A CW HIGH CHARGE STATE HEAVY ION RFQ FOR SSC-LINAC*

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Abstract

To improve the super heavy ion beam injection efficiency and supply high current heavy ion beam for Separated Sector Cyclotron, A CW RFQ for heavy ion with high charge state has been designed and manufactured in the last two years. This RFQ will operate at 53.667MHz, will accelerate super heavy ions such as $^{238}U^{34+}$, $^{208}Pb^{30+}$ and $^{209}Bi^{30+}$ to 143keV/u. This paper will introduce the SSC-LINAC components, especially the RFQ beam dynamics, full length structure design, tuning and cooling method. Furthermore RF system commissioning with full power will also be presented.

INTRODUCTION

The electron Cooler Storage Ring of heavy ion accelerator facility at IMP in Lanzhou has been running successfully for several years. It can provide almost all heavy ion particles in periodic element table. It consists of main and experimental rings. The injector includes a Sector Focusing Cyclotron (SFC), which accelerate ions up to 1AMeV, and a Split Sector Cyclotron (SSC), ion energy up to 10AMeV. They are all operating in series, as shown in Figure 1.

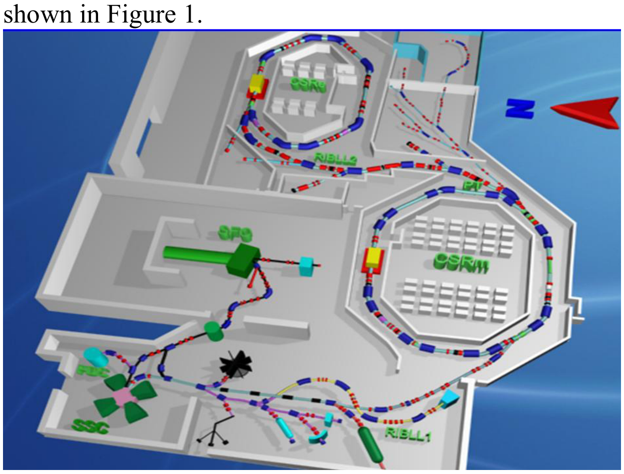

Figure 1: SFC, SSC, CSRm and CSRe in series [1].

To improve injected beam current and beam transmission in the current injector, it is very necessary and urgently to develop one or even two linear injectors for SSC and CSR. Then all above accelerators can be running in parallel mode. As RF linear accelerators can be developed step by step, a RF linear injector was proposed for SSC, called SSC-LINAC as shown in Figure 2. This paper will introduce the development of a CW four-rod RFQ, including beam dynamics simulation for different super heavy ions such as $^{238}U^{34+}$, $^{208}Pb^{30+}$ and $^{209}Bi^{30+}$, the CST simulation for RF structure and RFQ mechanical design, thermal analysis of water cooling and its RF system. The manufacturing and RFQ cavity has been completed.

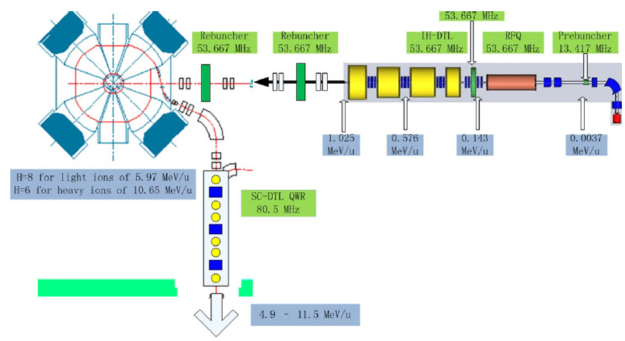

Figure 2 : Schematic diagram of SSC-LINAC.

BEAM DYNAMICS FOR SUPER HEAVY IONS

The beam dynamics simulation code is PARMTEQM. The designed RFQ will accelerate ions from 3.728keV/u to 143.0keV/u with ratio of ion charge to mass of 1/7, and operate at 53.667MHz in CW mode. The input parameters for the PARMTEQM are generated by MATCHDESIGN code, which was based on the equipartitioning method [2] developed at Peking University and is very helpful to optimize the RFQ design quickly. The beam dynamics design was described very detail in the paper [3]. Main parameters for this CW RFQ was listed in this conference paper [4]. The transmission for light ions such as $^{7}Li^{+}$ with 17emA is about 94.3%, which is slight better than 94.1% for 0.5pmA of $^{238}U^{34+}$.

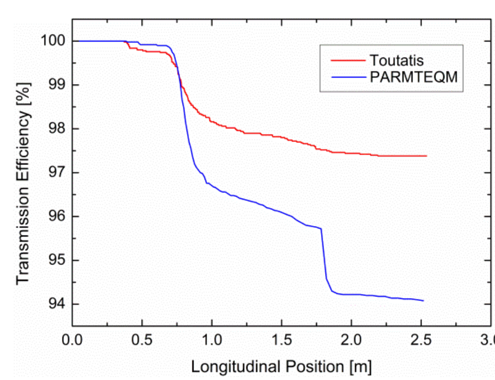

Figure 3: Comparison of the transmission efficiency results from the PARMTEQM and Toutatis.

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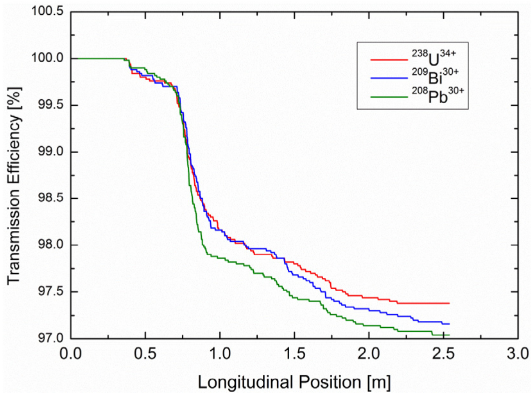

Figure 4: Transmission differences for $^{238}U^{34+}$,$^{208}Pb^{30+}$ and $^{209}Bi^{30+}$ by TOUTATIS software.

The beam dynamics simulations for other particles should also be verified, especially, high current beams for super heavy ions such as $^{208}Pb^{30+}$ and $^{209}Bi^{30+}$ are very important for the detection of new element of ^{271}Ds and ^{272}Rg on the CSRe heavy ion experiments. The simulations were done by the code TOUTATIS [5]. The transmission for $^{238}U^{34+}$ by TOUTATIS is about 97.5%, 3.4% higher than the result of 94.1% by PARMTEQM, as shown in Figure 3. Figure 4 shows the transmission differences for three different super heavy particles $^{238}U^{34+}$,$^{208}Pb^{30+}$ and $^{209}Bi^{30+}$ based on the TOUTATIS simulation. The vane tip data of these results is the same as the $^{238}U^{34+}$ simulation, which has a constant vane tip radius. The twiss parameters for the $^{209}Bi^{30+}$ and $^{208}Pb^{30+}$ beams are identical to the $^{238}U^{34+}$ beams. Therefore, it is not the optimized results for the $^{209}Bi^{30+}$ and $^{208}Pb^{30+}$ beams. This should be one of the reason that caused the transmission efficiency of these two beams lower than the $^{238}U^{34+}$ beams in Figure 4. In the simulation, the inter-vane voltage of $^{209}Bi^{30+}$ and $^{208}Pb^{30+}$ cases is 69.667kV and 69.333kV, respectively, as their ratio of charge to mass are larger than 1/7. Therefore, from the simulation, the SSC-LINAC RFQ has a good compatibility for different kinds of particles.

RFQ STRUCTURE DESIGN

Normally four-vane RFQ has many advantages to operate in CW mode. However, the traditional four-vane RFQ at 53.667MHz has very large dimensions, which makes big trouble to do the welding to form the vacuum cavity. The four-vane RFQ with windows could be good choice [6]. We are lack of experience to balance the field distributions and to fix the designed cavity frequency for such a cavity. It will be very suitable to adopt four rods RFQ structure. The diameters of RFQ will be similar to TRIUMF RFQ. To be more maintainable and high reliability, the mini-vane four rods with thicker plate stems will be adopted. The RFQ mini-vane electrodes [7] will be much stronger than cylinder RFQ rods, have a bit larger cross section for the inner water cooling channel and good mechanical strength to prevent the heat deforming at CW mode operation. Finally the four-rod RFQ structure was adopted as shown in figure 5. Big dimensions make the whole cavity has a large thermal capacity. 12 supporting stems, 4 electrodes, bottom plate and cavity are all cooled by cooling water. Four plungers will be used to tune the cavity frequency to 53.667MHz. one could also see the magnetic coupler, which is installed in the centre of the cavity. Figure 6 shows the water cooling effect and temperature distribution for inner structure.

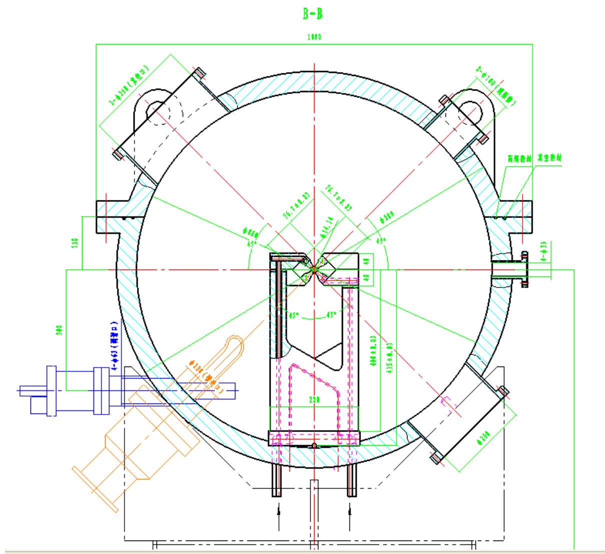

Figure 5: End view of SSC-RFQ cavity.

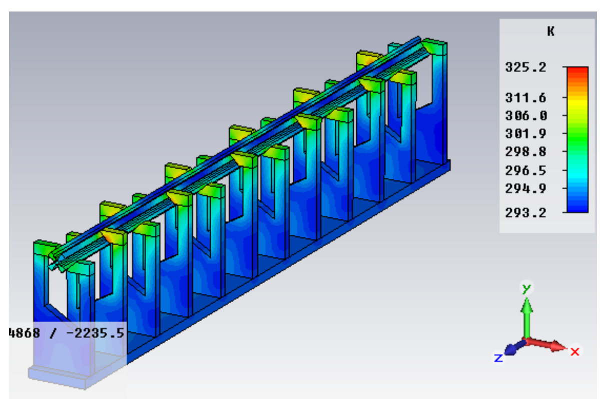

Figure 6: Temperature distribution.

According to hydrodynamics empirical formula, flow rate in the electrodes and in the stems is 0.38kg/s and 0.3kg/s, respectively. The velocity of water is 3.36m/s in rods and 6.1m/s in stems respectively.

Reynolds number is:

$$\mathrm{Re} = \frac{\rho \bar{v} d}{u} \tag{1}$$

$\bar{v}$ is the average velocity of water. u is the kinetic viscosity. d is hydraulic diameter

Prandtl number is:

$$\mathrm{Pr} = \frac{Cp\mu}{K} \tag{2}$$

Cp is specific heat, K is thermal conductivity.

Nusselt number is:

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$$Nu = 0.023\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{n} \quad (3)$$

In our case, n=0.4.
Film coefficient is:

$$h = \frac{NuK}{d} \quad (4)$$

According to the formula, the film coefficient in electrodes and in stems is h=12094W/m^{2}K and h=21147 W/m^{2}K, respectively. The water temperature at inlet is 20℃. Finally in a word for the thermal analysis and cooling design, the maximum temperature rising is 43℃. The maximum deformation is 88μm at the two ends of every electrode, which is acceptable.

CURRENT STATUS

Up to now the RFQ manufacturing has been completed by Shanghai Kelin Scientific and Technology Co. Ltd and the cavity has been transported to IMP. 60kW solid state amplifier was investigated by Beijing BBEF Science & Technology Co., LTD. The amplifier has been tested successfully and delivered to IMP last week. The output impedance of amplifier is 50 ohms, it can stand the full power reflected. But the reflected signal protecting circuit will cut off the driver signal through the voltage control RF switch.

The first LLRF measurement has been carried out in Kelin. The measured cavity frequency without plungers is 53.557MHz, which is very near the operating frequency, quality factor is about 4926. The S11 parameter for magnetic coupler has been tested to get –35dB, which means very good impedance matching between RF generator and the RFQ cavity. The field distribution is presented in this conference proceeding (THPWO047). The vacuum test in shanghai has reached 6.7×10^{-6}pa. The RFQ assembling precision and the influence of cavity transport from Shanghai to Lanzhou will be verified at the end of May. Figure 7 shows the RFQ inner structure and its manufacturing quality. Figure 8 shows its outlines.

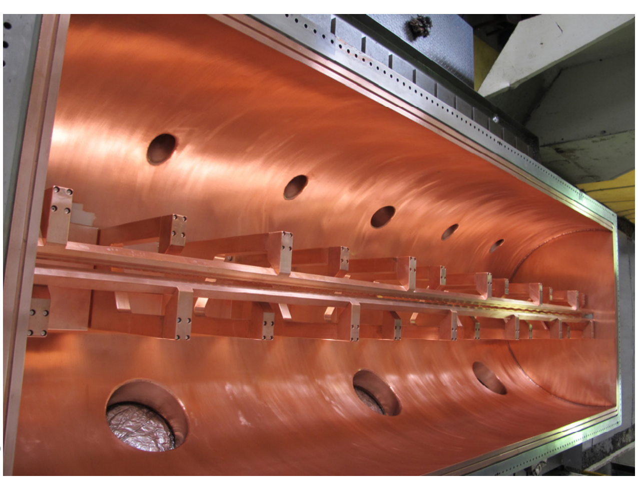

Figure 7: Assembled CW RFQ.

Figure 8: CW RFQ outline.

CONCLUSIONS

A 53.667MHz CW RFQ has been designed, manufactured in the past two years. The beam dynamics is designed for $^{238}U^{34+}$ by PARMTEQM and verified by TOUTATIS, Both have good designed transmission, not only for super heavy ions such as U^{34+}, Pb^{30+},Bi^{30+},also for $^{7}Li^{+}$ with same electron beam current. The technical parameters have been realized.

ACKNOWLEDGEMENT

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