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DEVELOPMENT OF CW HEAVY ION LINAC AT IMP*

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Abstract

A new heavy ion linac as the injector for the Separated Sector Cyclotron (SSC), named SSC-Linac [1], is being under constructed at the national laboratory Heavy Ion Research Facility in Lanzhou (HIRFL). The SSC-Linac mainly consists of a 4-rod RFQ and three IH-DTL cavities which can accelerate ion of $A/q \leq 7$ from 3.73 keV/u to 1.025 MeV/u. Both of them operating at 53.667MHz had been developed. In the commissioning, ions were successfully accelerated to 0.295 MeV/u by IH-DTL1. The beam commissioning of the IH-DTL2 which can accelerate the ion to 0.586 MeV/u will come soon. In this paper, the recent R&D progress of the SSC-Linac including the development of key components and the beam commissioning results are presented.

INTRODUCTION

As the main part of the upgrade project of Heavy Ion Research Facility in Lanzhou (HIRFL), a new heavy-ion linac which operated at Continuous Wave (CW) mode was designed and constructed as the injector for the separated-sector cyclotron (SSC).The design parameters of SSC-Linac were listed in Table 1.There are two stages for the energy upgrade project. In the first stage, the ion particles will be accelerated to 0.586 MeV/u using two IH-DTL cavities. And then they will be further injected and accelerated to 6 MeV/u by the SSC facility. In the second stage, the particle will be accelerated to 1.025 MeV/u by adding the DTL3.

Table 1: Design Parameters of SSC-Linac

Parameters	**Values**
Design ion	$^{238}U^{34+}$
ECR ion source	
Extraction voltage	25 kV
Max. axial injection field	2.3 T
Frequency	18 GHz
RFQ Type	4-rod
Input /Output energy	3.73/143 keV /u
Inter-electrode voltage	70 kV
Max.current	200.0 eμA
IH-DTLs	
Input /Output energy	0.143/1.025 MeV/u

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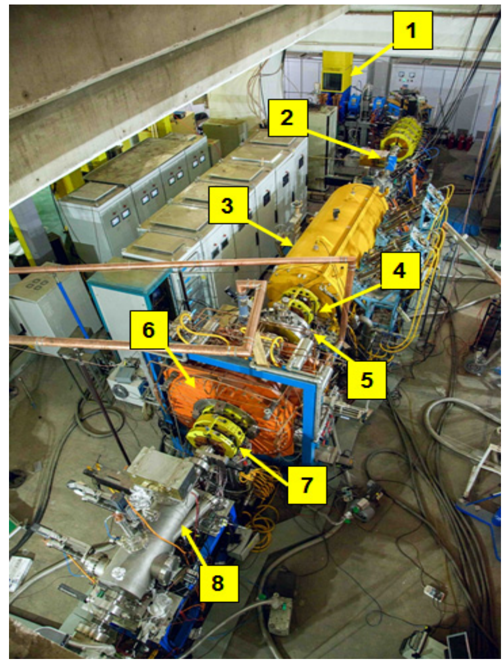

Figure 1: General view of the SSC-Linac. 1-ECR ion source; 2-LEBT section; 3-RFQ; 4-MEBT section; 5- Rebuncher cavity; 6- IH-DTL1; 7-Foucsing triplets; 8-Beam diagnostics system.

Finally, the particles will be accelerated to 10.7 MeV/u also by the SSC facility. Figure 1 shows the layout of the front end section of the SSC-Linac.

ION SOURCE&LEBT

The high charge state room temperature ECR ion source had been successfully constructed. This source magnet coils were cooled through evaporative cooling technology. The maximum mirror field was 2.3 T (with iron plug) and the effective plasma chamber volume was Ø76 mm×260 mm. The commissioning test of ECR ion source had been performed continually from 2014. Various specie ion beams had been successfully delivered for the linac commissioning.

With 0.1 kW RF injection power and 11.92 kV extraction voltage, 200 eμA of $^{16}O^{5+}$ was produced. The transverse emittances were measured by the emittance scanners located at the downstream of the analysing magnet. As shown in the Fig. 2, the measured normalized rms emittances at 200 eμA beam current for $^{16}O^{5+}$ were 0.22π mm.mrad and 0.15π mm.mrad in horizontal and vertical plane, respectively.

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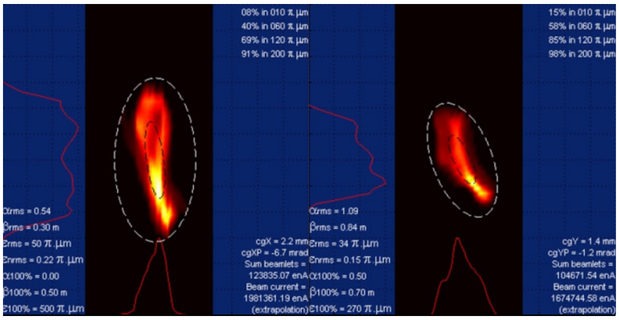

Figure 2: Measured transverse emittances after analysing dipole magnet.

CW 4-ROD RFQ

The CW 4-rod RFQ had been developed under the successful cooperation between Peking University and IMP. Low level RF measurement of RFQ was carried out. The frequency of the cavity without tuning was 53.607 MHz, which was not far from the operation frequency of 53.667 MHz and can be easily tuned by the tuners. On the critical coupling state, the Q_0 value of the cavity was 6440, which was 97% of the design value. The electric field distribution along the bam line was measured adopting the conventional perturbation method. The error of the results had been analysed in details [2].

The high power conditioning took a few days from pulse mode to CW. After about 30 hours conditioning, 35 kW with 30% duty factor was fed into the cavity. After then, 35 kW in CW mode had been successfully carried out almost no feedback. The temperature of the cooling water increased from 15.1 °C to 20.4 °C while the RF power increased from 0 to 32 kW. And the maximum temperature occurred at the RF power coupler.

The first beam commissioning ($^{16}O^{5+}$, 149.5 eμA) was successfully performed and ion was accelerated to 141.9 keV/u measured by the TOF method. After carefully RF conditioning, $^{40}Ar^{8+}$ ion beam was successfully accelerated, the measured energy and current were 142.8 keV/u and 198 eμA, respectively. The transmission efficiency was 94%. The more detail had been reported in [3].

MEBT RE-BUNCHER

In the MEBT section of SSC-Linac, a spiral re-buncher with four gaps structure had been developed to implement the longitudinal matching between the RFQ and the DTL operating, as shown in Fig. 3. The design β and the shunt impedance were 0.0175 and 5812 kΩ, respectively. Due to the limited space, the cavity was designed as Ø600 mm and 197 mm in length. The designed total power was 1.8 kW for the design ion and the corresponding gap voltage amplitude was 35 kV. The measured Q_0 was 3628 which was the 86.5% of the design value.

A fixed tuner and a movable tuner were employed for frequency compensated during the operation. It meant that the cavity was tuned to the working frequency by fixed tuner. After then the movable tuner was devoted into the normal operation.

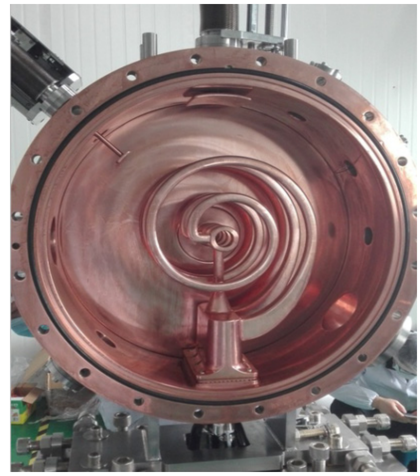

Figure 3: Spiral re-buncher cavity.

The RF power was generated and feed into the bunch cavity by a commercial solid state RF power amplifier system including the LLRF system. The conditioning process was smooth without any interruption. It took about 40 hours from low RF power in the pulse mode shift to the full RF power in CW mode.

Figure 4 shows the bunch efficiency when the buncher turns on comparing it turns off. It can be found that the bunch efficiency is very efficient. The measured energy spread of bunched beam was $|\Delta W/W| \leq \pm 2\%$.

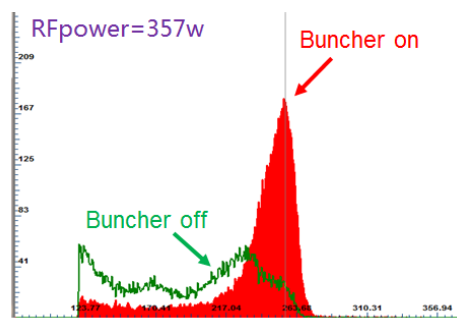

Figure 4: Measured bunch efficiency.

IH-DTLS

In the original design, the particle will be accelerated to 1.025 MeV/u by four IH-DTL cavities. However in the optimized design, the high energy section of the SSC-Linac adopted three IH-DTL cavities obtaining the same energy as origin design value. The first cavity DTL1(295 keV/u) had been installed and beam commissioning was successfully performed.

The second DTL had been finished in manufacture and is under the preparation of the RF measurement as shown in Fig. 5. The cavity body was made of steel ion with copper plated on the inner surface. The T-type stems and drift tubes were made of OFC. Water cooling channels were designed in the T-type stems which were housed in the tank wall.

The preliminary low level RF measurement for the DTL2 had been carried out using a network analyser in this May. The frequency response as a function of tuner

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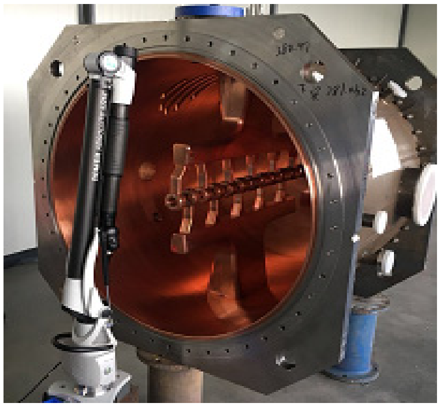

Figure 5: The second IH-DTL cavity.

position is plotted in Fig. 6. As shown in this figure, the adjustable range of the frequency change was up to 1.44MHz using the fixed tuner with Ø230 mm. As also indicated in the Fig. 6, the working frequency of 53.667 MHz can be obtained at the fixed tuner position of 82 mm from beam axis.

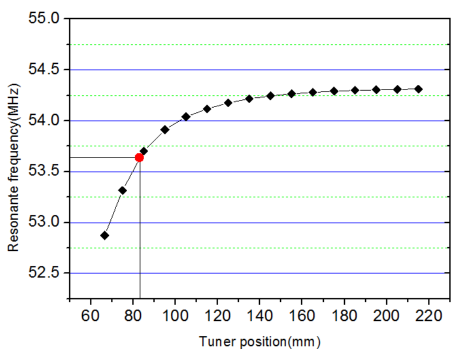

Figure 6: Frequency range of the DTL2 as a function of tuner position.

The electric field distribution along the beam axis had also been measured using the conventional bead perturbation method. Figure 7 shows the measurement result. Comparing with the simulation by CST-MWS code, the measured field distribution was consistent with the design value. The further measurement with fine RF coupler and tuners will be carried out as soon.

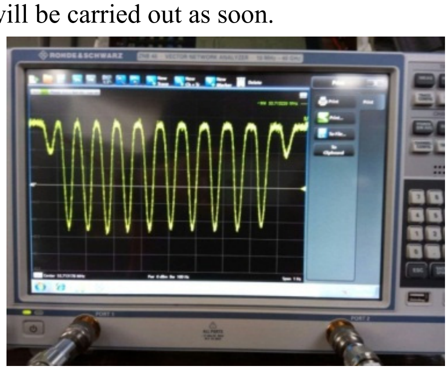

Figure 7: The field measurement results of the DTL2.

BEAM COMMISSIONING

The first beam commissioning had been performed using $^{16}O^{5+}$ ion. Beam current 100 eμA was extracted from ion source and accelerated by RFQ and IH-DTL1 in sequences. The commissioning results were listed in the Table 2. As can be seen, the transmission efficiency was only 70%. The main reason was that the match conditions were not implemented perfectly both at LEBT and MEBT section. Due to the lack of the diagnostic instrument, the matching condition between RFQ and DTL would be carefully tuned especially in the future experiment. The emittances at the DTL1 exit were also measured as shown in Fig. 8. Transverse normalized rms emittances both in horizontal and vertical plane were in good agreement with the simulation results. After this experiment, more beam experiments were carried out using some other specie ions such as $^{12}C^{4+}$, $^{40}Ar^{8+}$, $^{209}Bi^{30+}$. The higher transmission 82% was obtained in the experiment within $^{12}C^{4+}$ ion beam. Investigations of transmission are still under continuing.

Table 2: Beam Commissioning Results of SSC-Linac

Parameters	Values
Ion	$^{16}O^{5+}$
Measured beam current	70 eμA
Input/ Output energy	3.73/295.6 keV/u
$\varepsilon_{x/y\ nrms}$	0.18/0.14 πmm·mrad

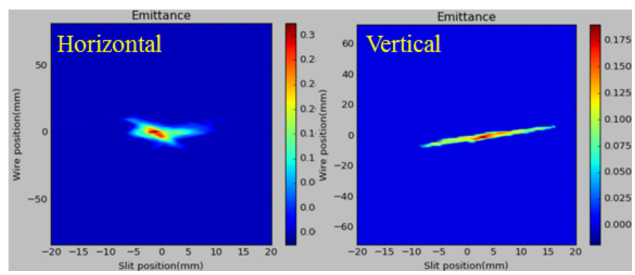

Figure 8: Measured transverse emittances at DTL1 exit.

SUMMARY AND OUTLOOK

The front end section of the SSC-Linac has been fabricated and commissioned at IMP. Beam commissioning with various specie ions had also been carried out successfully. The measured particle energy was in good agreement with design value. However the beam transmission has some optimize rooms. So the match input would be studied carefully for improving the beam transmission efficiency. Furthermore, the low level RF measurement and higher power conditioning of IH-DTL2 will be carried out in the near future. The beam commissioning will also be performed in the sequence.

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