PROGRESS OF THE HEAVY ION RESEARCH FACILITY IN LANZHOU

W.L Zhan, J.W. Xia, H.W. Zhao, Y.J. Yuan, K.D. Man, P.Yuan, D.Q.Gao, X.T.Yang, M.T.Song, G.Q.Xiao, W.M.Qiao, X.H.Cai, X.D.Yang, J.R.Dang, Y.F.Wang, B.W. Wei and HIRFL-CSR Group
Institute of Modern Physics, CAS
363 Nanchang Rd', 730000 Lanzhou, China

Abstract

Some improvements and upgrading project are progress smoothly at Heavy Ion Research Facility in Lanzhou (HIRFL). The beam intensity of SFC cyclotron is increase 3 to 10 times, the heaviest beam extracted is Pb after improvement of vacuum up to 10^{-8}mbar, reducing the influence the stray magnetic field and power supply system. The beam from SFC could be rebenched to matching SSC cyclotron after new rebuncher is success reaching its design performances. The upgrade project, Cooling Storage Ring (HIRFL-CSR), has been constructed about 4 year. The inject beam line from existing HIRFL system to main ring (CSRm) is installed and tested; CSRm is installed except few special devices; the RIB separator and experimental ring (CSRe) are being installed and will be finish within 2004. The most of setup at CSRm is better than its design that could be optimizing to increase maximum energy about 10 - 20% more than its original design (900 MeV/u for ^{12}C and 400MeV/u for ^{238}U). There will be some new features at CSR complex which new generation electron cooler, RIB reaction experiment inside CSRe and the digital remote control system. So far, the $^{12}C^{4+}$, $^{16}O^{6+}$ beam is tuning to inject beam line, and start CSRm commission before end of 2004.

INTRODUCTION

HIRFL-CSR[1,2] project was started in 2000 year. It consists of the inject beam line which is between the exist HIRFL system to new acilities, main ring CSRm, radioactive beam separator RIBLL-II, experimental ring CSRe and the improvement of exist system (Fig.1). So far, about 90% of the improvement items were finished and description in charter 2; It is the time that inject beam line is installed and tested in beam, CSRm has been installed end of Feb. 2004, RIBLL-II and CSRe is being installed now, all these will be presented in charter 3; In the charter 4, the future development of HIRFL is briefly introduced.

EXISTING SYSTEM IMPROVEMENT

The main goals of these items are improvement of the beam intensity, beam quality and efficiency on existing cyclotron system. The improvements focus on the following items: SFC, SSC cyclotrons, optimization of beam transport and some relative conditions. And, the cancer therapy phase I is also considered as one of upgrade item.

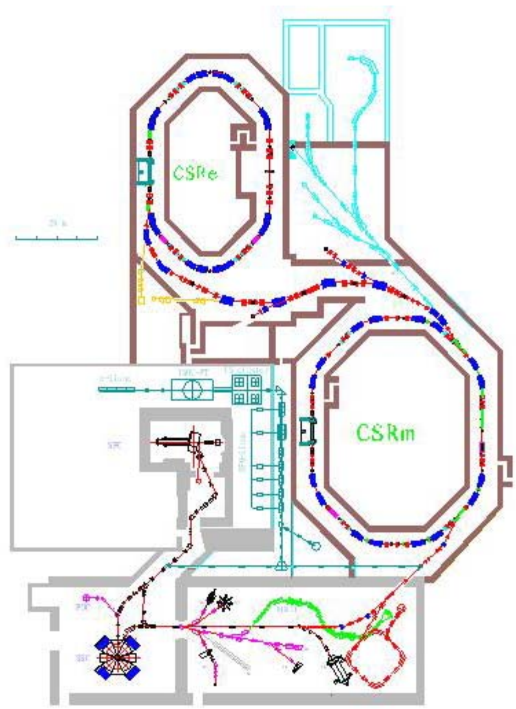

Figure 1: Layout of HIRFL-CSR.

SFC Improvements

The main efforts on SFC are improvement of SFC vacuum to increase efficiency of accelerate heavier ion and reduce the stray magnetic field influence by strong magnetic field saturation of SFC.

The SFC vacuum chamber is replaced by the two chambers structure. The outer chamber is working in low vacuum where the most of cable and cooling water tube are handled. In this case, the inner chamber, where is the ion beam accelerated, is become simple, clean and that reducing the out gassing and easier to get the higher vacuum by using this structure, SFC vacuum is improved from 10^{-7} mbar to 10^{-8} mbar and recently, pb ion was accelerated as heaviest ion.

To reduce the strong saturation of SFC magnet, about 15% ion is added to the magnetic yard and some shielding are added between SFC and inject beam line. Now, the strong saturation is improved. Finally, it is significantly reduced the stray magnet field about 75% to less than 4 guass. These improvements are reducing the beam losses at the beam line and easier to optimize parameters of the beam line to reach a good match

Besides above improvements, low energy beam line from ECR ion source to SFC was improved. The resent injection efficiency from ECR to SFC is from 10 % to 40%. So far, the higher beam intensity is obtained as that the beam intensity from SFC could reach 10^{13}pps for the light ions < Ar, 10^{12} pps for the medium heavy ions < Kr.

Rebunch between SFC and SSC

The new rebuncher between SFC and SSC is used to match the two cyclotrons in the phase. It was assembled and tested online. The range of frequency is from 22 MHz to 54 MHz, maximum RF voltage about 150kV and maximum power is 40kW. About the factor 2 beam injection efficiency from SFC to SSC could be obtained by the pre-test.

DC Power Supplier

It is necessary to improve the power suppliers since these have operated about 18 years, that causing more problems and difficult to find the out of date devices for maintaining. Therefore, about 300 power suppliers were re-built in types of switching, clan and thyristor. Theses new power suppliers are operation in more stability, higher efficiency and easy to use.

Optimization of Beam Line

The goals of beam transport optimization are switching the different energy beam to downstream setup and share beam for injecting CSR and performing experiment inside the experimental hall. It is designed as follow.

I, A pair switching magnets are set at two end of by pass beam line from SFC direct to the experimental hall. By this way, the post setup could get low energy beam (SFC) or higher energy beam (SSC) by switching this pair magnets in different moment.

II, Another pair switching magnets are set at close to the entrance of experimental hall. This setting serves as to share the beam between the setup inside of experimental hall, injecting beam to the CSR in very short moment.

Cancer therapy in phase I

The cancer therapy phase I at HIRFL system is considered using the 240 MeV Proton or 120 MeV carbon beam. The treat room arrange in sub-experiment hall as fig. 2.

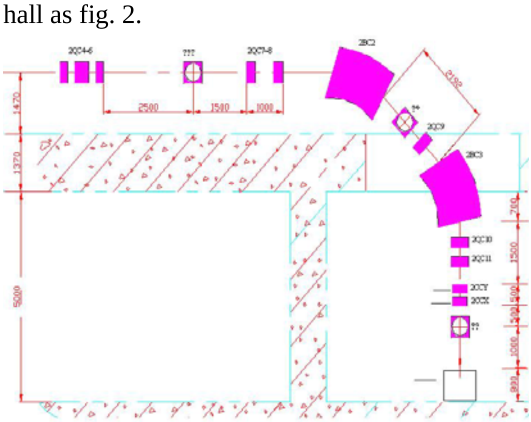

Figure 2: layout of cancer therapy phase I at HIRFL

The beam is bended 90 degree by a pair of dipoles in vertical direction, which are main components in an achromatic beam transport line. The beam energy will be varied by energy degrader in front of the achromatic beam section. There is a pair slits are set in the middle of two dipole which is used to qualify the beam. Now, this upgrade item is under construction.

PROGRESS OF CSR PROJECT

The main parameters of CSR are optimized that the accelerated energy increase about 20% and proton beam will be ready for meson and nucleon study after key prototypes finish and requirements of physics. CSR project consists of four sections: inject beam line, CSRm, RIBLL-II and CSRe. So far, the inject beam line and CSRm were installed, the most devices of RIBLL-II, CSRe is ready to assemble and more than 60% were installed. Meantime, the test offline and starting commission beam in the inject beam line and main ring are underway.

Optimize the Design of CSR

The optimization of CSR design is based on achieving higher performances of the prototype setup and physics requirement. The optimization parameters are listed in Table 1.

Table 1: Main parameters of CSR

	CSRm	CSRe
Ion Species	P(proton), C-U	P, C-U, RIB,HCI, Molecular&Cluster
Energy (AMeV) (Bmax=1.4~1.6T)	2350~2800 (P) 900~1100($^{12}C^{6+}$) 420~520($^{238}U^{72+}$)	2000 (P) 620~760 ($^{12}C^{6+}$) 400~500 ($^{238}U^{>90+}$)
ΔP/P	$\sim10^{-4}$	$<10^{-5}$
δP/P (entrance)	±0.15%	±0.25~0.5%
Emmitance	≤5 π mm-mrad	≤1π mm-mrad

The energy increase is easy due to the maximum field of the magnet dipole prototype could reach 1.6 T in qualify field distribution. And, physicist expect have the reaction energy as higher as CSR could do. Therefore, with the maximum field increasing from 1.4T to 1.6T, the maximum energy increase about 20%.

II, Proton beam is considered to accelerate at CSR since the physics requirement and without radiation protect problem. Hence, the internal experimental target with a mini 4π detector is proposed to perform the meson and nucleon experiment at the opposite side of the electron cooler of main ring.

III, The striping inject system was adopted to inject light ion in higher efficiency, easy operation and shorting injection time.

Inject Beam Line

Inject beam line is used to transport the lower energy beam from existing HIRFL system. The beam is bended from 1st floor to sub-floor by a pair of 60° dipoles in vertical direction, then, bended 64.7° to matching entrance of CSRm by 3 dipoles in horizontal direction. Total length of this beam line is about 61.09 meter. Another function of this beam line is to transit vacuum from 10^{-8} to 10^{-11} mbar oil free.

This beam line was installed about two years. So far, ~$1.5*10^{-11}$ mbar UHV has been achieved at the entrance point of CSRm for more than one year. The about 7AMeV ^{12}C, ^{16}O beams have been injected for starting commission.

CSRm Progress

CSRm is a quasi-synchrotron and used to collect the beam from existing HIRFL system, cooling down by electron cooler, then, accelerating. Its circumference is 161.20 meter, and consists of 16 dipoles, 30 quadric-poles, 8 sextupole, 8 corrector, one set of electron cooler, one set of inject & extract devices (1 kicker, 4 bump, 3 magnetic septum and 2 electrostatic septum), 2 RF system and relative driver power suppliers, vacuum, beam diagnostic, control system and so on. CSRm is installed end of Feb. 2004 (Fig.3).

The main performances of devices are met design as follow[4,5,6,7]: D-pole of integral field BL accuracy $<\pm 1.5*10^{-4}$, Q-pole gradient $\Delta K/K$ accuracy $<\pm 1.5*10^{-3}$; power supplier of long tern stability $10^{-4\sim-6}$, cycle to cycle repetition error $< \pm 4.0*10^{-4}$; vacuum $10^{-9\sim-10}$ mbar without baking, 10^{-11} mbar after baking, 10^{-12} mbar with titanium pump; RFs frequency range from 0.25~1.MHz with Vmax = 8.25kV and 6.0~14MHz with Vmax = 25kV respectively. All setup were alignment at very high accuracy (error ± 0.1~0.3mm).

Figure 3: Overview of CSRm installation

New generation electron cooler (Vmax = 35 kV) produces the 3A electron with full and hollow structure in cross section, magnetic field inside the solenoid reaches 10^{-6} ratio of horizontal to vertical component and the efficiency of current collector is 99.99%. It has been installed in more than 1.5 year and kept UHV better than 2*10-11mbar. Many times offline test shows its quit confident quality. It is the one of innovation in this project.

RIBLL-II

RIBLL-II locate between the storage ring CSRm and CSRe and used to transport beam from CSRm to CSRe, external experimental sites, produces the radioactive ion beam (RIB) and high charge state ion beam (HCI). So far, more than 2/3 is installed. Its total length is about 111.98 meter and divides as four parts by different function.

CSRe Progress

CSRe is designed as the high accuracy (10^{-6}) and high sensitive spectrometer. The configuration of CSRe is similar as ESR at GSI, except increase the momentum acceptances at the entrance point of ring. This different could improve the RIB collected inside the ring and open RIB reaction experiment with internal target in high accuracy. Its energy could be varied by decelerating injecting beam energy. Its circumference is 128.96 meter, and consists of 16 dipoles, 22 quadric-poles, 12 sextupole, 12 corrector, one set of 300 kV electron cooler, one set of inject & extract devices (1 kicker and 1 magnetic septum), 2 RF system, one set of gas jet internal target and relative driver power suppliers, vacuum, beam diagnostic, control system and so on. Now, CSRe is installed >60%.

The main performances of CSRe are similar as those of CSRm event heavy magnet devices, C type dipole, large power supplier and big vacuum chamber.

Figure 4: 300kV electron cooler at CSRe

300kV electron cooler has been installed in site this spring (fig.4). The new type 300 kV power supplier is designed by cascade mode and isolated by SF6 gas in the tank. This design avoids the difficulty of HV cable connector in the air. Up to now, the maximum high voltage is 300 kV and the maximum electron current is more than 2 A in the high stability and high accuracy. Besides this new feature, the main performances of 300 kV electron cooler are similar as those of 35kV electron cooler.

The internal target designed gas (cluster) jet, the pump system adopt the cascade of turbo molecular pump to achieve high pumping speed (Fig.5). The target thickness is about 10^{13} atoms/cm^2 for N_2, Ne and Ar gas during the test and about 10^{12} atoms/cm^2 of H_2 gas will be obtained by recombination the cascade turbo molecular pump. The vacuum is 10^{-10} mbar at place 50 cm far from target point and 10^{-11} mbar at the place 1 meter far from target point.

The first commission beam is 7MeV/u ^{12}C from SFC and injects into CSRm by stripping since higher injection beam intensity and easy to operation in beginning.

Figure 5: Gas jet internal target at CSRe

FUTURE DEVELOPMENT

The future development of HIRFL-CSR are optimization and integral this configuration according the physics requirement and high operation efficiency.

CSRe injection

Obviously, it is worth to have a straight beam line, after first RIBLL-II separator direction, to inject the primary beam or HCI beam into CSRe since RIBLL-II separator is used for experiment quit often and usually operate in not very high vacuum. This will cause difficult and lower efficiency operation.

New booster

The cancer therapy by heavy ion has quit successful which is one of the important R&D at HIRFL-CSR. In order to enhance the reliability of HIRFL-CSR complex, the small booster (~12MeV/u) is proposed to set in upstream of CSRm as the red drawing inside of HIRFL experimental hall in fig.1. This item consists of laser ion source, Vandgraf static electric accelerator and booster.

This development will benefit not only for cancer therapy but also for meson, nucleon study and others by more flexible operation mode.

ACKNOWLEDGMENT

We are very grateful for the valuable advices of HIRFL-CSR international advisory committee, help of GSI colleagues and the collaboration from BINP and academic exchange with RIKEN colleagues.

REFERENCES

[1] B.W.Wei, et. al., Results from Lanzhou K450 Heavy Ion Cyclotron, Proc. Of 1989 Particle Acc., IEEE.

[2] J.W. Xia, et. al., HIRFL Status and HIRFL-CSR Project in Lanzhou, Proc. of the First Asian Part. Acc. Conf., KEK, Japan, 1998.

[3] W.L.Zhan, et. al,. HIRFL-CSR Project, 16th Inter. Conf. of Cyclotrons and their Applications, Michigan 2001.

[4] P.Yuan, et. al., A C Type Dipole with Imbedded Windings to Improve the Field Distribution, Inter. Conf. of Cyclotrons and their Applications, Michigan 2001.

[5] D.Q.Gao, et. al., HIRFL-CSR Power Supply System, Inter. Conf. of Cyclotrons and their Applications, Michigan 2001.

[6] X.T.Yang, J.H.Zhang *et al*. The first prototype of the HIRFL-CSR UHV system. [J], Vacuum 68 (2003): 11

[7] X.D.Yang, et. al., HIRFL-CSR Electron Cooling Devices, Inter. Conf. of Cyclotrons and their Applications, Michigan 2001.