THE LLRF MEASUREMENT AND ANALYSIS OF THE SSC-LINAC RFQ*

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Abstract

The manufacturing process of the SSC-LINAC RFQ went to end and the LLRF measurement has been done. To reduce the disturbance from the test environment, a dielectric block has been used as the perturbation body instead of the beads. The error induced by the block and the sampling approach have been investigated. As the results, the frequency of the RFQ is 53.557 MHz without tuning, which is not far from the design value 53.667 MHz. The Q_0 value is 4925.8. The unflatness of the field along the beam axis is less than ±4%, which meets the simulation results. The frequency will be adjusted by tuning plungers in operation. In this paper, the measured results of the field distribution along the cavity will be compared with the modulated electrodes simulation.

INTRODUCTION

The SSC-LINAC project has been proposed as a new injector for the Heavy Ion Research Facility of Lanzhou (HIRFL) to improve the beam efficiency of the whole system[1]. The RFQ accelerator of the injector has been designed and manufactured, whose main parameters are listed in Table 1. It is designed for the heaviest ions $^{238}U^{34+}$ among the particles needed to be accelerated. The machine will work on continuous wave (CW) mode. The resonance structure of the RFQ is shown in Figure 1. As the cavity working in low frequency, the four-rod structure is adopted. The rods, stems and the base plate are made of oxygen free copper, with water cooling tunnels inside. The cavity is made of carbon steel plating with copper. The RFQ is manufactured in Shanghai Kelin Technology Development Co., LTD.

Table 1 Design Parameters of the SSC-LINAC RFQ

Parameters	Values
Frequency / MHz	53.667
Ratio of charge to mass	1/7
Current / pmA	0.5
Inter-vane voltage / kV	70
Duty factor / %	100
Input energy / (keV/u)	3.728
Output Energy / (keV/u)	143.0
Length of electrodes / mm	2508.46
Transmission efficiency ($^{238}U^{34+}$) / %	94.1
Q_0 value	6562.8
Power dissipation (70kV, peak) / kW	52.6

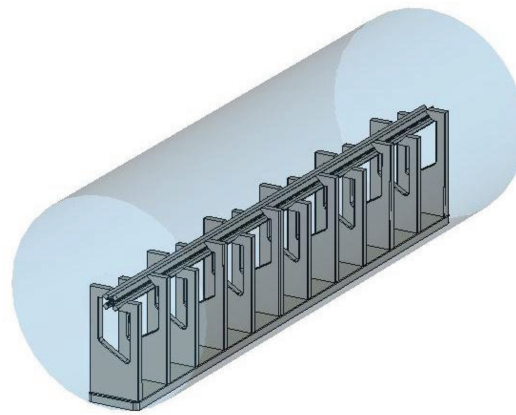

Figure 1: Resonance structure of SSC-LINAC RFQ.

The beam dynamics design [2] provides theoretically high transmission efficiency for the RFQ. This should be realized by certain electric field distribution in the paraxial area. To form such field, precisely manufacturing and installation of the structure are necessary. To check these, one way is to use three-dimensional coordinator instrument to measure the installation location of the rods and its supporting stems, and to verify whether they have reached the required machining precision and are assembled right well or not. Another way is to measure the electric field distribution among the rods by the low level RF (LLRF) measurement. Comparing the measured and simulated field distribution, one can evaluate the installation quality of the rods and whether the field distribution meets the beam dynamics design. This paper will focus on field distribution results from the LLRF measurement.

CONSIDERATION OF THE MEASUREMENT

The perturbation method is used as usually in the LLRF measurement of the SSC-LINAC RFQ. Many factors such as temperature, mechanical vibration, accuracy of the equipment [3], and so on, will affect the measured results. In this test, some other special factors make troubles even more evidently, including the disturbance from other running machines and the gravity of the beads. The former one comes from the industrial site, because the cavity measurement has to be carried out in the

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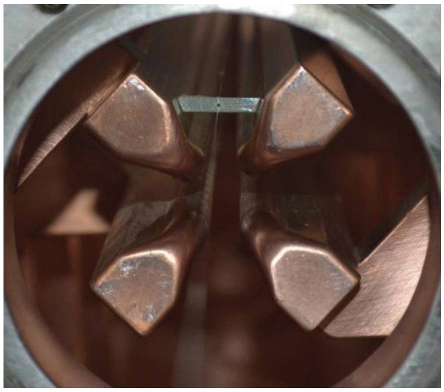


Figure 2: The dielectric block that used to perturb the field. This figure is viewed at the entrance of the RFQ. The block is sliding in the upper quadrant.

workshop before the cavity is delivered to the laboratory in Lanzhou. Such disturbance reduces the reproducibility of the measurement. The latter factor comes from the mass of the beads.

To solve these problems, a dielectric block has been used to replace the bead. The block standing on two rods, is cramped by the slopes of the neighboring two mini-vanes as shown in Figure 2. When the block is towed by the string, it could move without oscillating up and down. Therefore, the effect of gravity is eliminated. Furthermore, the larger volume of the block than the bead provides stronger perturbation to the field, which leads to a better signal to noise ratio. However, taking the measurement error into consideration, the volume has a balance point. The larger block induces larger phase shift. The error of the voltage deviation quantity vs. the phase shift follows the relation [4]:

$$\frac{\Delta V}{V} = \frac{\sqrt{\tan \Delta\phi} - \sqrt{\Delta\phi}}{\sqrt{\tan \Delta\phi}} . \quad \textbf{(1)}$$

Figure 3 represents the trend of eq.(1). In the LLRF measurement of the SSC-LINAC RFQ, the phase shift induced by the block is no more than 19°, then the error is less than 2%. Since the field unflatness is a relative quantity, such level of error is acceptable.

The location of the block in the transverse plane is important, because the field strength depends on the distance to the beam axis. Further, the modulation of the vane tip makes the distance between two rods at difference longitudinal positions vary. Then the sampling points should keep away from the area affected by the modulation. Figure 4 (b) represents the simulation results of the electric field and the inter-vane voltage sampling at the position shown in Figure 4 (a). The distance from the red point in Figure 4 (a) to the beam axis is 20mm. It could be seen that at such position, there is good agreement between the distribution of the electric field and the inter-vane voltage. So the distance from the block to the beam axis in the transverse plane keeps 20mm during the LLRF measurement.

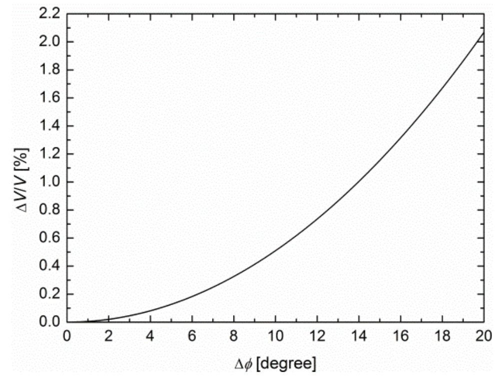
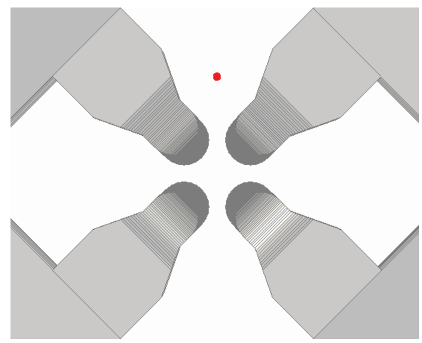
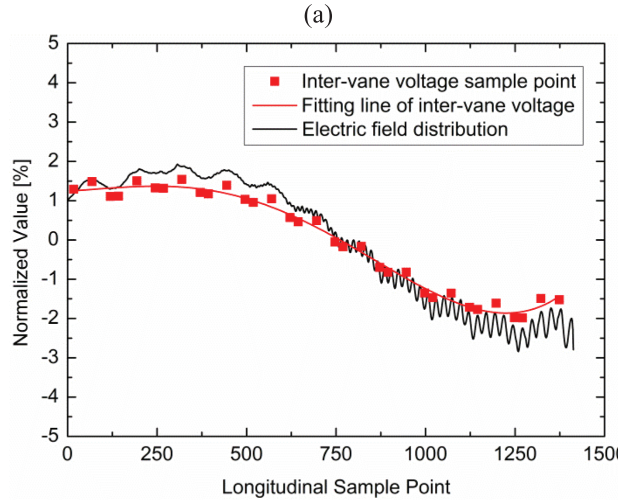


Figure 3: The error of voltage perturbation quantity depending on the phase shift.



(a)



(b)

Figure 4: Simulation result of the distribution of the electric field and inter-vane voltage along the longitudinal direction. (a) the red point is the sample position in the transverse plane and (b) the electric field and inter-vane voltage distribution.

RESULT OF THE MEASUREMENTS

Before measuring the field distribution, the power coupler has been adjusted to critical coupling state. And the frequency of the cavity without tuning is measured to be 53.557 MHz, which is near the working frequency 53.667 MHz. This result means that it is no needed to use the tuning blocks [5] to adjust the frequency. The measured Q_0 value of the cavity is 4925.8. Figure 5

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represents the results of the field distribution along the longitudinal direction. In all four figures, the simulated curves have oscillations in the high energy parts, which are caused by the modulation of the vane tip. Besides, there are some large cycle undulations which are induced by the supporting stems in Figure 1. Although these undulations break the flatness of the field, the range of the amplitude is small. The high frequency oscillations of the measured curves are caused by the background noise. It could be seen that the measured field distributions agree with the simulation results. The unflatness of the electric field in all four quadrants are less than ±4%, especially in Figure 5 (b), (c) and (d), the unflatness is better than ±3%. The result of the upper quadrant is worse than others because the flange on the upside of the cavity didn't cover during the measurement for the convenience of the manipulation, so the field in the upper quadrant will be disturbed by the environment. However, the result is good enough to represent the quality of the field. The dipole field has not been evaluated from these results. The reason is that the disturbance from the industrial site is too large that the background noise is not stable during the measurement, which causes the phase shift fluctuated in about 1°. It means additional error will be induced to the results. So it is not possible to compare the field strength between different quadrants. But for the normalized results, the phase shift caused by the block is enough to cover the background fluctuation. Therefore, it is reasonable to evaluate the flatness of the field. The dipole field will be measured in the laboratory environment later after the cavity is delivered to Lanzhou.

CONCLUSION

The manufacturing process of the SSC-LINAC RFQ went to end and the LLRF measurement has been done. To reduce the disturbance from the test environment and error of the measurement, a dielectric block is used in this test instead of small beads. As a result, the frequency of the RFQ is 53.557 MHz without tuning. The Q_0 value of the cavity is 4925.8. And the normalized field strength represents that the unflatness of the field in four quadrants are better than ±4%. The test results are also consistent with the simulation results.

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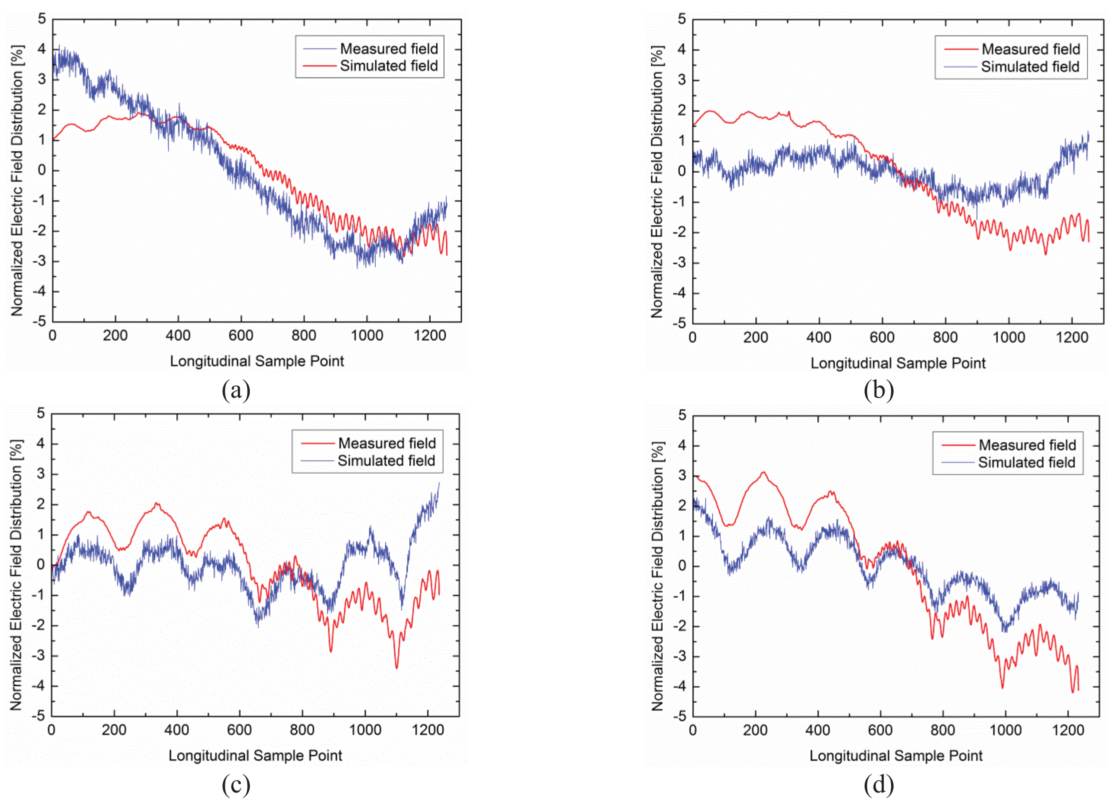

Figure 5: E field distribution measured along the longitudinal direction. The distance from the sample point to the beam axis in the transverse plane is 20mm. The four figures are results of each quadrant watching from the entrance of the RFQ, which are (a) Up, (b) down, (c) left and (d) right.

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