HIRFL STATUS AND HIRFL--CSR PROPOSAL

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Since the Heavy Ion Research Facility at Lanzhou (HIRFL) was put into operation in 1989, 19 kinds of ion have been extracted for the experiments and a lot of improvements was finished. In order to provide high quality stable and unstable nuclear beams for many experiments, the HIRFL Cooler--Storage Ring Proposal has been submitted to Chinese Academy of Sciences. The HIRFL status and the main performance, lattice as well as the main technical problems of Cooler-Storage Ring (CSR) are described in this paper.

I. HIRFL STATUS

A. Operation

After the first beam was extracted from the main accelerator SSC (k=450) on Dec.12,1988, HIRFL has been operated successfully except 1991 when the injector SFC (k=69) was shut down to upgrade and install ECR source as well as its beam line. Layout of HIRFL is shown in Fig.1 and the accelerated ions are listed in Table 1.

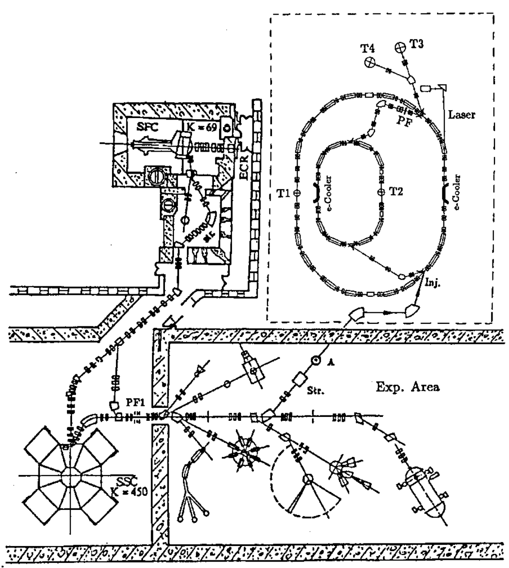

Fig.1 Layout of HIRFL

The layout of CSR is shown in the block of dotted line. T1--Internal target for atomic physics and RIB physics; T2--Internal target for the studies of exotic nuclei and atomic physics; T3--External target for cancer therapy research; T4--External target for researches on the properties of nuclear matter under extreme conditions.

Table 1 Accelerated beams and operated parameters of HIRFL

ION	Z	RF(MHz)	h	E(MeV/u)	I(μa)
SFC					
^{12}C	4	6.26	1	4.5	5
^{16}O	5	6.26	1	4.5	3
^{12}C	4	7.53	1	6.6	3
^{40}Ar	8	13.54	3	2.4	2
^{20}Ne	4	13.54	3	2.4	2
^{18}O	6	6.26	1	4.5	2
^{14}N	5	6.26	1	4.5	3
^{16}O	6	8.54	1	8.5	2
^{12}C	5	8.23	1	7.9	2
^{12}C	4	8.02	1	7.5	2
^{84}Kr	13	10.98	3	1.5	0.25
SSC					
^{12}C	6	9.39	2	50	0.4
^{16}O	8	9.39	2	50	0.05
^{12}C	6	11.29	2	75	0.05
^{40}Ar	15	13.54	4	25	0.05
^{20}Ne	8	13.54	4	25	0.04
^{18}O	8	9.39	2	50	0.04
^{14}N	7	9.39	2	50	0.05
^{16}O	8	12.80	2	100	0.01

B. Improvements

1. ECR ion source and its beam line installation

In order to increase the ion species and improve the beam qualities, a Caprice ECR source purchased from CENG Lab, and the beam line from ECR to SFC had been installed in 1991. To meet the need for ions of heavier element, some possible modifications had been tried. As a result, a considerable increase in beam current with a factor of 1.5 to 2 is gotten for Ne and Ar respectively[1]. Meanwhile a new 10GHz ECR ion source has been developed in our laboratory and its performance is satisfactory.

2. Upgrading the SFC

To meet the requirement of the external injection system a lot of improvements had been done. The central region of SFC was redesigned. Following the general design principles and the equations of motion a slanted electrostatic inflector had been designed and fabricated[2]. The central trajectories had been studied carefully and in detail. Because the new coils took the place of the original one which had been used for about 30 years and the external injection system was adopted, the magnet field must be mapped again. At same time the Dee and dummy Dee was rebuilt. The electrostatic deflector was replaced by new one. Two HIRFL-800 cryopumps took the place of two oil diffusion pumps. And the microcomputer--CAMAC system is used to control SFC and the beam line.

3. Bypass beam line construction

The bypass beam line from former beam line to the post one was constructed to deliver the beam extracted from SFC directly to the experimental terminals in 1993.

4. Improvement of phase stabilization system

There are 6 sets of RF amplifier with different frequency range and power in RF system. The No. 0 cabinet was added as the reference phase to improve the phase stability of RF system. Using the victor resultant principle a new 360° phase shifter adjusted by microprocessor with phase resolution of better than $\pm 0.1^{\circ}$ has been developed and took the place of the mechanical phase shifter.

5. Development of HIRFL--800 cryopump

Owing to larger consumption of liquid nitrogen, the Balzers cryopump of RKP 800 with a combined pumping speed of about 20000l/s was replaced by the HIRFL 800 cryopump without using liquid nitrogen. Its pumping speed has been tested at a standard test dome to be 25000 and 27000l/s for nitrogen and hydrogen respectively.

II. HIRFL--CSR PROPOSAL

A. General Description

HIRFL-CSR, a heavy ion Cooler-Storage Ring, is a new accelerator plant. It could provide stable and unstable nuclear beams with high quality for experimental researches. The CSR consists of a main ring (CSRm)with a circumference of 141.051m and an experimental ring (CSRe) with a circumference of 70.525m. It will accelerate the particles up to 900MeV/u for light heavy ions (Z/A=1/2) and 600MeV/u for heavier ions (Z/A=1/2.6) by using the existing two cyclotrons SFC (k=69) and SSC (k=450) as injectors respectively. The heavy ions from the injectors will be accumulated, cooled and accelerated in the main ring, and then extracted to produce radioactive ion beams (RIB) or high charge state heavy ions. After that the secondary beams can be injected into the experimental ring for internal target experiments. Those beams stored in the experimental ring can also be decelerated to low energy (≅10MeV/u) for physical experiments, or reinjected into the main ring for acceleration to high energies (500--900MeV/u) for the internal or external target experiments.

The expected mean luminosity of internal target experiment in CSRe will be of 10^{21-24} for short lifetime RIB (0.1-100 ms) and of 10^{24-28} for long lifetime RIB (0.1-5 s).

B. Main Parameters and Lattice of CSR

The main parameters of CSR are tabulated in Table 2. Fig.2 and Fig.3 show the distributions of β-functions and dispersions for CSRm and CSRe respectively.

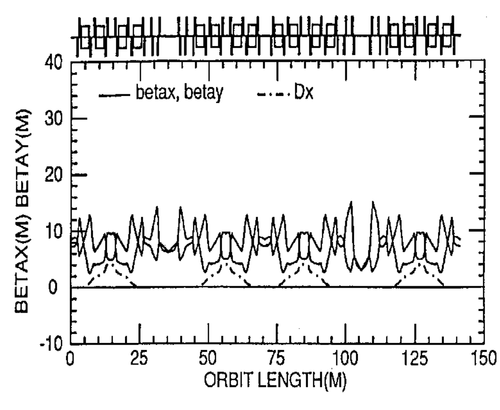

Fig.2 β-functions and dispersions of CSRm

Table 2 Main Parameters of CSR

Ring	CSRm	CSRe
Circumference (m)	141.051	70.525
Average radius (m)	22.449	11.2244
$B\rho_{max} / B\rho_{min}$(T.m)	10.584/0.64	6.4/0.91
<u>Acceptance</u>		
$\varepsilon_{\perp}$(πmm.mrad)	50	25
$\Delta p / p$(%)	1.0	1.0
<u>Lattice</u>		
γ_{tr}	4.44	2.35
Q_h / Q_v	4.24/3.23	2.73/2.35
Max. β_h / β_v (m)	14.94/14.11	16.34/14.32
Max. D_x(m)	3.971	3.944
<u>Electron cooling</u>		
E_{emax} (keV)	165	165
I_{emax} (A)	4.8	4.8
cathode diameter(mm)	50	50
β_{hc} / β_{vc}(m)	6.0/6.0	6.2/6.2
cooling section length(m)	3	3
<u>RF--system</u>		
harmonic number	1	1
f_{max} / f_{min}(MHz)	2.0/0.2	3.05/0.62
voltages (n×kV)	2×8	2×12
<u>Vacuum(Torr)</u>	1×10^{-10}	1×10^{-10}

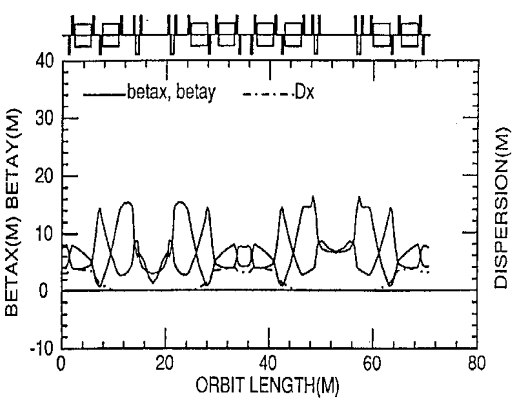

Fig.3 β--functions and dispersions of CSRe

C. Lifetime of Stored Ion beams[3]

At the injection energies the main factors defining the survival of ion beams are related to the three processes. 1. Single and multiple Coulomb scattering on residual gas molecules. 2. Charge exchange (i.e., electron capture and electron stripping) with residual gas molecules. 3. Radioactive electron capture (REC) in the e-cooler.

The theoretically calculated partial lifetimes demonstrate that the REC process in the electron cooler restricts the lifetimes of light heavy ions(C-Kr) injected into CSRm, the electron capture mechanism dominates the lifetimes of heavier ions (Xe-U), and the beam loss caused by Coulomb scattering is negligible. However, under the vacuum conditions of CSRm, lifetimes of the typical heavy ions at the injection energies are longer than the needed time for RF stacking (~5s) and electron cooling (~1s). This allows to obtain high intensity accumulated ion beams.

Besides the above three processes, the charge exchange with target atoms and Coulomb scattering on target atoms have to be taken into account when determining lifetimes for thin internal target experiments. In this case electron capture on target atoms dominates the circulating beam lifetimes. Anyhow, the calculation results predict that the CSRe internal target thickness of 10^{15}atoms/cm^2 is reasonable.

D. Electron Cooling Time

The electron cooling time has been computed by using the more accurate cooling theory[4]. The results show that for the combination method of multiturn injection and RF stacking at the injection energies, beam emittance of the order of 0.1 πmm.mrad is achieved in a typical cooling time of less than 1.0s, while the longitudinal momentum spread at the top of stack is damped from 2.5×10^{-4} to 2.0×10^{-5} in a time of 1.0ms, which is much shorter than RF stacking period(~20ms), while for the multiple single-turn injection the emittance and momentum spread are decreased by 2 orders in a cooling time of less than 60ms and 120ms respectively.

Hence this fast cooling makes it possible to increase the accumulated ion beam intensity to a limitation of space charge effect rather than the phase space of machine.

III. REFERENCES

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