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OPERATION STATUS AND UPGRADING OF CYCLOTRON IN LANZHOU

W. Q. Yang†, L. T. Sun, J. C. Yang, L. J. Mao, J. W. Xia
Institute of Modern Physics, Chinese Academy of Sciences, 730000, Lanzhou, China

Abstract

IMP operates the Heavy Ion Research Facility in Lanzhou (HIRFL), which consists of the Sector Focusing Cyclotron, the Separated Sector Cyclotron, the Cooler Storage Ring, and a number of experimental terminals. The HIRFL is mainly used in fundamental research of nuclear physics, atomic physics, irradiation material and biology, and accelerator technology. This paper mainly introduces the operation status and upgrading of HIRFL. So far, HIRFL achieves all-ion acceleration from proton to uranium. In addition, in order to improve the efficiency of HIRFL, we will build two new Linac injectors for SSC and CSR, respectively.

INTRODUCTION

HIRFL (Heavy Ion Research Facility in Lanzhou) is the major facility of national laboratory of heavy ion accelerators. It is one of the national laboratories of China, which focused on nuclear physics, atomic physics and heavy ion related application and cross-disciplinary researches. As shown in Fig. 1. HIRFL consists of the ECR (Electron Cyclotron Resonance) ion sources, the Sector Focus Cyclotron (SFC), the Separated Sector Cyclotron (SSC) and the Cooler Storage Ring (CSR). SFC is a k = 69 and SSC is a k = 450. The CSR is a double cooler-storage-ring system consisting of a main ring (CSRm), an experimental ring (CSRe), and a radioactive beam line (RIBLL2). Presently, the heavy ion beams with an energy range of 1(U) – 10(C) MeV/u could be provided by the SFC and 10(U) – 100(C) MeV/u by the SFC + SSC.

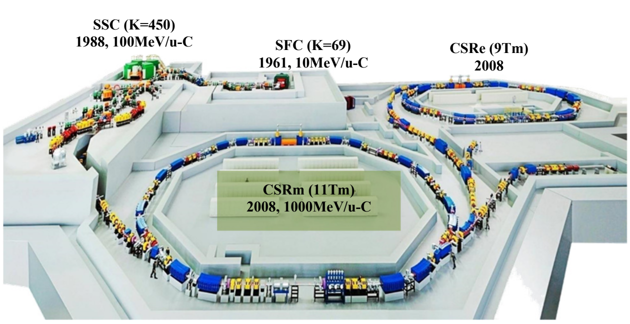

Figure 1: Present layout of the HIRFL.

OPERATION STATUS OF HIRFL

The machine combination operation modes of the HIRFL are SFC, SFC+SSC, SFC+CSRm and SFC +CSRm+CSRe. The time distribution of HIRFL operation consists preparation of machine, beam commissioning, the target beam and failure during the target beam. As shown in Fig. 2, HIRFL is operated about 7500 h during the last 5 years, the target beam time exceeds 70% of the total operating time. Average proportion of faults in each system during the five-year is shown in Fig. 3.

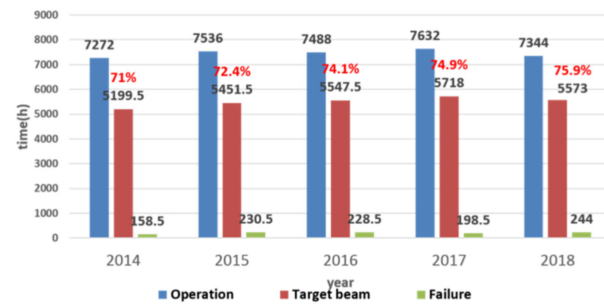

Figure 2: Operation time of the HIRFL.

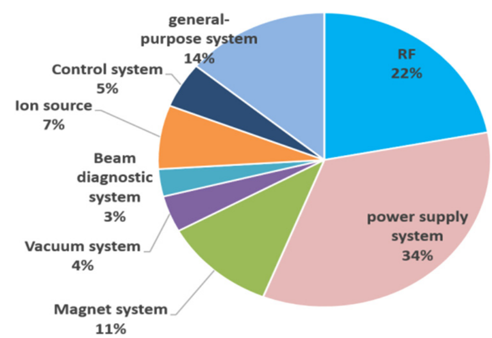

Figure 3: Average failure ratio of the accelerator subsystem during the recent five years.

The element types accelerated by HIRFL shown in Fig. 4, and 25 kinds of beams are provided annually. In the past five years, 61 kinds of new beams with different ions, different charge states and different energies have been produced. Typical ions accelerated by the HIRFL are listed in Table 1.

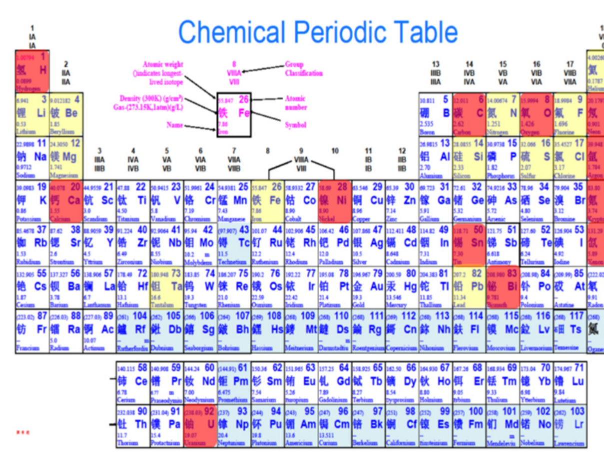

Figure 4: The element species provided by the HIRFL.

† ywq@impcas.ac.cn

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Table 1: Typical Ions Accelerated by the HIRFL

Ion beams	Energy (MeV/A)			Intensity
	SFC	SSC	CSR	(eμA)
H_2^{1+}	10		400	30
$^{7}Li^{3+}$	9			2
$^{9}Be^{3+}$	6.89			0.55
$^{12}C^{5+/6+}$	8.47	100		0.4
$^{12}C^{4+}$	7		1000	3200
$^{26}Mg^{8+/12+}$	6.17	70		0.35
$^{36}Ar^{8+}$	2.07	22		3.3
$^{36}Ar^{8+}$	2.07	22	368	650
$^{22}Ne^{7+/10+}$	6.17		70	1700
$^{40}Ca^{12+}$	5.63			3.5
$^{56}Fe^{17+}$	6.3			1.5
$^{58}Ni^{19+}$	6.3		463.4	500
$^{78}Kr^{19+/28+}$	4		487	750
$^{112}Sn^{26+/35+}$	3.7		391	1000
$^{129}Xe^{27+}$	3		235	500
$^{129}Xe^{27+}$	1.84	19.5		0.4
$^{181}Ta^{31+}$	1.19	12.5		0.03
$^{208}Pb^{27+}$	1.1			1
$^{209}Bi^{31+}$	0.91	9.5		0.05
$^{209}Bi^{36+}$	2		170	60
$^{238}U^{26+}$	0.81			0.33
$^{238}U^{32+}$	1.22		100	160

In the past five years, more than 200 heavy ion experiments have been completed in the HIRFL. Users are from universities, enterprises and research institutes in China and abroad. The ratio of planned and implementation experiments are shown as Fig. 5.

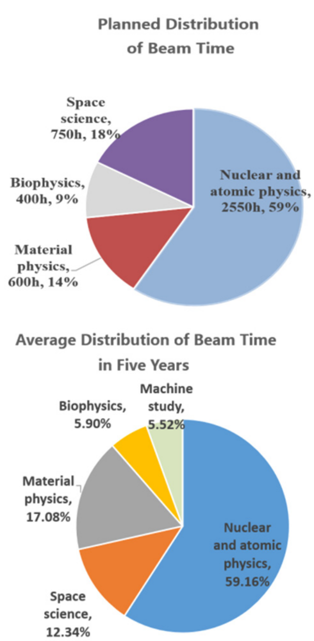

Figure 5: Planned and implementation time of experiments for the HIRFL.

SFC Operation Status

Presently, about 10 major terminals, which are TL1, TL2, RIBLL, CSR, nuclear pore membrane, Single Event Effects, New SEE, Super Heavy Elements and Micro-Beam, can be operated using the SFC. It provides users with about 15 kinds of beams and about 2000 hours of experimental time each year. As an injector of CSR, SFC provides matching beams to CSR according to experimental requirements. The operation time distribution of the SFC from 2014 to 2018 is shown in Fig. 6. SFC beam injection and extraction efficiency is shown in Fig. 7.

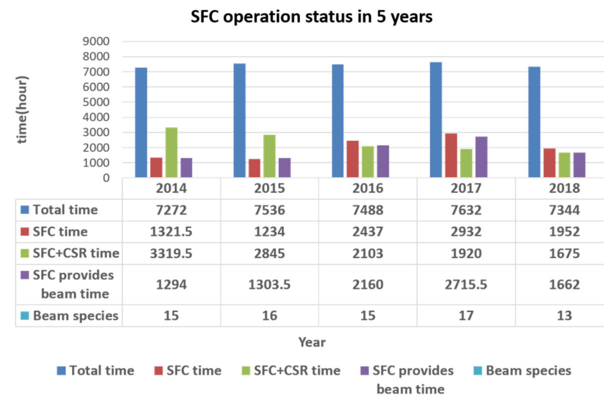

Figure 6: Operation time distribution of the SFC.

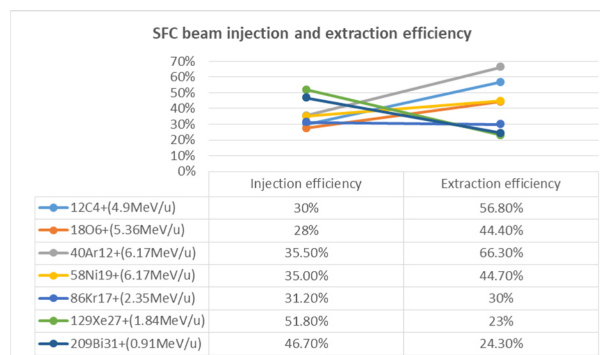

Figure 7: SFC beam injection and extraction efficiency.

SFC+SSC Operation Status

Currently, there are about 8 major terminals could be operated by using the SFC + SSC. The operation time distribution of the SFC + SSC is shown in Fig. 8. SSC beam injection and extraction efficiency is shown in Fig. 9. With the increasing demand for user experiments, the beam time of the experimental terminals around the SSC was still increased during the last 5 years.

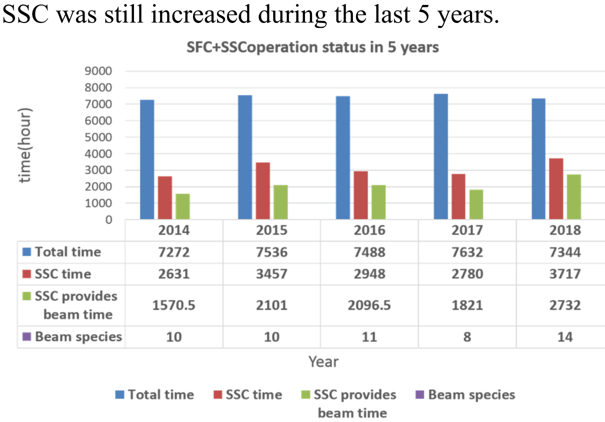

Figure 8: Operation time distribution of the SFC+SSC.

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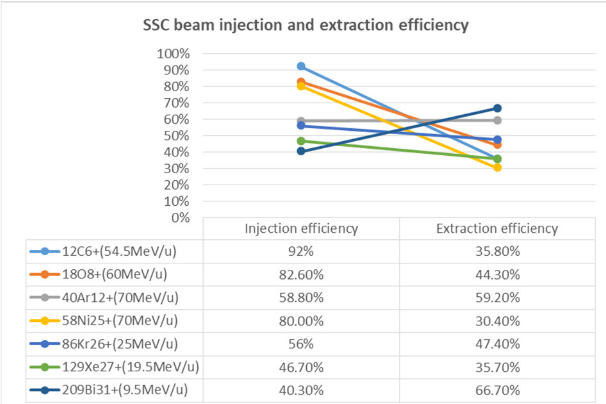

	Injection efficiency	Extraction efficiency
12C6+(54.5MeV/u)	92%	35.80%
18O8+(60MeV/u)	82.60%	44.30%
40Ar12+(70MeV/u)	58.80%	59.20%
58Ni25+(70MeV/u)	80.00%	30.40%
86Kr26+(25MeV/u)	56%	47.40%
129Xe27+(19.5MeV/u)	46.70%	35.70%
209Bi31+(9.5MeV/u)	40.30%	66.70%

Figure 9: SSC beam injection and extraction efficiency.

Experiments and Studies

Experiments in the SFC and the SFC+SSC are focused on nuclear physics, atomic physics, biology, and ion irradiation physics. While satisfying the user's experimental needs, we should strengthen the study on the improvement and performance improvement of HIRFL. Examples of experiments and studies are:

- The SFC provides Ar, Ca, S, Mg, Ni and other beams for new nuclide synthesis experiments.
- The Sn^{35+} beam, provide by the SFC, is accumulated in CSRm with intensity of 1 emA, and accelerated to high energy of 401 MeV/u. Then, it is delivered to the CSRe to carry out nuclear mass measurement experiment.
- The SFC used as the injector to provide $^{12}C^{4+}$ - 10 eμA (7 MeV/u) beam for CSRm. Impulse electron beam cooling experiment is realized in the CSRm. The CSRe achieves stochastic cooling of beams.
- The SFC+SSC provides He, C, O, Ne, Si, S, Ar, Ni and other beams for RIBLL1. Many physical experiments have been completed in RIBLL1.
- The SFC+SSC used as injector to provide $^{36}Ar^{8+}$ 3.5 eμA (22 MeV/u) beam for CSRm. It accelerates to 368 MeV/u, beam intensity is 680 eμA.
- The SFC+SSC provides Kr, Bi, Ta, Xe and other beams for TR5 experiment terminal. The single event effect of many electronic components has been studied and tested.

HIRFL IMPROVEMENT AND UPGRADE

HIRFL was built-up in 3 periods, lasting about half century. We have made some equipment improvements and upgrade. Improvement of SFC vacuum chamber, vacuum pressure increased from 3×10^{-7} mbar to 5×10^{-8} mbar. The beam transmission line from SFC to SSC is equipped with a buncher to compress the longitudinal phase space of heavy ion beam, and the beam intensity of SSC is increased by two times. Replacement of SSC injection and extraction magnetic aging coils reduces the faults. The control system was changed to EPCIS. Power supply system gradually was changed to digital power supply. High frequency power source of SSC changed from Electron Tube Amplifier to Solid State Amplifier. The low-level system should be digitized, etc.

In the current accelerator, the SFC plays an important role in HIRFL operation. However, when the SFC provides ion beams to experiment terminals alone, the SSC and the CSR could not carry out other experiments. This cannot provide full-time operation for SSC and CSR simultaneously. Therefore, to enhance the performance of the HIRFL, two heavy-ion Linacs, called the SSC-LINAC and the CSR-LINAC, are proposed as a new injector of the SSC and the CSR, as shown in Fig. 10. Due to the limit of budget, SSC-Linac was built in first.

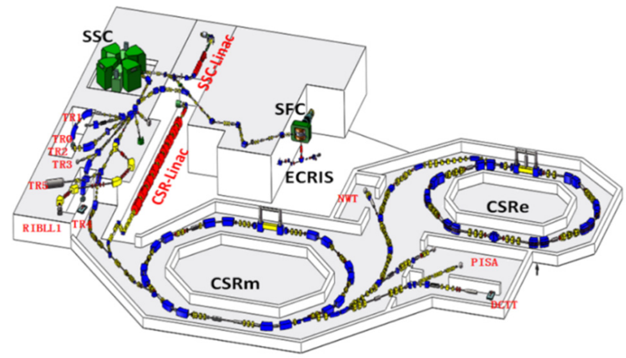

Figure 10: Layout of the new injector SSC-LINAC and CSR-LINAC.

Overview of SSC-LINAC

Focusing on the high intensity of heavy ion beam, the SSC-LINAC consists of a superconducting ECR ion source, LEBT, RFQ, MEBT, IH-DTL and HEBT, as shown in Fig. 11. The main parameters of the ECR ion source, RFQ and IH-DTL of the SSC-LINAC are listed in Table 2. As a high intensity heavy ion injector of the SSC, the SSC-LINAC could increase the beam intensity by 1 ~ 2 order.

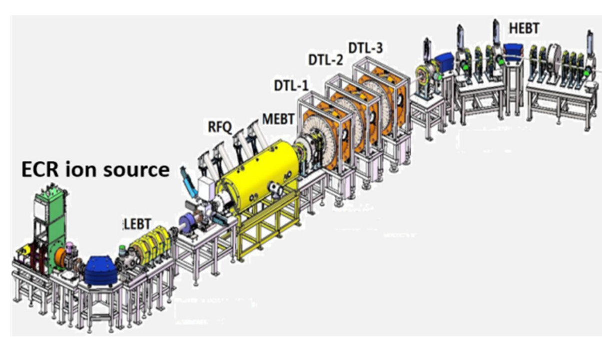

Figure 11: Layout of the SSC-LINAC.

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Table 2: The Main Parameters of the SSC-LINAC

Parameters	**Values**
Design ion	$^{238}U^{34+}$
ECR ion source	
Extraction voltage	25 kV
Max. axial injection field	2.3 T
Microwave frequency	18 GHz
4-rod RFQ	
Frequency	53.667 MHz
Input energy	3.728 keV/u
Output energy	143 keV/u
Inter-electrode voltage	70 kV
RF power	35 kW
Max. current	0.5 emA
IH-DTL	
Frequency	53.667 MHz
Input energy	0.143 MeV/u
Output energy	1.025 MeV/u

Overview of CSR-LINAC

The CSR-LINAC consists of a superconducting ECR ion source, a normal-conducting IH-RFQ, and six Interdigital H-type Drift Tube linac (IH-DTL) cavities. The main parameters of the CSR-Linac are listed in Table 3. Compared with the SSC, the CSR-LINAC could increase the beam intensity by 1 ~ 2 order, the beam current could be reached 1 ~ 10 pμA for various ions, and can accelerate all kinds of heavy ions to 7.272 MeV/u.

Table 3: The Main Parameters of the CSR-LINAC

Parameters	**Values**
Q/A	1/3-1/7
Frequency	108.48/216.96 MHz
Beam current	3 emA
Duration	3 ms
Repetition	10 Hz
RFQ input/out energy	4/300 keV/u
DTL input/out energy	0.3/7.272 keV/u
Transmission (design)	90%

CONCLUSION

The operation performance of the HIRFL has been improved significantly in the recent five years, and many important experiments are studied. To meet the requirement of nuclear physics, atomic physics and other related application, the two new injectors of the SSC-Linac and CSR-Linac will be built. The SSC-Linac is to commission in 2020 and the CSR-Linac is to be finished in the next few years. As a result, the whole performance of the HIRFL-CSR complex will be further enhanced.