SESRI 300MeV 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 300MeV proton and heavy ion accelerator is a major radiation source, which will supply 100-300MeV protons and 7-85MeV/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 $^2$H to Bi. The linac injector supplies 1MeV/u heavy ion beams and 5MeV 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 85MeV/u and proton beam 300MeV. And the 3rd integer resonance and RF-KO (RF-Knock-Out) method are adopted for slow extraction. The status of 300MeV proton and heavy ion accelerator design and construction works are briefly described below.

1. 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 300MeV proton and heavy ion accelerator is a major radiation source, which will supply 100-300MeV protons and 7-85MeV/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 $^2$H to Bi, by using the ECR ion source[1]. The linac injector supplies 1MeV/u heavy ion beams and 5MeV proton beam by using RFQ and IH-DTL linac structures[2]. The synchrotron accelerates heavy ions up to 85MeV/u and proton beam 300MeV. 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 300MeV proton
and heavy ion accelerator at the terminals are shown in Table 1. General scheme of the facility is presented in Figure 1.

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

**Table 1.** Main parameters of the Facility

![Figure 1. General scheme of the facility.](image)

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

## 2. Linac Injector

The linac injector is used to supply 1MeV/u heavy ion beams and 5MeV proton beam, which will be injected to synchrotron. In order to accumulate the design number of ions in synchrotron, the intensity of output $^{209}\text{Bi}^{32+}$ beam of the linac should be greater than 25eA, proton beam 200eA. 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 Figure 2.

### 2.1. ECR Ion Source and LEBT

In order to provide all stable nuclide beams from $\text{H}_2^+$ to Bi, one 2kW 18 GHz microwave-driven ECR ion source is being manufactured[5]. Its extraction voltage is 30kV. 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 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 Figure 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(μA) | Emittance(π mm·mrad) |
|-----------------|-------------|----------------------|
| H$_2^+$         | ≥ 250       | ≤0.8 (Normalized, 90%) |
| $^4$He$^{2+}$   | ≥ 50        | ≤0.6 (Normalized, 90%) |
| $^{84}$Kr$^{18+}$ | ≥ 84       | ≤0.6 (Normalized, 90%) |
| $^{209}$Bi$^{32+}$ | ≥ 50       | ≤0.6 (Normalized, 90%) |

2.2. 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 4keV/u to 300keV/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.

2.3. IH-DTL

The linac injector accelerates heavy ion beams to 1MeV/u, proton beam to 5MeV/u. So there are two IH-DTL cavities after the RFQ. The first cavity accelerates all ions to 1MeV/u, all heavy ions(exclusion of H$_2^+$) will drift at the second IH-DTL cavity without acceleration, and
Figure 3. Layout of Ion source.

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 |

then will be injected to synchrotron. But the injection energy of proton is 5MeV. 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 5MeV 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.

3. Synchrotron

The circumference of synchrotron is 43.8864m. The 6-fold symmetric lattice design chooses 6 dipoles FODO structure, and has 6 super-periods. The maximum magnetic rigidity is 2.8T · m,
### Table 4. The main parameters of IH-DTL

| Parameter                     | Value & Unit |
|-------------------------------|-------------|
| Input Energy                  | 0.3 MeV/u   |
| Output Energy                 | 1(heavy ion) |
| Output Energy (proton)        | 5 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 (209Bi^{32+}) |
| Energy spread (%)             | <±0.3       |
| Transmission efficiency       | >90%        |

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.

### Table 5. Main parameters of the synchrotron

| Main Parameters | Value (MeV/u) |
|-----------------|---------------|
| Input beam      | 1^{4}He^{2+} ~ 209Bi^{32+} |
|                 | 5(p)          |
|                 | 0.53~0.81     |
| Period(s)       | 3~10          |
| Repetition frequency(Hz) | 0.1~0.3 |
| Circumference(m) | 43.88 |
| Magnetic rigidity(T · m) | 0.28~2.8 |

| Beam in synchrotron | Ion: p ~ 209Bi^{32+} |
|---------------------|----------------------|
| Energy(MeV/u)       | 300(p), 80^{4}He^{2+}, 15^{84}Kr^{18+}, 7^{209}Bi^{32+} |
| Beam intensity(ppp):^{4}He^{2+} ~ 209Bi^{32+} | 1.1×10^{6} ~ 1.1×10^{7} (p: 1.1×10^{6}) |

| Beam in terminal    | Beam intensity(p/spill) |
|---------------------|-------------------------|
|                     | 1×10^{6} ~ 1×10^{9} |
|                     | 2×10^{-3}              |

| Lattice parameters  | Value (π mm · mrad) |
|---------------------|---------------------|
| Super-period        | 6                   |
| Tune(Q_x/Q_y)       | 1.72/1.62(Injection), |
|                     | 1.68/1.62(Extraction) |
| Acceptance A_k/A_v  | 200/30(ΔP/P=±0.5%)   |

The 3rd integer resonance and RF-KO method are adopted for slow extraction[7]. The extraction time can be varied from 3s to 10s. The extraction elements consist of 4 sextupoles, 2
Figure 4. Layout of main ring elements.

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.

4. Conclusions
A 300MeV proton and heavy ion accelerator has been designed. All accelerator sub-systems have completed their final design and are being manufactured now. 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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