PRESENT STATUS AND FUTURE IMPROVEMENT OF HIRFL-CSR*

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Abstract

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

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 two cyclotrons complex (see Table 1)[1]. Its total budget is around 27 million euro. The main parameters are listed in Table 2.

Table 1: Major Parameters of Injector

	SFC	SSC
Energy constant	69	450
Ion source	ECR	-
Ion species	Carbon~Uranium	Carbon~Uranium
Magnet rigidity	0.6~1.2Tm	1.5~3.2Tm
Max. Energy	$^{12}C^{4+}$-7.6MeV/u $^{238}U^{29+}$-1.0MeV/u	$^{12}C^{6+}$-108MeV/u $^{238}U^{37+}$-10Mev/u
Beam intensity	$^{12}C^{4+}$-2pμA $^{238}U^{29+}$-0.1pμA	$^{12}C^{6+}$-1pμA $^{238}U^{37+}$-0.02pμA
Emittance	20π mm mrad	8π mm mrad

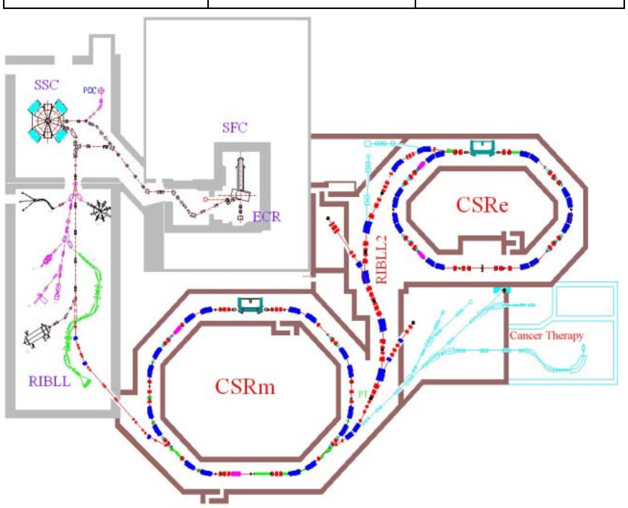

Figure 1: Layout of HIRFL-CSR.

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.

Table 2: 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^{9}ppp $^{129}Xe^{27+}$-1×10^{8}ppp	$^{12}C^{6+}$- 7×10^{9}ppp $^{129}Xe^{27+}$-1×10^{8}ppp
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

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(Figure 2).

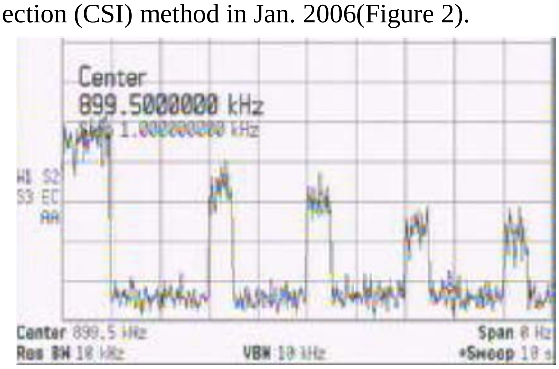

Figure 2: The first stored beam observed by periodical RF capture and release.

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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 (Figure 3). The main goals of CSRm were fully finished.

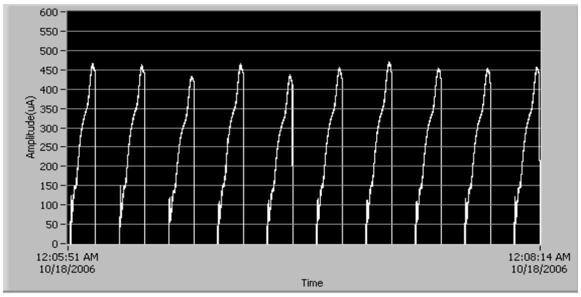

Figure 3: Beam current observed for 10 periods of acceleration of $^{12}C^{6+}$ beam from 7MeV/u to 1000MeV/u.

As a key point for accumulation of ion beam, the electron cooler system was in function by the end of 2006[2]. The new generation of electron cooler system uses tuneable electron beam intensity distribution technique. The beam intensity is improved dramatically to 2×10^9 pps (Figure 4). The record was renewed to 7×10^9 pps in Sep. 2007.

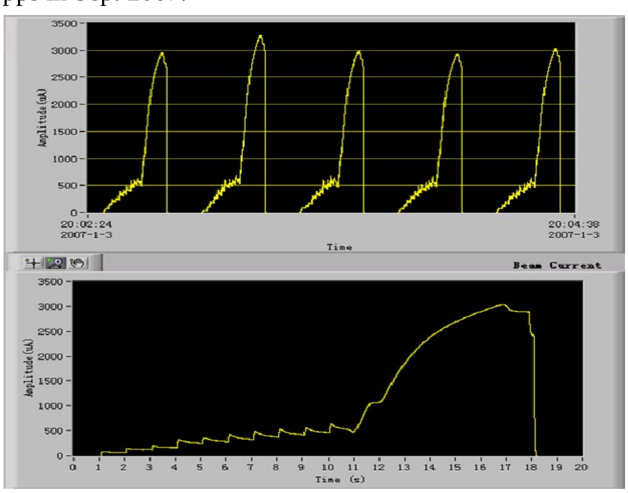

Figure 4: Accumulation and acceleration of $^{12}C^{6+}$ beam with electron cooler.

The charge stripping injection method is fit for elements light 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(Figure 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 50Hz ripple of power supply is obvious, estimated to be around 5×10^{-4}.

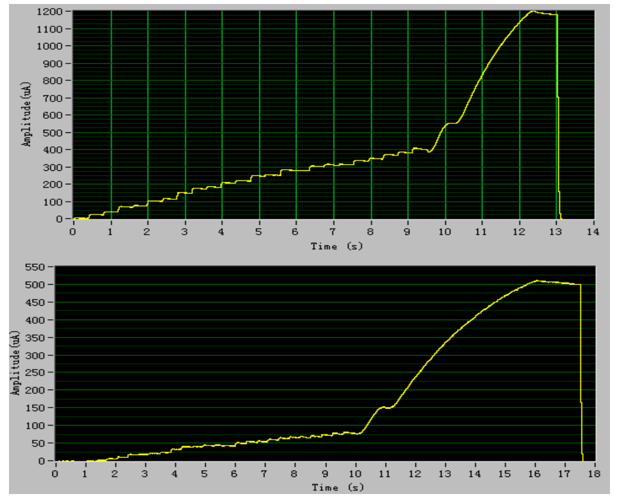

Figure 5: Accumulation and acceleration of $^{36}Ar^{18+}$(up) and $^{129}Xe^{27+}$ beam by MMI.

During the commission, the matching parameters including betatron functions, tunes(Figure 6), closed orbits and momentum spreads are measured at different ramping level. They reveal some difference from theory study and systematic error in field measurements; these should be studied carefully in the near future.

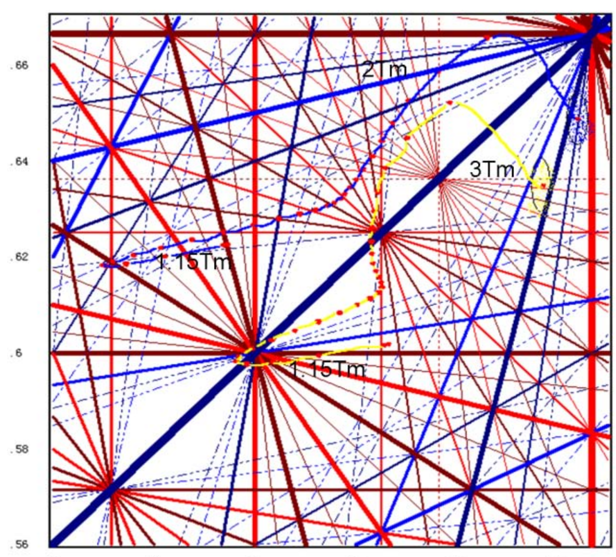

Figure 6: Trace of working points during ramping before(blue) and after correction of the field measurements

TESTING EXPERIMENTS

Mass Measurement

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).

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

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).

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

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}(Figure 7)[4].

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

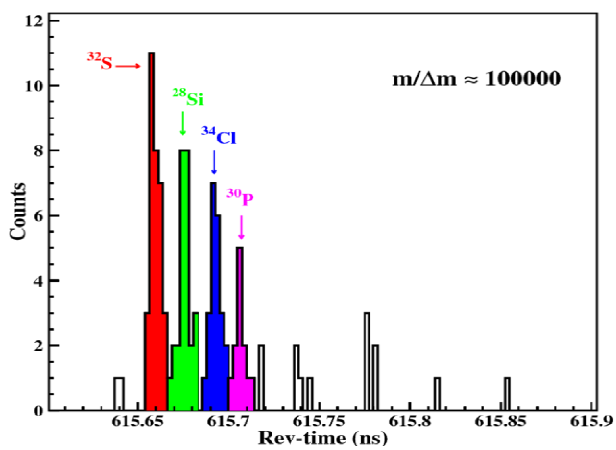

Figure 7: Mass measurement result for A=2Z.

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.

FUTURE IMPROVEMENT

Many aspects of the HIRFL-CSR need to 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.

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.

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, real time data collection and analysis software should be developed.

Experiment Aspects

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

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