STUDY FOR A 162.5 MHz WINDOW-TYPE RFQ*

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Abstract

A window type of four vane radio-frequency quadrupole accelerator has been designed to accelerate 50 mA deuteron beam from 50 keV to 1 MeV. It will operate at 162.5 MHz in CW mode. Compared to the traditional four-vane RFQ, the window-type RFQ is more compact and has higher mode separation without π-mode stabilizing loops or dipole rods. A detailed full 3D model including vane modulation was developed. For the purpose of high shunt impedance, high quality factor and low power dissipation, the RF structure design was optimized by using electromagnetic simulations. Following the EM design optimization, an aluminium model of the window-type RFQ was fabricated and tested.

INTRODUCTION

The RFQ accelerator is normally used as injector in high-current linear accelerators [1]. Window-type RFQ, which has special RF characteristics different from traditional 4-vane and 4-rod structures, has been initially proposed at ITEP Moscow [2]. Generally, it is suitable in the condition of low frequency, continuous wave operation and high current [3]. The basic parameters of this 162.5 MHz RFQ required by the beam dynamics design are given in the Table 1[4].

Table 1: Main Parameters of the RFQ

Parameters	Value
Particle	D^+
Frequency [MHz]	162.5
Beam current [mA]	50
Beam duty factor [%]	100
Inter-vane voltage [kV]	60
Input energy [MeV]	0.05
Output energy [MeV]	1.01
Average radius [mm]	3.88
Vane tip radius [mm]	2.57-3.32
Length of the RFQ vanes [m]	1.809

Figure 1 presents the geometry of the structure and magnetic field distribution calculated by using CST-MWS [5]. The optimized electromagnetic design shows that the coupling windows can provide frequency separation more than 6 MHz from neighbouring dipole mode and quality factor of the structure nearly 10000. Resonant frequency and quality factor of the aluminium prototype are 0.2% and 14.8% deviating from simulation results.

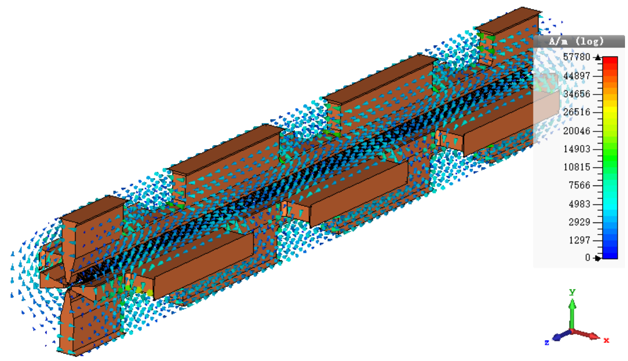

Figure 1: Full-length RFQ cavity.

RF CAVITY DESIGN

Just as Fig. 1 shows, rotational magnetic fluxes circulating around the windows enhance the magnetic coupling among quadrants, and then increase not only the frequency separation from parasitic modes but also the dissipated power because of more naked surface current area [6]. In order to obtain optimal simulation results, we have studied different size of the window varying *width* and *depth* Frequency, mode separation between operating mode (TE_{210}) and dipole mode (TE_{110}), and quality factor are plotted changing with *width*, for three values of *depth*. As Fig. 3 shows, mode separation increases linear along with *width* and *depth*. Quality factor increases by reducing *width* and increasing *depth* within a certain range of *width*. The simulations were done by using minimum aperture (2.5 mm) and maximum vane tip radius (3.5 mm), and they have the same variation trends with that using average aperture radius and vane tip radius. The selected values were *width* = 240.0 mm and *depth* = 80.0 mm as there is a compromise between mode separation and quality factor.

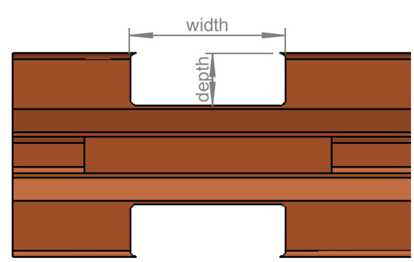

Figure 2: Geometrical parameters of the window.

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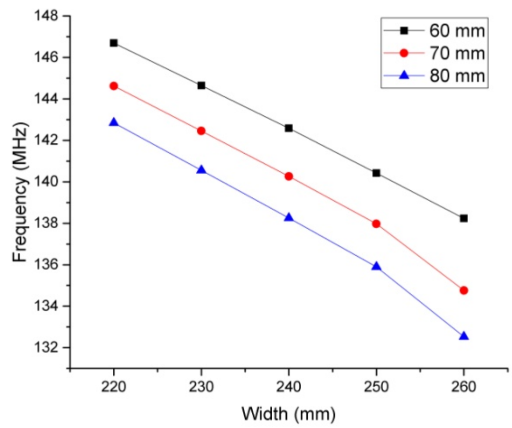
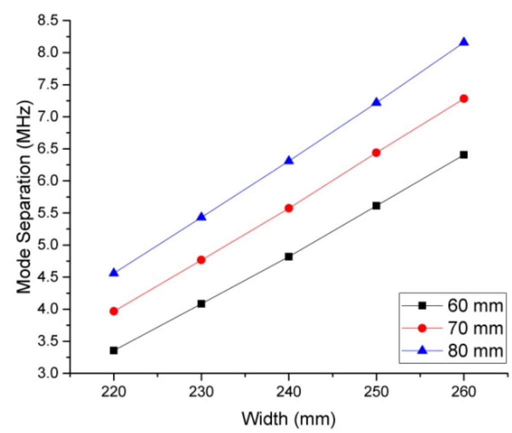
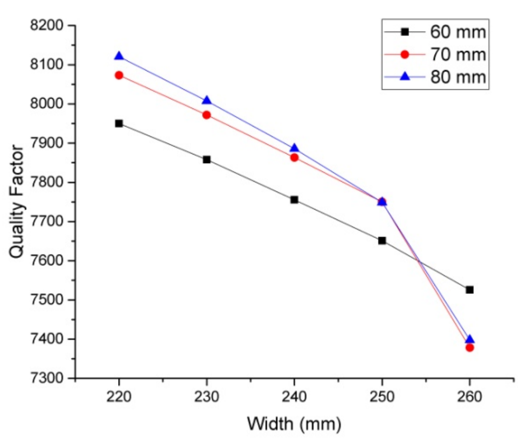


(a)



(b)



(c)

Figure 3: Evaluation of frequency (a), mode separation (b) and quality factor (c) as a function of *width* and *depth*.

The number of windows also has been studied. From Fig. 1 we can see that windows are equidistantly arranged in the vane and four vanes have the same number of windows (two half windows at both ends of the horizontal vane can be treated as one complete window). We have analysed the case of three windows and four windows respectively, while maintaining the length of the vane (1.809 m), and the results are shown in Table 2. When frequency and quality factor of the two are basically same, three windows can provide higher mode separation. It can be expected that in case of increasing *width*, four windows will have the same mode separation as that of three windows, and its quality factor will be lower than that of three windows. Finally, three windows were selected as more windows will decrease quality factor (just like 4-rod structure) and fewer windows will impact the flatness of longitudinal electric field.

Table 2: RF Characteristics at Different Number of Windows

Parameters	Three windows	Four windows
Frequency [MHz]	160.896	160.867
Mode separation [MHz]	7.017	5.278
Quality factor	7909.8	7964.7
Width [mm]	240.0	210.0
Depth [mm]	80.0	80.0
Inner cavity diameter [mm]	323.62	331.62

The current design with vane modulation was simulated. A total of sixteen 50-mm-diameter tuners, which can raise the frequency up to 1.3 MHz, make it possible to achieve the target frequency. A list of parameters of the whole structure is given in Table 3.

Table 3: Simulation Results and Geometrical Parameters of the RFQ

Parameters	Value
Frequency [MHz]	161.979
Nearest dipole mode (TE_{110}) [MHz]	168.229
Nearest quadrupole mode (TE_{211}) [MHz]	180.206
Mode separation [MHz]	6.250
Quality factor	9807.8
Stored energy [J]	0.405
Power loss [kW]	42.072
Special shunt impedance [kΩ·m]	77.396
The number of windows	3
Width [mm]	240.0
Depth [mm]	80.0
Inner cavity diameter [mm]	312.00

RFQ PROTOTYPE

In order to verify the reliability of the simulations, we have built an aluminium model of full-length RFQ. Besides, 16 tuners and vane modulation also have been manufactured, as shown in Figs. 4 and 5.

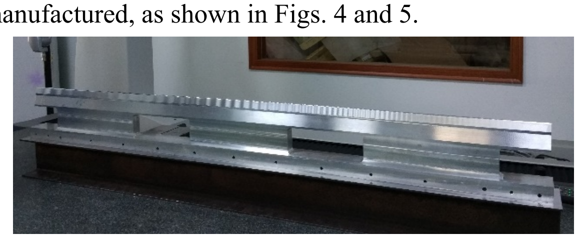


Figure 4: One of the modulated vanes.

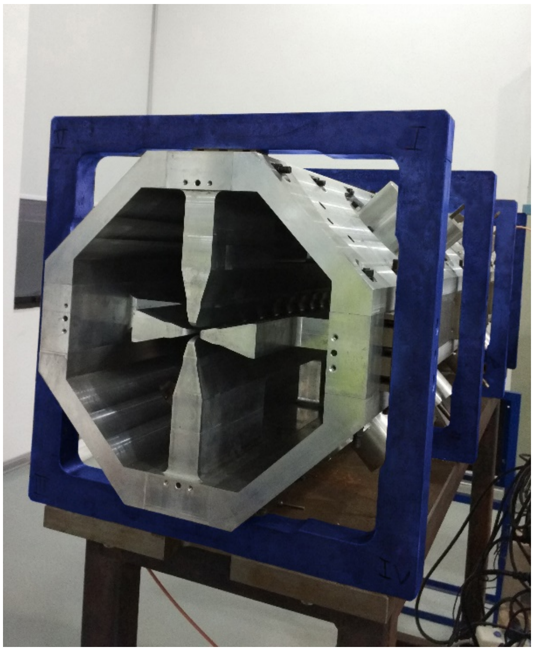


Figure 5: Aluminium RFQ prototype with open cavity.

The RFQ cavity consists of 4 vanes and 4 cavity walls. There are 4 steel frameworks outside the cavity, which were used to fix the position of vanes. After assembling all the components and correcting each vane's position, we obtained similar results with the simulations, as shown in Table 4. The approximately 0.3-MHz difference between the measured and simulated operating mode frequency can be eliminated by the frequency tuning.

Table 4: Comparison of the Simulated and Measured Parameters of the RFQ

Parameters	Simulated	Measured
Operating mode frequency [MHz]	161.979	161.680
Nearest dipole mode (TE_{110}) [MHz]	168.229	167.982
Nearest quadrupole mode (TE_{211}) [MHz]	180.206	180.438
Mode separation [MHz]	6.250	6.302
Quality factor ($\sigma = 1.9 \times 10^7$ S/m)	5614	4783

The measured distributions of longitudinal electric field for 4 quadrants are shown in Fig. 6. Due to the deformation of material and assembling error, the field unbalance among the 4 quadrants was measured to be within ±2.4%. The longitudinal field distribution has an average fluctuation of ±3.3%, as simulated field fluctuate nearly ±2%.

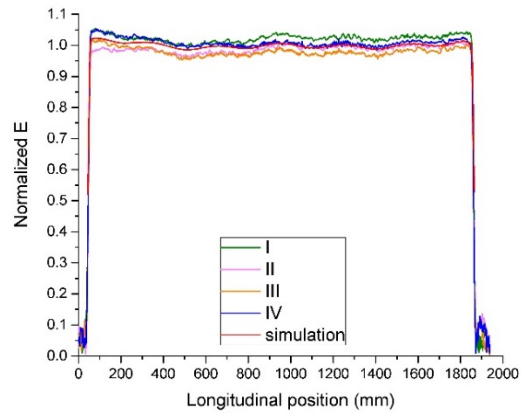


Figure 6: Normalized inter-vane electric field along the RFQ for 4 quadrants. Simulated result acts as contrast.

CONCLUSION

We have designed a window-type CW RFQ with large mode separation, low power dissipation and compact cavity diameter. The tests of the RFQ prototype show a good agreement with the simulations. However, there are some optimizations still needed for further improving the flatness of modulated electric field. Moreover, thermo-structural analysis and mechanical design are in progress.

REFERENCES

[1] V. A. Andreev and G. Parisi, "A 90 degree apart-stem Low Frequency RFQ", in *Proc. EPAC'96*, Sitges, Barcelona, Spain, 10–14, Jun 1996, p. 789.

[2] V. A. Andreev and G. Parisi, "90°-apart-stem RFQ structure for wide range of frequencies", in *Proc. PAC'93*, Washington, DC, USA, May 1993. Proceedings of the 1993 IEEE, 1993: 3124-3126, vol. 4.

[3] P. N. Ostroumov *et al.*, "Design of 57.5 MHz cw RFQ for medium energy heavy ion superconducting linac", *Phys. Rev. ST Accel. Beams*, vol. 5, no. 6, p. 060101, Jun 2002.

[4] F. J. Jia *et al.*, "Beam dynamics design of a 50 mA D+ RFQ", submitted for publication.

[5] CST Microwave Studio, https://www.cst.com/.

[6] Zhao Q *et al.*, "Design improvement of the RIA 80.5MHz RFQ", in *Proc. LINAC'04*, Vol. 4, Lübeck, Germany, 2004, p. 599.

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