STATUS OF HIRFL-CSR PROJECT*

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Abstract

The HIRFL-CSR project is a national mega project of China, which concentrates on heavy ion synchrotrons and cooling storage rings. It is finished recently. The present commissioning results, testing experiments and new development are introduced in this paper. The future improvement of the machine is also discussed in this paper.

INTRODUCTION

The HIRFL-CSR project consists of CSRm (main synchrotron), RIBLL2 (RIB production and transfer line), CSRe(experimental storage ring) and experimental terminals (see Fig. 1). Its injector is a two cyclotrons complex. Its total budget is around 27 million euro. The main parameters are listed in Table 1.

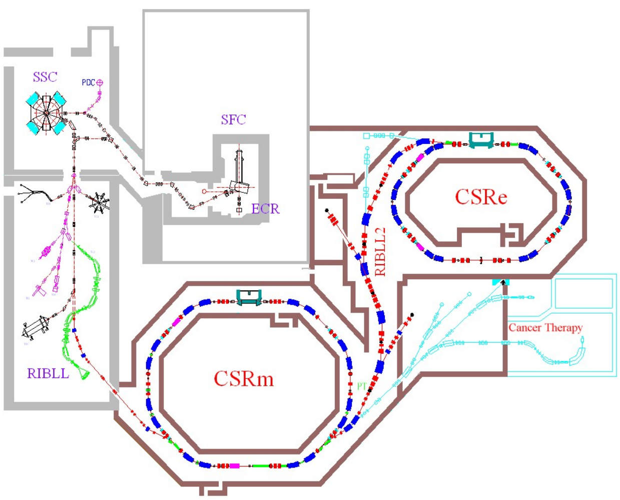

Figure 1: Layout of HIRFL-CSR.

The project starts in Apr. 2000 and gets the first stored beam in CSRm in Jan. 2006. By end of 2007, the commission and official tests are done successfully.

Up to now, several species of beam are commissioned at CSR, including Carbon, Argon, Krypton and Xeon. The intensity of them reached 7×10^9, 4×10^8, 1×10^8 and 1×10^8 pps respectively. The energy of Carbon and Argon reached 1AGeV, which surpassed the designed magnet rigidity value 10.64Tm. The Carbon, Argon and Krypton beams are injected into CSRe, and two mass measurement experiments are done with Argon and Krypton beams.

The slow extraction is realized for CSRm, it's the first step towards external target experiments and cancer therapy study.

*Work supported by HIRFL-CSR project

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Table 1: Major Parameters of CSR

	CSRm	CSRe
Ion species	Carbon~Uranium	Carbon~Uranium
Magnet rigidity	0.7~11.5Tm	0.6~9Tm
Max. Energy	$^{12}C^{6+}$-1000MeV/u $^{238}U^{72+}$-460MeV/u	$^{12}C^{6+}$-700MeV/u $^{238}U^{91+}$-460Mev/u
Beam intensity	$^{12}C^{6+}$- 7×10^9ppp $^{129}Xe^{27+}$-1×10^8ppp	$^{12}C^{6+}$- 7×10^9ppp $^{129}Xe^{27+}$-1×10^8ppp
Emittance	~1π mm mrad	~1π mm mrad
Tunes	3.63/2.62	2.53/2.58
e-cooler energy	35keV (50MeV/u)	300keV (400MeV/u)
Vacuum Pressure	<6×10^{-11}mbar	<6×10^{-11}mbar
RF cavity	0.24~1.7MHz 7kV	0.5~2MHz 2×10kV
Injection	Multi-turn Charge exchange	Single turn
Extraction	Fast Slow(RF KO)	-

COMMISSIONING AND OPERATION

At beginning of 2005, the commission of CSRm started. The first beam passed CSRm in Feb. 2005. During 2005, a lot of work was done to improve the beam diagnosis system, power supply system and local control system. The first stored beam was obtained by charge stripping injection (CSI) method in Jan. 2006(Fig. 2).

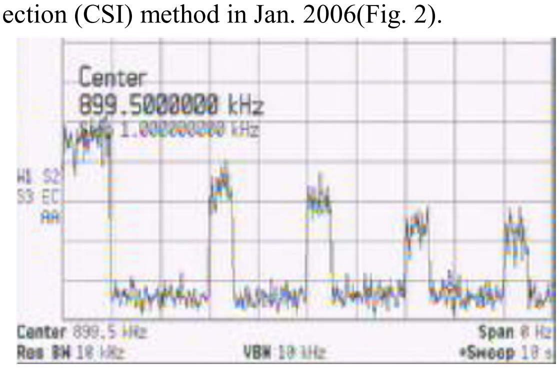

Figure 2: The first stored beam observed by periodical RF capture and release.

Later, the remote control system, the beam current monitor, and tune measurement were available. The magnet field measurement data is investigated and repaired to fit the system error. The RF harmonic transfer technique was realized In Oct. 2006, the $^{12}C^{6+}$ beam was accelerated from 7MeV/u (0.76Tm/0.1T) to 1000MeV/u (11.3Tm/1.5T) with a beam intensity of 2.8×10^8 pps (Fig. 3). The main goals of CSRm were fully finished.

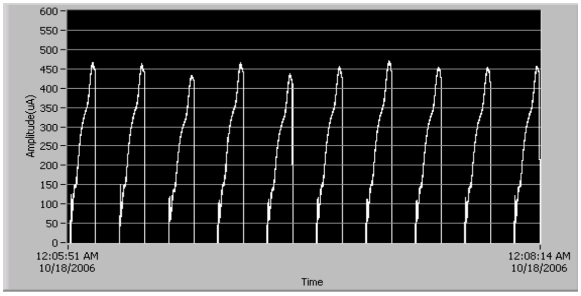

Figure 3: Beam current observed for 10 periods of acceleration of $^{12}C^{6+}$ beam from 7MeV/u to 1000MeV/u.

The beam intensity is improved dramatically to 2×10^9 pps (Fig. 4) with e-cooling in CSRm[2]. The record was renewed to 7×10^9 pps in Sep. 2007.

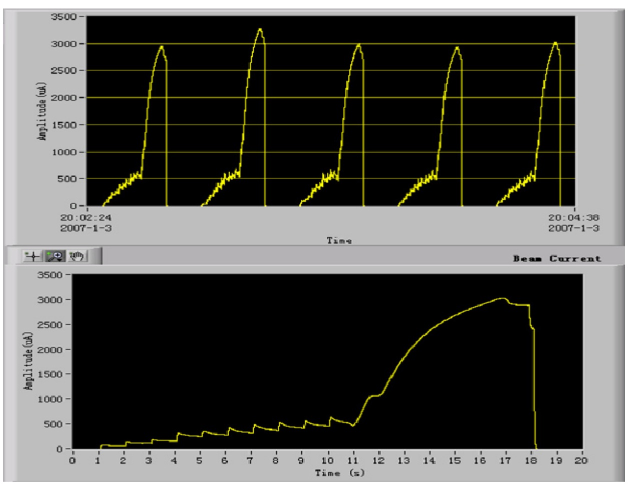

Figure 4: Accumulation and acceleration of $^{12}C^{6+}$ beam with electron cooler.

The charge stripping injection method is fit for elements lighter than argon, only. To accumulate heavy ions, multi-multi-turn injection (MMI) method is the major scheme. The MMI was first realized in Apr. 2007 with carbon beam. After that the first argon (4×10^8 pps) and xenon (1×10^8 pps) beam was accumulated and accelerated in CSRm(Fig. 5).

In Aug. 2007 the first fast extracted beam was available. After struggling with the beam line the first beam was stored in CSRe in October. The stored beam reached 7×10^9pps for $^{12}C^{6+}$ and 1.2×10^8pps for $^{36}Ar^{18+}$.

The first slow extracted beam is seen on detector in Jan. 2008. The time structure of first slow extracted beam ($^{36}Ar^{18+}$-368AMeV) is shown in Fig. 6. The spill length is about 1s. The effect of 50Hz ripple of power supply is obvious, estimated to be around 5×10^{-4}. Recent results also show similar structure.

During commissioning and about one year operation, HIRFL-CSR provided $^{12}C^{6+}$,$^{36}Ar^{18+}$,$^{129}Xe^{27+}$ and $^{78}Kr^{36+}$ beams for experiments and cancer therapy research. The maximum rigidity reached 11.3Tm.

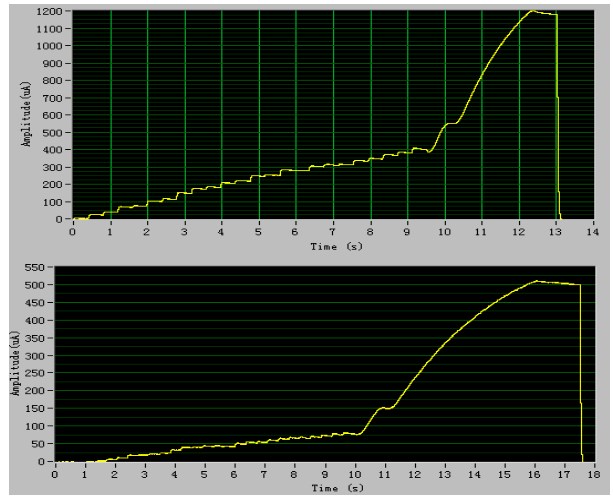

Figure 5: Accumulation and acceleration of $^{36}Ar^{18+}$(up) and $^{129}Xe^{27+}$ beam by MMI.

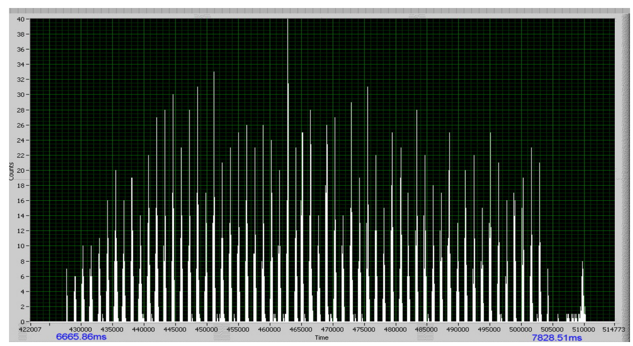

Figure 6: Time structure of first slow extracted beam from CSRm, detected by plastic scintillator.

E-COOLER COMMISSIONING

The e-coolers play essential role in CSR project. As a new generation of e-cooler developed by BINP, the coolers can provide controlled electron beam density distribution [5, 6].

The e-cooler for CSRm was in function by the end of 2006[2]. The study of e-cooler is done during the commissioning for official tests. Up to now, the grid to anode voltage ratio is set around 0.2 to get a pizza-like density distribution, which is the "best" to reach high ion current at present condition of the ring.

Although the profile and closed orbit monitoring system are not in function properly, many tests are done to test the operation condition of e-cooler in CSRm. Most of the results show the "big" crossing angle between the ion beam and electron beam.

By using of single wire scanning profile monitor, the transverse emittances are estimated to be around 35 π mm mrad after cooling($\Delta p/p\sim2\times10^{-4}$), which indicates that the crossing angle is about 1.9 mrad. According to ref.[7], the beam phase space is hollow with misalignment angle.

The relation of momentum spread to number of particles (N) is proportional to $N^{0.11\sim0.2}$(Fig.7), which is different from theory prediction. Some other results also hints to the effect of misalignment to beam cooling(Fig.8).

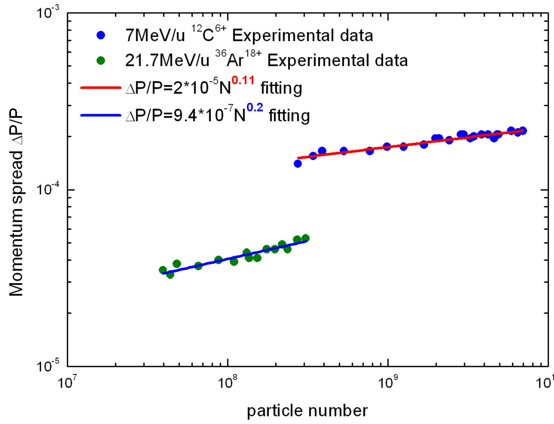

Figure 7: Measured relation of momentum spread to number of particles of cooled beam

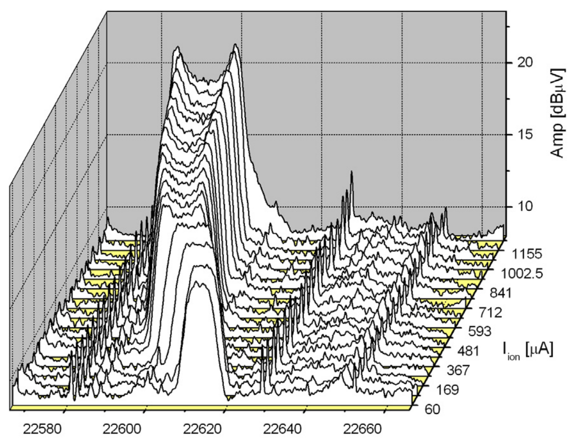

Figure 8: Spectrum of longitudinal beam signal during decay of beam intensity. The increase of frequency centre during decay is reverse from IBS theory.

The longitudinal cooling force is measured. Some results are shown in Fig. 9 and Fig. 10. The result in Figure 10 is an authentic evidence of the misalignment.

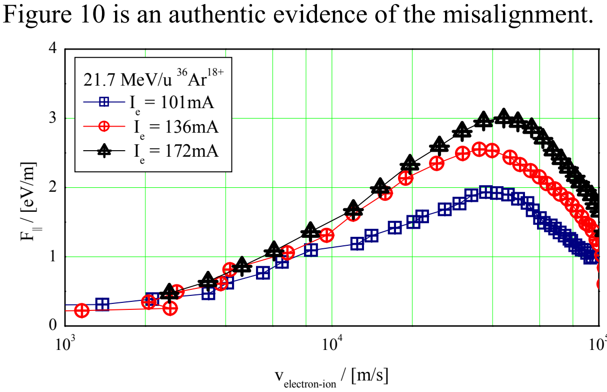

Figure 9: Measured cooling force relative to electron beam intensity.

The cooler for CSRe is ready to cool beams up to 400MeV/u.[8]

For both cooler precise and reliable closed orbit measurement and correction will be improved, the cooling force will be enhanced.

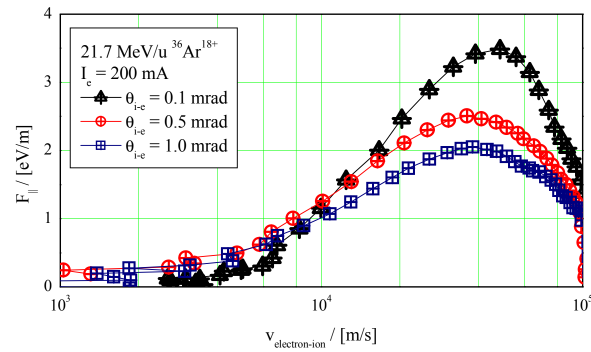

Figure 10: Measured cooling force relative to changing of crossing angle between ion beam and electron beam.

EXPERIMENTS

Mass Measurement Testing

For CSRe, to measure the mass of RIBs produced in the beam line, isochronous mode[3] is designed. The transition energy is reached to γ_{tr} =1.395. When the primary beam from CSRm matches the condition, the frequency spread from momentum spread can be neglected (see Eq. 1).

$$\frac{\delta f}{f}=\left(\frac{1}{\gamma^2}-\frac{1}{\gamma_{tr}{}^2}\right)\frac{\delta P}{P} \quad (1)$$

The measured frequency spread in CSRe for primary beam is 1×10^{-7}, which proves the isochronous mode is reached. After RIBs are produced on the target, the fragments with the same magnetic rigidity can be accepted by CSRe. Additional frequency shifts relative to the frequency of primary beam can be observed for fragments with different mass to charge ratio(see Eq. 2).

$$\frac{\delta f}{f}=-\frac{1}{\gamma_{tr}{}^2}\frac{\delta(m/q)}{m/q} \quad (2)$$

Using $^{36}Ar^{18+}$ 368MeV/u as primary beam, the fragments(A=2Z) are measured and identified in CSRe. The resolution of mass reaches 10^{-5}(Fig. 11)[4].

To measure the fragments with A=2Z+1, the energy of primary beam is increased to 400MeV/u. Similar resolution is reached.

Recently another mass measurement experiment is done using Krypton beam. The data analysis are in processing (Fig. 12).

Testing of Atomic Physics Experimental Platform

The atomic physics experimental platform is installed in both CSRm and CSRe. The hardware installed passed vacuum test and motor driven motion test. The data acquisition system passed primary test.

This platform is now ready to study the RR and DR procedure of H+ like and naked atoms. It's also possible to be used in beam profile monitor after improvements.

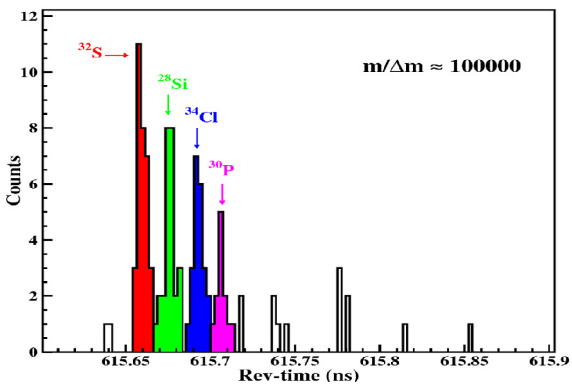

Figure 11: Mass measurement result for A=2Z.

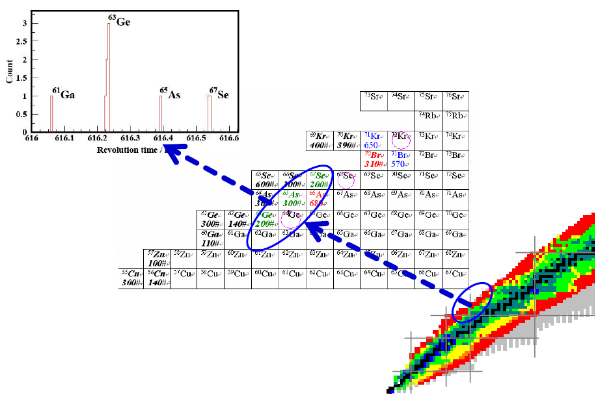

Figure 12: Mass measurement of nuclei near drip-line.

Research of Tumor Therapy with Carbon Beam

IMP puts efforts to do research of tumour therapy for several years. Before the new project is finished, low energy carbon beam(<100MeV/u) is used to do research on superficially-placed tumour therapy. Since autumn 2008, IMP extends the research to deep-seated tumour therapy by using the slow extracted carbon beam from CSRm.

There is only one horizontal terminal recently. By using of SOBP, multi-leaf collimator, large area ionization chamber and other techniques, two runs of research study were done recently. Based on the virtual accelerator concept, the energy switching between cycles is tested.

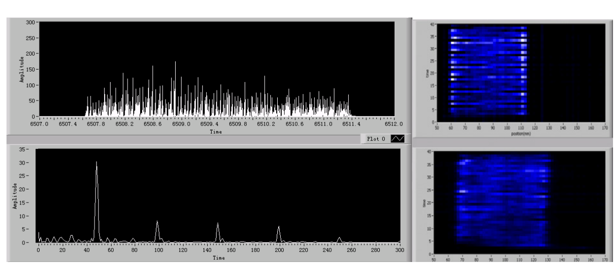

Figure 13: The time structure and X-Y scanned distribution of slow extracted beam

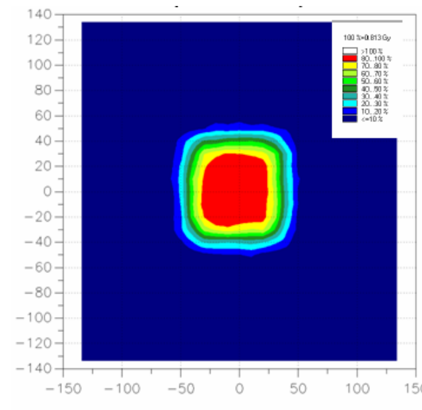

Figure 14: The measured dose distribution at therapy site

FUTURE IMPROVEMENT

Many aspects of the HIRFL-CSR need to be optimized to improve the performance of machine and convenience of commission. Some major requirements are listed in the following subsections.

Hardware Aspects

Power supply system should be improved to reduce ripple to about 10^{-6}, which is needed for stable slow extraction for external target experiments and therapy study.

The control system is being improved to reduce data flow, to realize multiple virtual machine operation and to reduce noise disturbance induced from environments. The realization of multiple virtual machine operation makes it possible to change energy from pulse to pulse. There are still some devices are controlled using temporary local computers, which should be made to join the system.

New sets of controller for power supplies and RF system are installed recently to match the requirement from cancer therapy study. The application software are revised and improved accordingly.

For diagnosis system, new devices should be introduced to observe beam intensity and position of the extracted beam. They are urgently needed to improve commission efficiency of the beam line between CSRm and CSRe. Two sets of ICT are installed recently at the beam line.

Software Aspects

The application software is developed based on intra-network for HIRFL-CSR project. For making the commission convenient and systematic, it's necessary to devote manpower and budget to develop software for automatic data generation, feedback commission and operation data collection. The structure of database based on ORACLE should be studied in detail to fulfil the demand from beam physics.

For diagnosis system, status monitoring, real time data collection and analysis software should be developed.

Experiment Aspects

The mass measurement in CSRe with cooled secondary beams is being studied.

The internal target is installed in CSRe, but detectors and data acquisition system is not finished. The external targets are being developed.

The possibility of acceleration of molecular beams in CSRm is been studied.

ACKNOWLEDGMENTS

The authors wish to thank the international advisory committee members: N. Angert, V.V. Parkhomchuk, D. Reistad, Y. Yano, T. Katayama, A. Goto, M. Steck, A.N. Skrinsky, J. Xu, S. Fang et al for their enthusiastic contributions to the project.

Thanks to BINP and JINR for the enthusiastic cooperation in design and construction of electron coolers, RF systems and internal target.

Thanks also to the official delegations for their help and advices during commission.

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