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THE R&D STATUS OF SSC-LINAC*

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Abstract

A powerful heavy ion injector SSC-linac is under constructing at IMP in Lanzhou. The continuous wave (CW) 4-rod RFQ operating at 53.667 MHz has been developed as the low beam energy injector linac. The $^{40}Ar^{8+}$ ion beam extracted from the ECR ion source was used for the RFQ commissioning. The particle energy 142.8 keV/u and the 198 eμA beam current were measured at the exit of RFQ with the 94% transmission. 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

A new heavy ion linac based on CW 4-rod RFQ as the injector for the Separated Sector Cyclotron (SSC), called SSC-Linac[1], is being constructed at national laboratory HIRFL (Heavy Ion Research Facility of Lanzhou), IMP of Chinese Academy Sciences (IMP,CAS). The SSC-Linac consists of an ECR ion source, LEBT, a 4-rod RFQ, MEBT, IH-DTL and HEBT. The injection and extraction energy are 3.7 keV/u and 1.025 MeV/u, respectively. Furthermore, the particle will be injected and accelerated to 10.7 MeV/u by the SSC facility. The front end section of the SSC-Linac has been constructed as shown in Fig. 1.

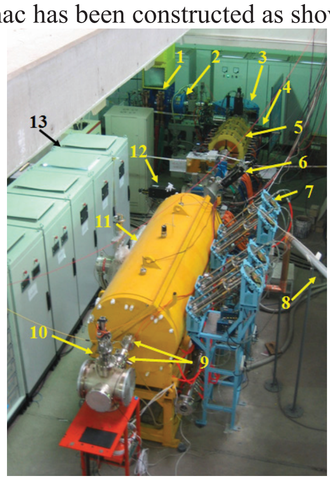

Figure 1: General view of the SSC_Linac. 1-ECR ion source; 2-focusing solenoid; 3-90° dipole magnet; 4-emittance scanner; 5-quadrupoles; 6-movable wire scanner; 7-movable tuner; 8-3-1/8″ coaxial tubes; 9-two FCTs; 10, 12-Faraday cup; 11-RFQ; 13-power supplies.

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Table 1: Main Parameters of SSC-Linac

Parameters	Values
Design ion	$^{238}U^{34+}$
ECR ion source	
Extraction voltage	25kV
Max. axial injection field	2.3 T
Frequency	18GHz
RFQ	
Type	4-rod
Frequency	53.667MHz
Input energy	3.728keV/u
Output energy	143keV/u
Inter-electrode voltage	70kV
RF power	35kW
Max. current	0.5mA
Operation mode	CW
Length	2.52m
Max. modulation	1.996
IH-DTL	
Frequency	53.667MHz
Input energy	0.143MeV/u
Output energy	1.025MeV/u
Length	5.85m
Operation mode	CW

ION SOURCE&LEBT

The high charge state room temperature ECR ion source has been successfully constructed at IMP. This source magnet coils are cooled through evaporative cooling technology which is the first attempt in the ion source field in the world. The maximum mirror field is 2.3 T (with iron plug) and the effective plasma chamber volume is Ø76 mm×260 mm. It was designed to be operated at 18GHz and aimed to produce high charge state gaseous and metallic ion beams for the SSC-Linac.

As part of SSC-Linac, the LEBT consists of three solenoids, four quadrupoles, a bending magnet and four steering magnets. The total length of this segment is about 7.2 m. The continuous beam from the ion source is first transported to the charge-to-mass selection dipole. And the selected beam is then efficiently transported and optimally matched into the RFQ for further acceleration. The 90% beam transmission was obtained in the first beam test and the transmission can be further improved by optimizing operation.

The commissioning test of ECR ion source has been performed continually from January 2014. The $^{16}O^{5+}$ and

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$^{40}Ar^{8+}$ ion beams have been successfully delivered for the RFQ commissioning, respectively. With only 0.1 kW RF injection power and 11.92 kV extraction voltage, about 200 eμA of $^{16}O^{5+}$ was produced.

The transverse emittances were measured by the emittance scanners located at the downstream of the analyzing 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.

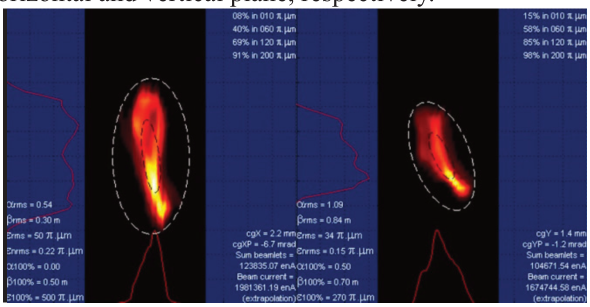

Figure 2: Measured transverse emittances after analyzing dipole magnet.

RF POWER AMPLIFIER

A new solid state CW 60 kW RF amplifier has been developed under the collaboration between IMP and Beijing BBEF Science & Technology Co., Ltd specialized in RF broadcasting equipment. The amplifier has been designed with the following specifications as shown in Table 2.

Table 2: Parameters of CW 60 kW RF Power Amplifier

Parameters	Values
Centre frequency	53.667MHz
RF signal	0~10dBm
Output power	≥60kW(CW or Pulse)
Harmonic content	≤-30dBc
High voltage instability	$\leq\pm1\times10^{-2}$/24 hrs
Phase instability	≤±5°/24hrs
Bandwidth	±2MHz

The amplifier module is designed based on the LDMOS transistor which can deliver 400 W output power with excellent capabilities. Nine modules are combined together to form a 3 kW RF power amplifier unit as shown in Fig. 3. Each 3 kW amplifier modules is equipped in one 19″ case. To obtain the required linearity it is better to assemble 6 cases in one cabinet which can deliver 18 kW in maximum. Each cabinet has a depth of 95 cm to allow space for the RF combiners and the connections for the water cooling.

To obtain the required RF power, four cabinets are combined together containing a centre control unit (see Fig. 4). Together they can deliver more than 60 kW CW power. And the output power is transmitted to the RFQ cavity by 3-1/8″ coaxial tubes.

The amplifier is water-cooled using de-ionized water and each 3 kW unit contains a cooling plate inside. A dedicated cooling chiller is applied to guarantee a constant temperature inside the amplifier unit, thus insuring gain and phase stability.

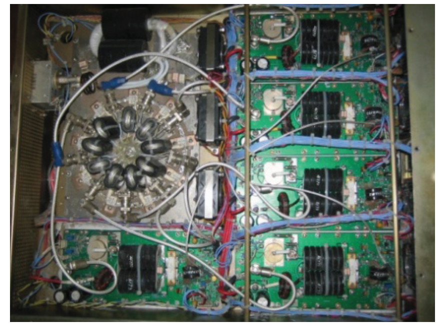

Figure 3: 3 kW amplifier unit.

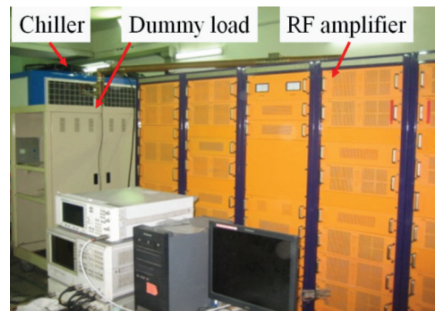

Figure 4: CW 60 kW RF amplifier and dummy load.

The RF power amplifier was fully tested with a dummy load and the maximum output power 60 kW was obtained. Figure 5 shows the measured relation between the input and output power.

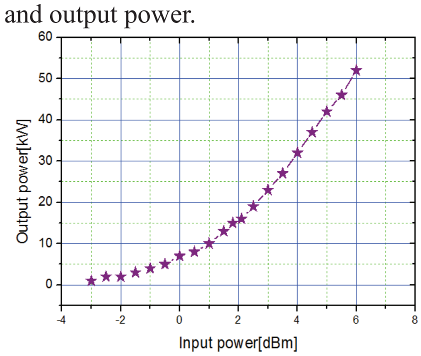

Figure 5: Output power versus input power.

The output ripple was less than ±2% at 60 kW output. The higher harmonics were kept below -55 dBc at the maximum output. The phase linearity was measured between input and output and the measured maximum phase deviation was ≤±0.7°, which is well within the required specifications.

RFQ COMMISSIONING

Low Level Measurement

Low level RF measurement of RFQ was carried out in last October. The frequency of the cavity without tuning is 53.607 MHz, which was not far from the operation frequency of 53.667 MHz and can be easily tuned by the plunges. On the critical coupling state, the Q_0 value of the cavity was 6440, which was 97% of the simulation result.

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According to these results, the RF performance of the cavity has satisfied the expectation and the tuning plate can be omitted.

The longitudinal electric field distribution was measured adopting the conventional perturbation method. The error of the results has been analyzed in details [2]. The un-flatness of the electric field in longitudinal direction is ±2.5% after correction, and the dipole field is 9.4% at maximum. The field distribution represents a good agreement with the simulation results.

High Power Conditioning

In January 2014, the high power conditioning of RFQ was implemented. The conditioning was begun in the pulse mode from low RF power with 10% duty factor. After about 30 hours conditioning, 35 kW with 30% duty factor was fed into the cavity almost no feedback. After then, the power conditioning of 35 kW in CW mode has been successfully carried out.

The shunt impedance of RFQ was also measured by measuring the inter-electrode voltage and the RF power. To obtain the inter-electrode voltage, a high purity Ge detector was placed opposite to the observation window to measure the energy spectrum of X-ray. From the measured X-ray spectrum at RF power 35 kW, the inter-electrode voltage reaches 70 kV. Then the shunt impedance is 140 kΩ. The result is some agreement with the simulation and the RF properties can be further improved via the advance power test. The temperature of the cooling water increases from 15.1 °C to 20.4 °C while the RF power increases from 0 to 32 kW. And the maximum temperature occurs at the measure point of the RF power coupler. These results indicate that the RFQ cavity possesses good mechanical strength and the water cooling is effective.

Beam Commissioning

Beam tests are now underway. The beam energy was measured using the time of flight (TOF) method with two FCTs (Fast Current Transformer) installed after the RFQ exit. The distance of two FCTs is 240.7 mm and the corresponding time of flight is 8.6ns. Figure 6 shows the beam signals detected by FCTs. Beam current and transmission were measured by three Faraday cups which were equipped in various positions along the beam line. The first cup was installed just after the dipole magnet to measure the current coming from ECR source. Another two cups were located at the upstream and downstream of the RFQ.

The first beam ($^{16}O^{5+}$) was successfully transported through the RFQ and accelerated to 141.9±0.15 keV/u on April 4th. The measured current was 149.5 eμA. After carefully conditioning, $^{40}Ar^{8+}$ ion beam was successfully accelerated in May 23rd, the measured energy and current were 142.8±0.21 keV/u and 198 eμA, respectively. The beam transmission was up to 94%. At the same time, the transmission as a function of RF input power through the RFQ was also measured as shown in Fig. 7. The transmission can be improved by finely tuning using the matched input.

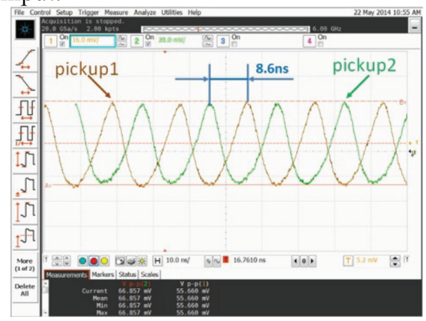

Figure 6: Beam signals detected by two FCTs.

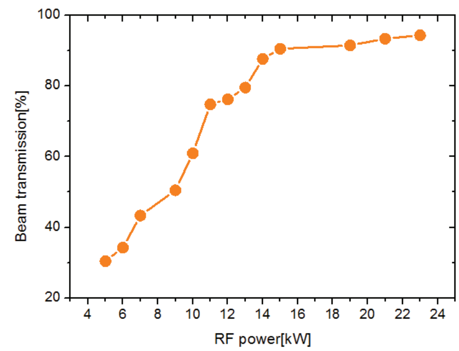

Figure 7: Transmission efficiency as a function of RF power.

SUMMARY AND OUTLOOK

The new high charge injector SSC Linac was fabricated and commissioned at IMP. The initial results look very promising. Two kinds of ion beam ($^{16}O^{5+}$ and $^{40}Ar^{8+}$) have been used for the commissioning. The beam energy reaches 142.8 keV/u and the transmission is greater than 94% for $^{40}Ar^{8+}$ ion beam.

High power conditioning of RFQ and beam tests with higher ratio of mass to charge for different ions would be desirable. Furthermore, some beam tests such as the energy spread and the acceleration efficiency will be carried out in the future using an analyzing magnet.

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