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SESRI 300 MeV PROTON AND HEAVY ION ACCELERATOR

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Abstract

The SESRI (Space Environment Simulation and Research Infrastructure) is the new national research infrastructure under construction at Harbin Institute of Technology (HIT) in China. This infrastructure is specifically built to simulate the space environment on the ground. The SESRI has kinds of accelerators, and the 300 MeV proton and heavy ion accelerator is a major radiation source, which will supply 100-300 MeV protons and 7-85 MeV/u heavy ions for studying the interaction of high energy space particle radiation with material, device, module and biological entity. To meet above requirements, the facility adopts the combination of room temperature ECR (Electron Cyclotron Resonance) ion source, linac injector and synchrotron. The ion source is required to provide all stable nuclide beams from H_2^+ to Bi. The linac injector supplies 1 MeV/u heavy ion beams and 5 MeV proton beam by using RFQ (Radio Frequency Quadrupole) and IH-DTL (Interdigital H-mode type Drift Tube Linac) linac structures. The synchrotron accelerates heavy ions up to 85 MeV/u and proton beam 300 MeV. And the 3rd integer resonance and RF-KO (RF-Knock-Out) method are adopted for slow extraction. The status of 300 MeV proton and heavy ion accelerator design and construction works are briefly described below.

INTRODUCTION

The new infrastructure SESRI aims at the simulation of space environment on the ground. In order to simulate accurately, there are kinds of accelerators, including electron accelerator, dust accelerator, tandem accelerator, proton and heavy ion accelerator to supply different kinds and different energy particles. The 300 MeV proton and heavy ion accelerator is a major radiation source, which will supply 100-300 MeV protons and 7-85 MeV/u heavy ions for studying the interaction of high energy space particle radiation with material, device, module and biological entity.

To meet above requirements, the facility adopts the combination of room temperature ion source, linac injector and synchrotron. The ion source is required to provide all stable nuclide beams from H_2^+ to Bi, by using the ECR ion source [1]. The linac injector supplies 1 MeV/u heavy ion beams and 5MeV proton beam by using RFQ and IH-DTL linac structures [2]. The synchrotron accelerates heavy ions up to 85 MeV/u and proton beam 300 MeV. And the 3rd integer resonance and RF-KO method are adopted for slow extraction [3].

There are two terminals, one mainly for studying the interaction of the high space particle radiation with device, another one for studying the interaction of the high space particle radiation with life, by using the extracted heavy ion and proton beams. There are also a spare space for upgrades to study of the high energy ion micro-beam [4]. Main parameters of 300 MeV proton and heavy ion accelerator at the terminals are shown in Table 1. General scheme of the facility is presented in Fig. 1.

Table 1: Main Parameters of the Facility

Ions	Energy(MeV)	Intensity(ppp)
p	300	1×10^9
$^{4}He^{2+}$	80	1×10^7
$^{84}Kr^{18+}$	15	1×10^7
$^{209}Bi^{32+}$	7	1×10^6

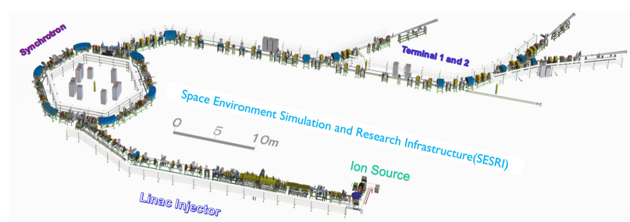

Figure 1: General scheme of the facility.

The details of 300 MeV proton and heavy ion accelerator design and construction works are briefly presented below.

LINAC INJECTOR

The linac injector is used to supply 1 MeV/u heavy ion beams and 5 MeV proton beam, which will be injected to synchrotron. In order to accumulate the design number of ions in synchrotron, the intensity of output $^{209}Bi^{32+}$ beam of the linac should be greater than 25 μA, proton beam 200 μA. The linac injector is composed of ECR ion source, Low Energy Beam Transport line (LEBT), four-rode type RFQ, Medium Energy Beam Transport line (MEBT), IH-DTL, High Energy Beam Transport line (HEBT) and the corresponding RF power source system. The layout of linac injector is presented in next page Fig. 2.

ECR Ion Source and LEBT

In order to provide all stable nuclide beams from H_2^+ to Bi, One 2 kW 18 GHz microwave-driven ECR ion source is being manufactured [5]. It's extraction voltage is 30 kV. There are some beam measurement instruments, including Faraday cups, emittance measurements and fluorescent screens. There is also a spare space to upgrade another ion source for saving the time of changing ions and improving the efficiency

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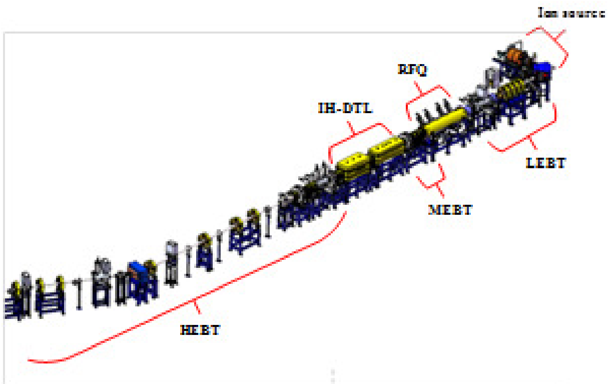

Figure 2: Layout of Linac injector.

of this facility. The LEBT is used to match the RFQ. Main parameters of the ion source are shown in the Table 2 and the layout of ion source is shown in the Fig. 3. The whole ion source system will be assembled and commissioned in the next half year.

Table 2: The Main Parameters of Ion Source

Ions	Current(eμA)	Emittance(π mm·mrad)
H_2^+	$\geqslant$ 250	$\leqslant$0.8 (Normalized, 90%)
$^{4}He^{2+}$	$\geqslant$ 50	$\leqslant$0.6 (Normalized, 90%)
$^{84}Kr^{18+}$	$\geqslant$ 84	$\leqslant$0.6 (Normalized, 90%)
$^{209}Bi^{32+}$	$\geqslant$ 50	$\leqslant$0.6 (Normalized, 90%)

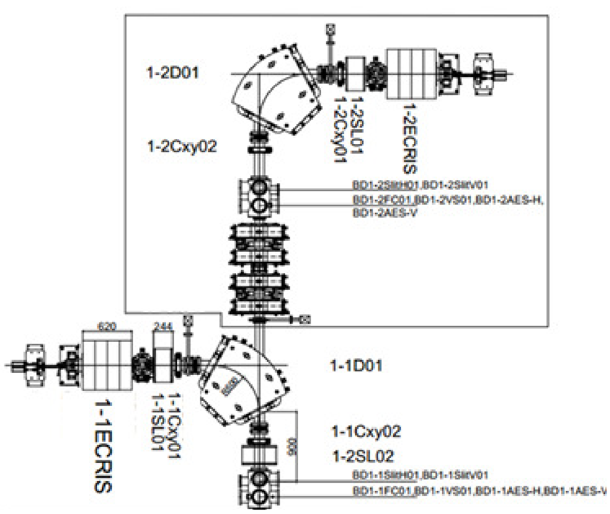

Figure 3: Layout of ion source.

RFQ

The four-rod cavity is used mostly in the lower-frequency range, below about 200 MHz, and is the most commonly used RFQ structure for very low-velocity heavy ions [6]. So one 2.5-meter-long four-rod RFQ will accelerate all kinds of ions from 4 keV/u to 300 keV/u. The electron tube power amplifier with peak RF power of 200 kW is used to accelerate ions from the smallest charge to mass ratio ion $^{209}Bi^{32+}$ to the largest H_2^+. In order to improve the inter-rode voltage and the stability of the RFQ, H_2^+ is accelerated instead of proton. The main parameters of RFQ are shown in the Table 3.

Table 3: The Main Parameters of RFQ

Parameter	Value	Unit
Input Energy	4	keV/u
Output Energy	300	keV/u
Charge to Mass Ratio	1/6.5~1/2	q/A
Frequency	108.48	MHz
Beam pulse width	1	ms
Repetition Frequency	1	Hz
Duty factor	1%	
Transmission efficiency	>90%	
Emittance of output($^{209}Bi^{32+}$)	0.5	π mm·mrad
Emittance of output(H_2^+)	0.75	π mm·mrad

IH-DTL

The linac injector accelerates heavy ion beams to 1 MeV/u, proton beam to 5 MeV/u. So there are two IH-DTL cavities after the RFQ. The first cavity accelerates all ions to 1 MeV/u, all heavy ions(exclusion of H_2^+) will drift at the second IH-DTL cavity without acceleration, and then will be injected to synchrotron. But the injection energy of proton is 5 MeV. So H_2^+ beam will be stripped into proton beam by a carbon foil, which is located in between the two IH-DTL cavities. Proton beam will continue to be accelerated to 5 MeV by the second IH-DTL cavity and then will be injected to synchrotron. The main parameters of IH-DTL are shown in the Table 4.

Table 4: The Main Parameters of IH-DTL

Parameter	Value & Unit
Input Energy	0.3 MeV/u
Output Energy	1(heavy ion) 5(proton)MeV/u
Charge to Mass Ratio	1/6.5~1 q/A
Frequency	108.48 MHz
Beam pulse width	1 ms
Repetition Frequency	1 Hz
Duty factor	1%
Emittance of output	0.6($^{209}Bi^{32+}$) 1.2(proton)
Energy spread(%)	<±0.3
Transmission efficiency	>90%

SYNCHROTRON

The circumference of synchrotron is 43.8864 m. The 6-fold symmetric lattice design chooses 6 dipoles FODO structure, and has 6 super-periods. The maximum magnetic rigid-

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Table 5: Main Parameters of the Synchrotron

Main Parameters	Circumference(m)	43.8864
	Magnetic rigidity(T·m)	0.28~2.8
	Accelerating time(s)	0.53~0.81
	Period(s)	3~10
	Repetition frequency(Hz)	0.1~0.3
Input beam	Energy(MeV/u)	1 ($^{4}He^{2+}$ ~ $^{209}Bi^{32+}$), 5(p)
	Momentum dispersion(ΔP/P)	$\leqslant\pm 2\times 10^{-3}$
	Emittance(πmm·mrad)	$\leqslant$ 13 (6σ)
Beam in synchrotron	Ion:p~$^{209}Bi^{32+}$	
	Energy(MeV/u)	300(p), 80($^{4}He^{2+}$), 15($^{84}Kr^{18+}$), 7($^{209}Bi^{32+}$)
	Beam intensity(ppp):$^{4}He^{2+}$ ~ $^{209}Bi^{32+}$	1.1×10^{6} ~ 1.1×10^{7}(p:1.1×10^{9})
Beam in terminal	Beam instensity(p/spill)	1×10^{6} ~ 1×10^{9}
	Momentum dispersion (ΔP/P)	2×10^{-3}
	Emittance(πmm·mrad)	$\leqslant$10
Lattice parameters	Super-period	6
	Tune(Q_x/Q_y)	1.72/1.62(Injection), 1.68/1.62(Extraction)
	Acceptance A_h/A_v(π mm·mrad)	200/30(ΔP/P=±0.5%)

ity is 2.8 T·m, which can accelerate all kinds of ions, from p to Bi. The Table 5 above presents main parameters of the synchrotron. Figure 4 shows the layout of synchrotron.

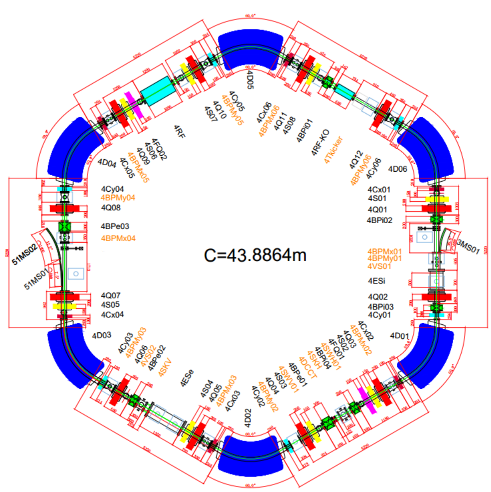

Figure 4: Layout of main ring elements.

The 3rd integer resonance and RF-KO method are adopted for slow extraction [7]. The extraction time can be varied from 3 s to 10 s. The extraction elements consist of 4 sextupoles, 2 extraction magnet septum, an electrostatic wired septum and a RF-KO. The RF kicker signal is turned on to excite the 3rd integer resonate of circulating beam. A complicated feedback system will be used to keep extracted beam current stable.

CONCLUSIONS

A 300 MeV proton and heavy ion accelerator has been designed and is being manufactured. All accelerator subsystems including cavities, main magnets, injection extraction elements and the power supplies have completed their final design. The facility will be assembled at the spring of 2020, and the beam commissioning is expected at the end of 2020.

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