DESIGN OF A 104-MHz TRAPEZOIDAL IH-RFQ*

Y. C. Nie, Y. R. Lu#, C. E. Chen, Z. Y. Guo, S. L. Gao, X. Q. Yan, K. Zhu, J. X. Fang
State Key Lab of Nuclear Physics and Technology, Peking University, Beijing, China

Abstract

RF design of a trapezoidal IH-RFQ (T-IH-RFQ) has been completed, combining with the low energy spread beam dynamics to accelerate $^{14}C^{+}$ from 40 to 500keV at 104MHz. RF properties of the T-IH-RFQ are studied and geometric parameters such as distance between two neighbouring support boards, width of stems and cavity diameter, have been optimized for improving transverse shunt impedance and quality factor, namely, reducing power consumption. Detailed description of the T-IH-RFQ and optimized results will be presented in this paper.

INTRODUCTION

A trapezoidal IH-RFQ is being built at Peking University, the length of which is about 1.1m operating at 104MHz, with the maximum required electrode voltage of 60kV [1]. A special feature is that the RFQ output beam energy spread of full width at half magnitude is as low as 0.6% approached by the method of internal discrete bunching, which makes potential application of RFQ to ^{14}C AMS and ion implantation possible [2]. T-IH-RFQ was proposed for the above beam dynamics design, because of its mechanical stability and absence of electrode voltage asymmetry which influences the beam quality. RF properties of T-IH-RFQ including electro-magnetic field distribution, resonant frequency and longitudinal flatness of electric field among 4 electrodes were studied by Microwave Studio (MWS) simulation [3]. Transverse shunt impedance was optimized in order to decrease power loss.

RF PROPERTIES OF T-IH-RFQ

According to beam dynamics design, average vane-tip radius is 3.1mm corresponding to average aperture radius of 3.5mm. Principal dynamics parameters needed in MWS simulation are listed in Table 1. The MWS model for the T-IH-RFQ is shown in figure 1. The electrodes are supported as figure 2. The whole cavity was simulated without being scaled in view of its short length and calculation accuracy. Electromagnetic field distribution has proven that T-IH-RFQ operates at $H_{21(n)}$ mode, not $H_{11(n)}$ as IH-RFQ [4]. Figure 3 is current flow, which means one support board is divided into two equal parts by electrodes fixed to it, forming a parallel circuit as inductive. As a result, T-IH-RFQ has higher resonant frequency than IH-RFQ and 4-Rod RFQ under the same transverse dimension. Moreover, in respect that the electrodes are supported by completely symmetry stem structure, quadrupole field of T-IH-RFQ is quite pure in contrast with 4-Rod RFQ and IH-RFQ, the dipole components of which are typically 2~3% and 0.5% respectively [5].

*Work supported by NSFC (19775009)
#yrlu@pku.edu.cn

Table 1: Principal Dynamics Parameters.

Operating frequency f (MHz)	104
Electrode voltage V_p (kV)	60
Average aperture radius a (mm)	3.5
Average vane-tip radius r_0 (mm)	3.1
Electrode length l (mm)	1091.3

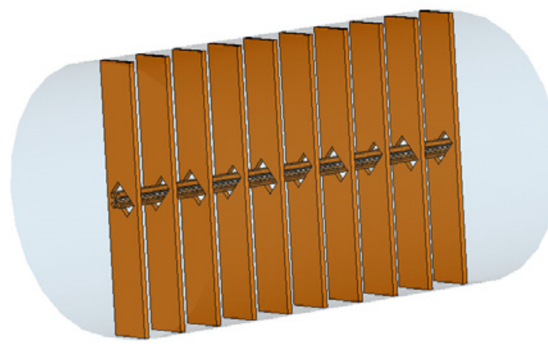

Figure1: MWS model of T-IH-RFQ.

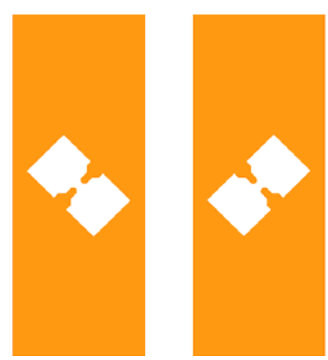

Figure 2: Electrodes and support boards.

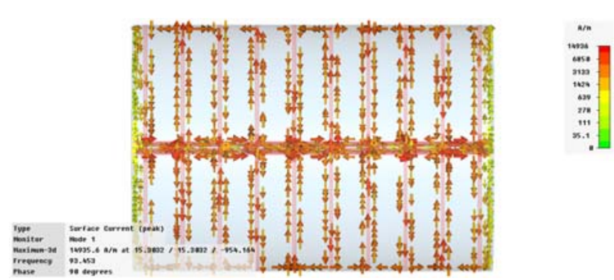

Figure 3: MWS simulation of current flow.

OPTIMIZATION OF T-IH-RFQ

Distance of Two Neighbouring Support Boards

The distance between two adjacent support stems, i.e. length of one basic resonant cell, is of great importance when optimizing T-IH-RFQ. High capacitance between electrodes or stems lowers the shunt impedance [6]. If the spacing is large enough, capacitance between the stems is small, so capacitance, dominated by electrode length, becomes bigger as the spacing increases. If the distance is too small, significant capacitive loading between stems becomes dominating. As a result, an optimum value of the distance is expected to make transverse shunt impedance maximal. MWS simulations were performed in a range from 80mm to 140mm while keeping resonant frequency constant by adjusting other parameters especially the height of support boards. Transverse shunt impedance and quality factor as a function of support boards spacing are plotted in figure 4. Apparently, ideal distance is about 120mm, but taking mechanical strength into account, 10 support boards have been adopted, so the distance was chosen to be 115mm.

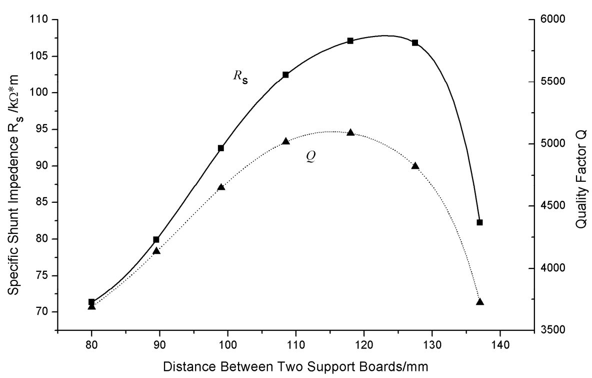

Figure 4: Transverse shunt impedance and quality factor of the T-IH-RFQ as a function of the distance between two neighbouring support boards.

Width of Support Boards

Wider support board means smaller inductance resulting in higher resonant frequency and lower shunt impedance [7]. Meanwhile, bigger the width is, bigger long interspace in the middle of support boards where no electrode is fixed (see figure 2) can be. An impressive thing is that greater long interspace of support board leads to larger resonant frequency and increases transverse shunt impedance, because the capacitance between electrode and support board becomes smaller. The support board width was simulated from 100mm to 140mm, while other structure dimensions were scaled to make frequency unaltered. Finally we obtain transverse shunt impedance and quality factor of the T-IH-RFQ as a function of support board width shown in figure 5, and then an appropriate value which is 130mm was chosen.

Cavity Diameter

Sensitivities of resonant frequency, transverse shunt impedance and quality factor of the T-IH-RFQ to cavity diameter were studied, since we decided to establish cavity diameter at last. Figure 6 is the results with the support boards spacing of 115mm and 130mm in width.

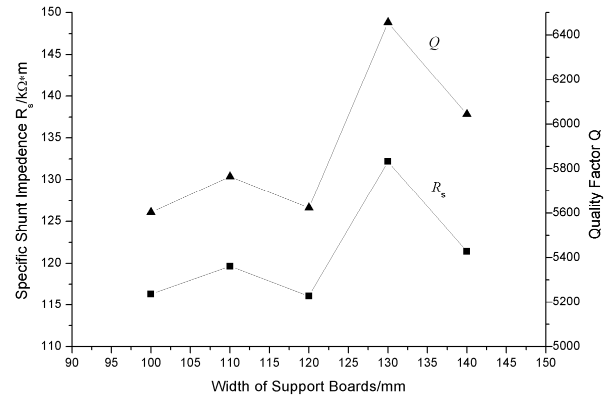

Figure 5: Transverse shunt impedance and quality factor of the T-IH-RFQ as a function of support board width.

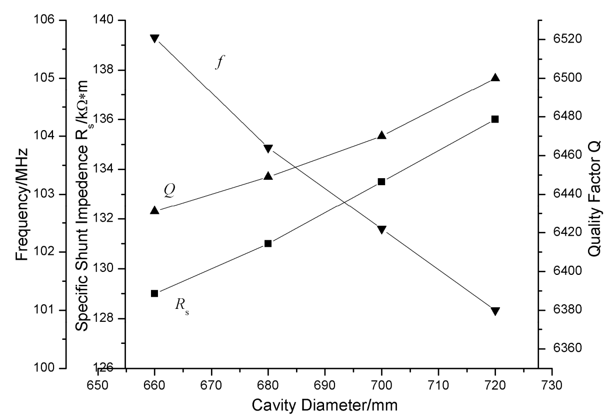

Figure 6: Sensitivities of resonant frequency, transverse shunt impedance and quality factor of the T-IH-RFQ to cavity diameter.

Finally, cavity diameter was chosen to be 720mm, with the support boards spacing of 115mm and support board width of 130mm to make the T-IH-RFQ resonant at 101MHz, about 3% lower than required operating frequency of 104MHz, in order to provide enough space for turning. The quality factor in MWS simulation is 6500, and transverse shunt impedance is expected to be 135kΩ·m under a conductivity of 5.0×10^7 S/m. According to the definition of transverse shunt impedance, the power loss P will be 29.3kW. The optimized structure parameters are listed in table 2.

Table 2: The Optimized Structure Parameters.

RF frequency f (MHz)	101
Cavity length L (mm)	1111.3
Number of support boards	10
Distance between support boards (mm)	115
Width of support boards (mm)	130
Thickness of support boards (mm)	12
Cavity diameter (mm)	720
Quality factor	6500
Specific shunt impedance (kΩ•m)	135
RF power (kW)	29.3

FLATNESS OF T-IH-RFQ

Longitudinal distribution of electric field between 4 unmodulated electrodes is plotted in figure 7. The field data has been normalized to average value. We can figure out that this T-IH-RFQ has a quite well flatness, which is less than 2% without turning. Actually, the electrodes are modulated, inducing a bad flatness due to different capacitance between electrodes along the axis because of the variation of aperture radius. As a result, tuning block should be used similarly to the case of 4-Rod [8].

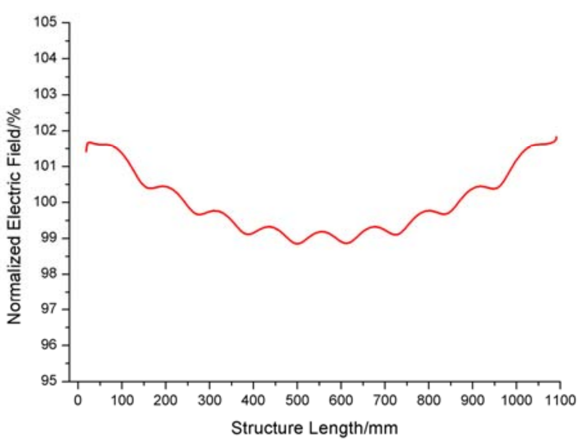

Figure 7: Longitudinal flatness of electric field.

SUMMARY

Based on the low energy spread beam dynamics design of $^{14}C^{+}$, T-IH-RFQ was proposed, which works at $H_{21(n)}$ mode. MWS simulations have been performed, which illustrates T-IH-RFQ possesses higher resonant frequency than 4-Rod and IH-RFQ with the same transverse dimension and electrode structure. Symmetry supporting method of T-IH-RFQ provides a symmetry quadrupole electric field among 4 electrodes, which ensures a good beam quality. Geometric parameters such as spacing between two support boards, width of support boards and cavity diameter have been optimized aiming to reduce power loss. Final results shows that 29.3kW RF power is needed to load the peak electrodes voltage of 60kV. The T-IH-RFQ power cavity is under construction at present. Tuning design will be carried out according to flatness measurements.

ACKNOWLEDGEMENTS

The authors would like to thank Prof. Dr. U. Ratzinger of IAP, Goethe University, Frankfurt am Main, for providing a PC to perform MWS simulation, and CSC of China for financial support. Discussions with Dr. Z. H. Li and Dr. C. Zhang at IAP are very fruitful.

REFERENCES

[1] Y. R. Lu, Y. C. Nie, C. E. Chen et al., "Low Energy Spread Beam Dynamics and RF Design of a Trapezoidal IH-RFQ", LINAC'08, Victoria, Canada, September 2008, MOP024; http://www.JACoW.org.
[2] Z. Y. Guo, K. X. Liu, X. Q. Yan et al., Nucl. Instr. and Meth. B 259(2007) 201.
[3] http://www.cst.com.
[4] U. Ratzinger et al., Nucl. Instr. and Meth. A 415(1998) 281.
[5] H. Podlech and U. Ratzinger, "Electromagnetic Design of an 80.5 MHz RFQ for the RIA Driver Linac", EPAC'02, Paris, France, June 2002, THPLE065, p.942 (2002); http://www.JACoW.org.
[6] P. G. Bricault and H. R. Schneider, "Simulation of the TRIUMF Split-Ring 4-Rod RFQ with MAFIA", PAC'95, Vancouver, Canada, May 1995, RPR03, p.1125(1995); http://www.JACoW.org.
[7] K. Zhu et al., HEP & NP 29(2005)512.
[8] P. Fischer, A. Schempp et al., "A CW RFQ Accelerator for Deuterons", PAC'05, Knoxville, Tennessee, USA, May 2005, RPAP002, p.794(2005); http://www.JACoW.org.