor rectifier were adopted for quadruple and dipole respectively. The results of the prototype test shows that the current stability is less than $\pm 1\times 10^{-4}$ /8h. and current ripple is less than $\pm 5\times 10^{-5}$ (at 200A).

7.4 Solenoid coil prototype of the e-cooler

In order to satisfy the strict requirement that the parallelism of magnetic field in the cooling section should be better than 1×10^{-4}, one prototype of the solenoid coil of the cooling section was made in a local company, shown in Fig. 17. The measured transverse field component B_T is 2.9×10^{-6} T, the longitudinal one is 1.75×10^{-2} T, and the corresponding angle of the field axis with respect to the reference plane is 1.6×10^{-4}. This result meets the requirement of the design.

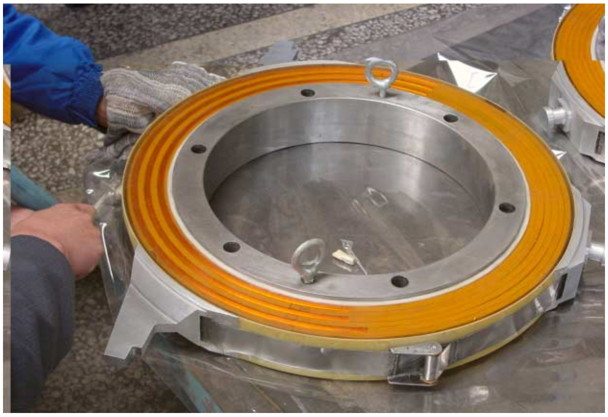

Fig. 17. Solenoid coil prototype of the CSR e-cooler

7.5 Vacuum chamber prototype

One section of the normal vacuum chamber of CSRm dipole was selected as the first prototype. The prototype experiment shows that the average vacuum pressure of 3×10^{-11} mbar can be reached in the section of dipole chamber. The further prototype is a 1/4-cell section of CSRm, and will be finished in the end of 2001.

7.6 Outline of the machine manufacture

In the beginning of 2000 the UHV bake oven was made in a local company. The construction of the injection beam line from HIRFL to CSRm will be finished in the end of 2001. Several subsystems, two e-coolers, RF system, kickers, internal-target system and the Mg-jet monitors, are being designed and fabricated jointly by IMP and the Russian BINP. The main subsystems, magnet, power supply, vacuum chamber, control, beam diagnosis and so on will be manufactured by several Chinese companies from 2001 to 2003.

8 FURTHER DEVELOPMENT

8.1 RIB slowdown

So far, RIB produced in CSR base on the energetic heavy ion beams with projectile fragmentation or fission as a production mechanism. As the RIB physics require the low energy RIB, the gas catcher as IGISOL [10] is taken into account for further development.

8.2 Molecular & Cluster beam

As the high sensitive and high accuracy characters, CSRe is useful equipment for the molecular and cluster physics study besides the atomic physics and nuclear physics. Therefore, the molecular, cluster source and inject into CSRe, like TSR [11], are under consideration.

8.3 New Linac injector

In order to obtain high intensity beam or switching the different ion beam within few second, a heavy ion LINAC injector with energy about 10 Mev/u will be the optimization injector for CSR complex. This injector will be designed similar like the CERN lead ion linear accelerator “Linac 3” [12].

8.4 New RIB Source

Following the above philosophy, a new very neutron rich fission fragments RIB source will enhance CSR complex capability for RIB research. This RIB source is considered using the intense 200 Mev proton beam bombarding ^{238}U to induced the fission reaction and setup as the one of new Linac injector source.

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