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

G. Liu, Y. R. Lu†, Z. Wang, K. Zhu, X. Q. Yan, S. L. Gao, Q. F. Zhou, J. E. Chen, State Key Lab of Nuclear Physics and Technology, Peking University, Beijing, China
Y. He‡, C. Xiao, Y. Q. Yang, Y. J. Yuan, H. W. Zhao, Institute of Modern Physics of Chinese Academy of Sciences, Lanzhou, China

Abstract

A new linear injector called SSC-LINAC has been proposed to replace the Sector Focusing Cyclotron (SFC) for the Separator Section Cyclotron (SSC) and Cooling Storage Ring (CSR) of the Heavy Ion Research Facility of Lanzhou (HIRFL). Ions with ratio of mass to charge up to 7 are accelerated in the SSC-LINAC. The design research on a CW 53.667MHz RFQ accelerator will be presented. The beam dynamic design is based on $^{238}U^{34+}$ beams with intensity of 0.5pmA. The inter-vane voltage is 70kV with the maximum modulation factor of 1.93. It uses a 2.5m long 4-rod structure to accelerate uranium ions from 3.728keV/u to 143keV/u with the transmission efficiency of 94%. The effect of different manufacturing crafts on beam dynamics has been checked. The specific shunt impedance has been optimized to 232.9kΩ • m. The water cooling system and design of the cavity tuning are also included in this paper.

INTRODUCTION

The new linac SSC-LINAC has been proposed as an injector to replace the current Sector Focusing Cyclotron (SFC) in order to improve the beam efficiency of the Heavy Ion Research Facility of Lanzhou (HIRFL) [1]. It should have the ability to provide various kinds of ions even ^{238}U on considerable beam intensity. To match the downstream Separator Sector Cyclotron (SSC), the linac will work on 53.667MHz and continuous wave (CW) mode. As a key component of the system, a CW high charge state heavy ion RFQ has been designed.

To satisfy the requirement of SSC-LINAC and the upgrade of HIRFL in future, the $^{238}U^{34+}$ ions has been chosen as the design particle of SSC-LINAC RFQ, and the beam current is 0.5pmA, which means 17emA. For high charge state particles, such high beam intensity brings some challenges on beam dynamics design. The beam envelope oscillation and emittance growth must be controlled carefully. The CW mode operation brings some restrains on the choice of structure parameters. Since the RFQ will work on low frequency, the resonance structure is designed as four-rod type. The specific shunt impedance of RFQ has been optimized to 232.9kΩ • m. The water cooling channel and tuning design will also discussed in this paper.

BEAM DYNAMIC DESIGN

The code PARMTEQM v3.05 [2]is used to design and simulate the beam dynamics. The parameters of SSC-LINAC RFQ are listed in Table 1. It is a compromising work to determine the parameters. For instance, the higher inter-vane voltage is benefits to enhance the focusing and accelerating effects; however, it will face the limit from power consumption and sparking risk. Small aperture is helpful to strengthen the field but adverse to high beam current. To transport the beams stably, the transverse focusing and longitudinal bunching should be treated carefully. In the traditional design strategy, the radial focusing strength *B* holds constant along the structure [3]. This method provides convenience to resonance structure design when the inter-vane voltage also unvaried along the RFQ. However, it may cause parameter resonance and mismatch in the beam transportation. In Figure **1**, the strengthening phase oscillation in the SHAPER section

Table 1: Main Parameters of SSC-LINAC RFQ

Parameters	Values
Frequency / MHz	53.667
Ratio of charge and mass	1/7
Current / pmA	0.5
Inter-vane voltage / kV	70
Kilpatrick factor	1.523
Minimum aperture / mm	4.721
Modulation factor	1~1.94
Synchronous phase	-90° ~-30°
Input energy / (keV/u)	3.728
Output Energy / (keV/u)	143
In. Trans. Norm. RMS Emit. / (cm • mrad)	0.0206
Out. Trans. Norm. RMS Emit. / (cm • mrad)	0.0204
Length of rod / mm	2508.46
Transmission efficiency (238U34+) / %	94.1

* Supported by NSFC(11079001)
† yrlu@pku.edu.cn
‡ hey@impcas.ac.cn

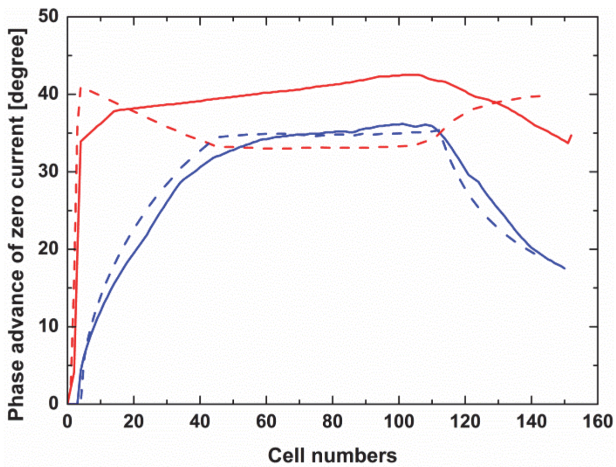

Figure 1: Comparison of the phase advance of zero current in the transverse (red) and longitudinal (blue) plane for both the traditional design (dash line) and optimized one (solid line).

will increase the phase advance of zero current in longitudinal plane, but reduce the one in transverse plane since *B* holds constant. Then the phase advance of zero current in both planes will nearly equate in the bunching process, causing parameter resonance. When the beam intensity increased, the radial phase advance with space charge will be even reduced, which will worsen the mismatch state. The beam loss and emittance growth will be significant in such a way. To solve the problem, it is better to enhance the radial focusing strength to keep the beam stable. The phase oscillation will still hold the similar level in order to avoid the longer structure or the worse phase slipping. To enhance the focusing effect, the aperture will be smaller and the surface electric field will be higher, but it is still in the acceptable range.

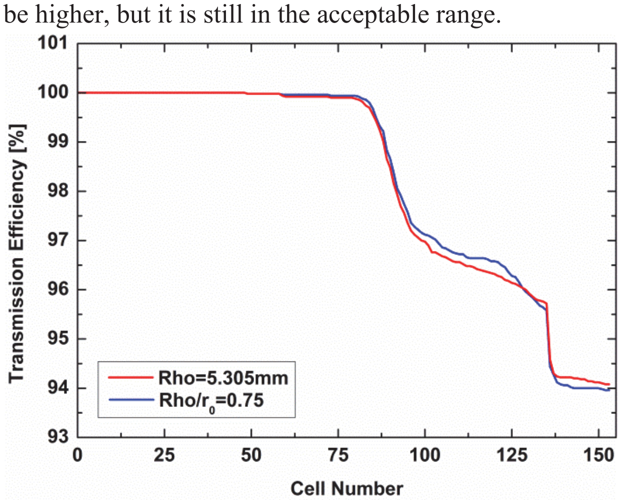

Figure 2: Efficiency of different rod machining crafts.

The above improvement on design strategy will bring some problems on the resonance structure design and rods manufacturing, because the capacitance between the rods and the average aperture r_0 in each cell will be difference. Fortunately, the frequency of SSC-LINAC RFQ is low, so the varied capacitance will not affect the flatness of the fields seriously. The different average apertures make the rod tip radius *Rho* also change along the structure, so the craft uses the two-dimensional machining tool with constant radius cutting arc will introduce error. However, if the constant ratio of rod tip radius to the average aperture is abandoned, the rod tip radius could be set to constant while the average aperture changes with radial focusing strength. The beam transportation in the two situations has been simulated by PARMTEQM. Figure **2** represents that there is just a little difference on the efficiency between these two kinds of rod tip radius.

STRUCTURE AND COOLING DESIGN

Resonance Structure

The SSC-LINAC RFQ will work on 53.667MHz, so it is suitable to use the four-rod structure since its radial size is smaller than the four-vane structure in the same frequency. To be more maintainable and reliability, the mini-vane rods are supported by thick plate stems, as shown in Figure **3**. The amount of stem is optimized compromisingly between structure stability and size. More stems could provide strengthened support to the rods, and the fraction of the rods outside the two stems at the entrance and exit will be shorter. The latter feature is benefits to cool the end of the rods. But meanwhile, the more stems leads to a large radial size of the cavity, because the reduction of inductivity between stems has to be offset by the height of the stem. To leave some margin for tuning and coupling devices, the structure

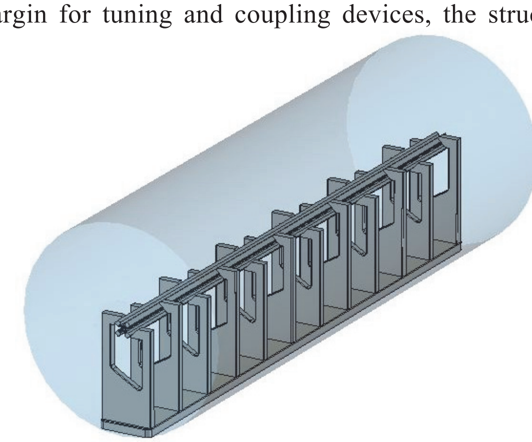

Figure 3: Resonance structure of SSC-LINAC RFQ.

Table 2: Structure Parameters of SSC-LINAC RFQ

Parameters	Values
Frequency(without modulation) / MHZ	52.967
Frequency(with modulation) / MHz	52.801
Cavity Diameter / mm	880
Q value	6562.8
Power dissipation (70kV, peak) / kW	52.6
Shunt impedance / (kΩ • m)	232.9

ISBN 978-3-95450-115-1

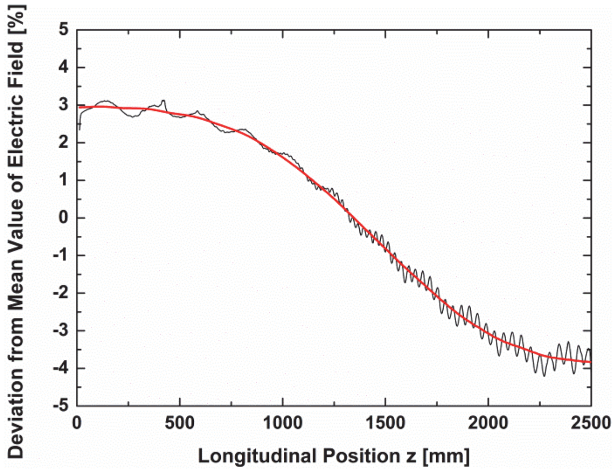

Figure 4: Deviation of the E field between the rods.

is optimized to the lower frequency than the operation state. The whole cavity has been simulated in the CST MWS [4]with vane tip modulation. Figure 4 represents the electric fields between the rods along the RFQ. The deviation of the fields is about ±4%. As mentioned above, this is not serious because the frequency is low.

Thermal Analysis and Cooling Channels

In the thermal analysis, the total power loss is supposed to be 33kW in average value, and the film coefficient of all cooling channel is 20000W/(m^2 • K). In four-rod structure, a large fraction of field energy will distribute in the area around the rods. The highest surface current intensity disappears at the connection between the rods and the arm of stems. So in Figure 5, the arms are also designed with cooling channels. This measure is benefits to cool the rods as well. In the current design, the cooling channel has been extended into the end of the rods. If the temperature of the inlet water holds on 20℃, the maximum temperature in the structure will be 43℃, and the largest deformation will be 88μm, which will happen at the end of the rods.

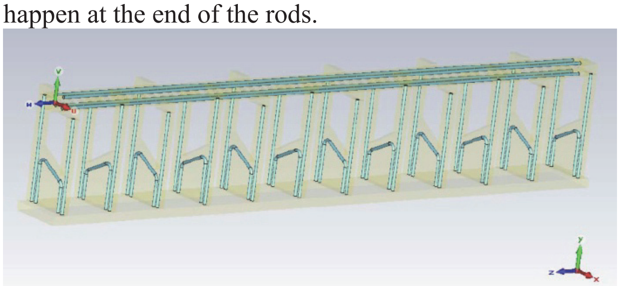

Figure 5: Cooling channel in the structure.

TUNING OF THE CAVITY

The resonance units in the four-rod RFQ are coupled by magnetic field [5], so it uses tuning plates and plungers to adjust the operation frequency. As shown in Figure 4, the flatness of the electric field between the rods has already at an acceptable level, so the main

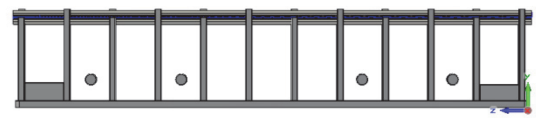

Figure 6: Tuning plates and plungers in the RFQ.

function of the tuning plates in this cavity is to offset the frequency deviation caused by vane modulation, manufacturing error or other factors. Figure 6 represents the location of the plates and plungers. The plates locate in the first and the last resonance units. The height between the upper surface of the plates and the base bound will be determined in the later cooling model experiment. According to simulation, the adjustment range of height is set to 100mm in order to cover all the possibility of frequency deviation. The real plates are copper billets with cooling channel and can move in the vertical direction. The plungers are cylinders which diameter is 55mm also with cooling channel. Their function is to offset the deviation of frequency caused by temperature fluctuation. Figure 7 represents the change of frequency when four plungers are inserted into the cavity with the same length.

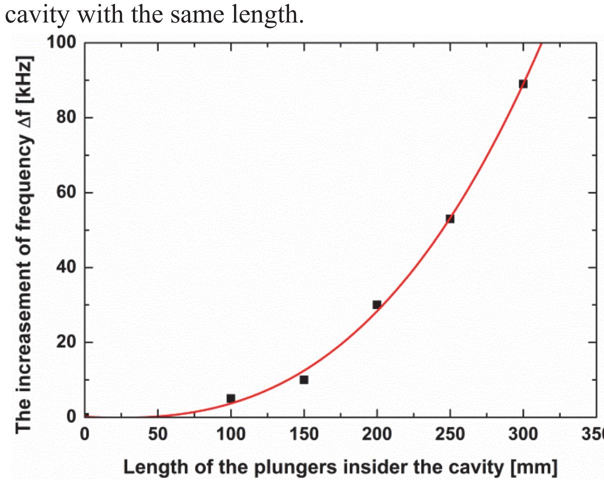

Figure 7: The change of frequency caused by all four plungers.

REFERENCE

[1] Yuan He, Zhijun Wang, Chen Xiao, et al, IPAC2011, 2011, WEPS052.

[2] K. R. Crandall, T. P. Wangler, L. M. Young and et al, LA-UR-96-1836 (revised), June 3, 2005.

[3] K. R. Crandall, R. S. Mills, T. P. Wangler, Proc. of LINAC1979, 1979, BNL-51134, p. 205.

[4] Computer Simulation Technology, www.cst.com.

[5] P. Fischer and A.Schempp, Proc. of LINAC06, 2006, p.728-730.