Transactions of the Korean Nuclear Society Autumn Meeting
Pyeongchang, Korea, October 30-31, 2014

Analysis of Beam Dynamics Design of the He2+ RFQ LINAC

Sungkyun Park*, Hyeok-Jung Kwon, Han-Sung Kim, Kyung-Tae Seol, Young-Gi Song, Yong-Sub Cho
Korea Multi-Purpose Accelerator Complex, Korea Atomic Energy Research Institute, Gyeongju 780-904
**Corresponding author: skpark4309@kaeri.re.kr*

1. Introduction

KOMAC has been developing a radio frequency quadrupole (RFQ) to use as the semiconductor irradiation system by accelerating helium beams. This 200 MHz RFQ can accelerate He2+ ions from an initial energy of 100 keV to 4 MeV with the peak beam current 10 mA and beam duty 1 %. The four-vane type is selected for higher efficiency at high frequency. The main design goals are to provide the 1.7 Kilpatrick as the maximum peak surface electric field while limiting the required rf power to less than 200 kW for the rf power economy point. The total length is limited as 3.2 m for the smooth brazing. The design specifications of the RFQ are listed in Table I.

Table I: The design specifications of the RFQ

parameter	Value	unit
Input energy	100	keV
Output energy	3	MeV
Peak beam current	10	mA
Particle	He2+	
Duty factor	1 %	
Frequency	200	MHz
Emittance	0.2	π mm mrad
Structure	4-vane type	
Length	3.2	m
RF power	< 200	kW
Max. peak surface field	< 1.7 Kil.	

2. Beam Dynamics Design

The beam dynamics design selects the proper dynamics parameters to satisfy the requirement of output energy, beam current, and output emittance from the given design specifications like the input energy, beam current, input emittance, operating frequency, inter-electrode voltage. The maximum transmission rate and the minimum growing of the emittance are the first conditions considered to optimize the design parameters of RFQ.

Figure 1 shows the variation of the beam dynamics parameters along the cell number of RFQ. These parameters are calculated with the the help of standard codes CURI, RFQUICK, PARI, and PARMTEQM [1]. Inter-vane voltage is the important parameter decided first. Higher vane voltage makes better performance of the RFQ. That is, the energy gain is increased and the length of cavity is decreased. However, this high value causes more RF power and the danger of RF sparking. In this design, the vane voltage is decided by the peak surface field and this peak electric field is limited to 1.7 times the Kilpatrick criterion [2].

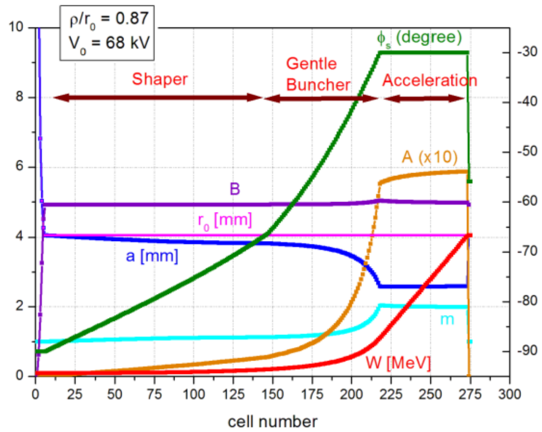

Fig. 1. Main RFQ parameters as function of cell. The axis for the stable phase is located in the right side and the others use the left axis values.

The first part of the RFQ is the radial matching section (RMS), which provides the transverse matching for a continuous dc input beam. In this design, 6 cells with the length z=3.31 cm is used for RMS. The next part of RFQ following the RMS is the shaper section where bunching process is started. The aperture 'a' , which is changed rapidly in RMS, is smoothly reduced from the 141 cells long shaper section.

The 71 cells long gentle buncher (GB) section, which is located at the downstream to shaper section, continues the bunching process until the beam is fully bunched and slightly accelerated. Therefore, the end of the GB is the most critical point of the RFQ since the charge density of the bunch is highest. So the size of the aperture 'a' becomes the smallest to have the maximum focusing strength. Parameters at the end of the GB such as the aperture 'a', the modulation 'm', the acceleration efficiency 'A', and the focusing parameter 'B" are decided in the CURLI code. The longitudinally bunched He beam enters into the accelerating section with the 54 cells, where the beam takes full energy in this area. Synchronous phase and modulation related with the high accelerating efficiency are nearly constant and the beam final energy reaches 4 MeV at the end of accelerating section. The ratio of the vane tip transverse radius of curvature to the average radius is 0.87 to have a constant capacitance per unit length along the axis of

RFQ. The table II shows the final values of the linac parameters optimized by the PARMTEQM code and Figure 2 shows the results of PARMTEQM simulation.

Table II: The RFQ linac parameters

parameter	Value	unit
Inter-vane Voltage	68	kV
Modulation parameter	1-2.0	
Minimum aperture	2.62	mm
Average radius	4.05	mm
Transverse radius of Curvature of vane tip	3.53	mm
Synchronous phase	-90 to -30	
Maximum surface field	22.97 (1.6 Kilp.)	MV/m
Beam transmission	95.0 %	
Total RFQ length	327.77	cm

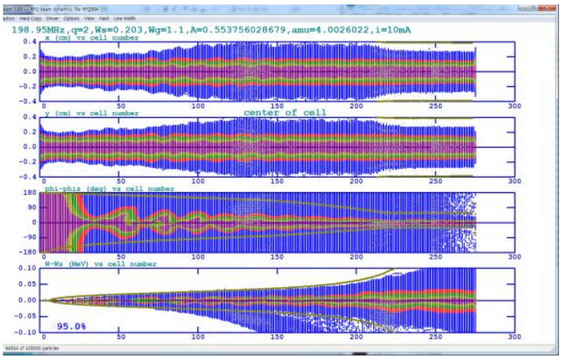

Fig. 2. Final results generated by the PARMTEQM code using 100,000 particles. From top to bottom are x, y, phase, and energy coordinates versus cell number.

3. RFQ cavity design using the SUPERFISH

.

The RFQ design using the SUPERFISH code [3] finds the proper cross section to obtain the resonance frequency 200 MHz with a given average radius and transverse radius of curvature of vane tip. The most important condition in this cross section design is to minimize the power dissipation for the easy cooling. The power dissipation value should have the less than 1 kW/cm at least. Table III shows geometrical parameters to design the quadrant of the RFQ cavity. In this design, power dissipation normalized by the gap voltage 68 kV is 73.25 W/cm.

Table III: Geometrical parameters of the RFQ

parameter	Value	unit
Corner radius	12	Mm
Break out angle	10 ˚	
Vane blank half width	5	mm
Vane blank depth	20	mm
Vane angle	20˚	
Vane shoulder length	15	mm
Vane base half width	20	mm
Vane base height	150	mm
Vane half width	73.56	mm

4. RFQ cavity design using the CST MWS

The electromagnetic field properties in the RFQ cavity can't be understood exactly by the two-dimensional cavity design done by the SUPERFISH code. The three dimensional model with large mesh numbers is needed and this model can be prepared in CST Microwave Studio (MWS) code [4]. Since the CST MWS code uses the Perfect Boundary Approximation (PBA) technique, the more detail electromagnetic field in the three dimensional space can be expressed in the RFQ. Figure 3 shows the unmodulated RFQ cavity model built in the CST MWS code.

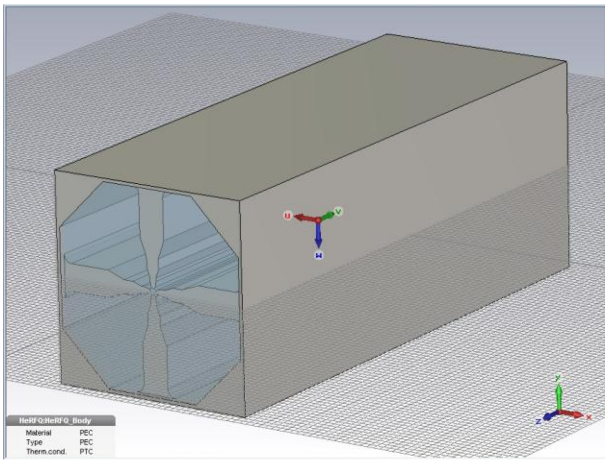

Fig. 3. The unmodulated RFQ model made by the CST MWS.

3. Conclusions

The beam dynamics design of 200MHz-He RFQ is done in PARMTEQM code. The input transverse normalized r.m.s. emittance is 0.2 π mm mrad and the output emittance is increased by 2.5 % with the beam transmission 95 %. The cross section of the two dimensional surface of the RFQ cavity is made by the SUPERFISH code with the proper power dissipation. The more detail design for the electromagnetic field distribution will be started using the CST MWS code.

REFERENCES

[1] K. R. Crandall, T. P. Wangler, L. M. Young, et al., "RFQ Design Codes". LA-UR-96-1836,
[2] W. D. Kilpatric, "Criterion for Vacuum Sparking Designed to Include Both rf and dc", Rev. Sci. Instr. 28, 824 (1957)
[3] J. H. Billen and L. M. Young, "Poisson Superfish", LA-UR-96-1834
[4] CST Studio Suite, "CST Microwave Studio", 2008, http://www.cst.com