CONCEPTUAL DESIGN OF A RADIO FREQUENCY QUADRUPOLE FOR HEAVY ION MEDICAL FACILITY

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Abstract

Design of conventional 4-vane/rod type of RFQ (Radio Frequency Quadrupole) for the heavy ion medical facility has been studied. The RFQ is capable of accelerating C^{4+} ions from an initial energy of 10 keV/u to 300 keV/u. In this work, all the design parameters have been optimized to achieve stable structure and compactness. The 3D electromagnetic field distribution and RF analysis were obtained by CST Microwave Studio and the field was used in TOUTATIS for beam simulation. This paper shows the determined physical and mechanical design parameters of RFQ.

BEAM DESIGN

At least a set of four parameters, consisting in aperture, modulation, synchronous phase and end-to-end voltage difference of the adjacent tips is necessary to define a tip geometry and analytic potential map of RFQ. The tip can be divided into four sections named radial matching, shaper, gentle buncher and accelerator sections. Each section has its own function. Using this functionality, we defined a set of design parameters, keeping below the current limit condition (<500 eμA), considered space charge effect, by applying smooth approximation. Fig. 1 shows the current limit condition and Fig. 2 shows the main design parameters. The output summary of the preliminary results is given in Table 1.

The aperture parameter was set from 4.1 mm to 3.1 mm to compensate the weakening focusing strength along the beam direction. Modulation and synchronous phase smoothly vary at the same time.

Table 1: Design summary

Parameter	Value	Unit
Particle	C^{4+}	-
Input energy	10	keV/u
Output energy	300	keV/u
Peak current	410	eμA
Input emittance x / y	1.43 / 1.41	π mm mrad (norm, rms, 90%)
Output emittance x / y	1.42 / 1.41	π mm mrad (norm, rms, 90%)
Energy deviation	0.86	%
Operating frequency	200	MHz
Duty	0.1	%
Pulse width	200	μs
Cavity length	1.6	m
Cavity diameter	28.2	cm
Peak power (4vane)	150	kW
Q (4rod / 4vane)	4200 / 10500	-
Average V0	96	kV
Transmission	98.9	%
Number of cells	283	-
Maximum surface field	1.6	Kilpatrick

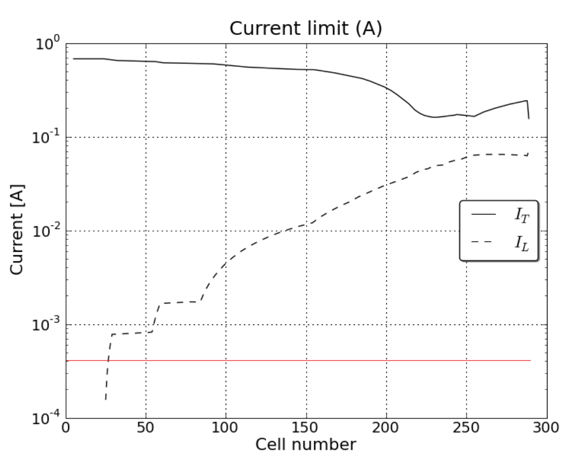

Figure 1: Current limit with smooth approximation line (I_T is transverse current limit and dashed line; I_L is longitudinal current limit)

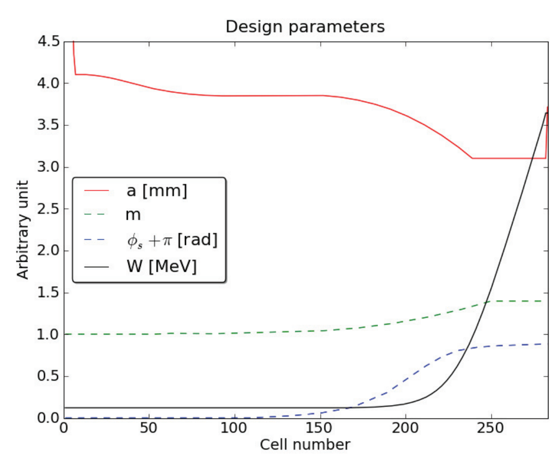

Figure 2: Main design parameters of RFQ consisting of a(aperture), m(modulation), phi(synchronous phase) and W(kinetic energy of synchronous particle)

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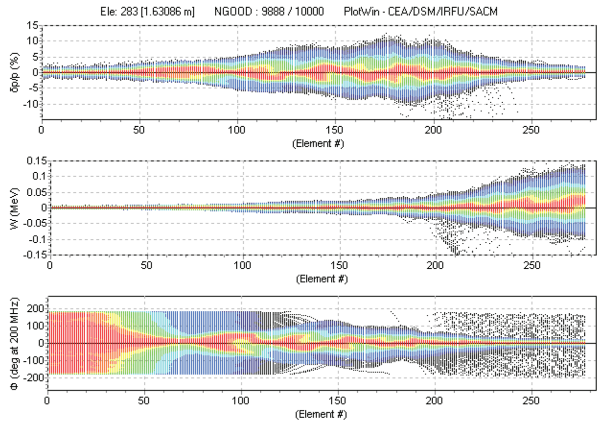
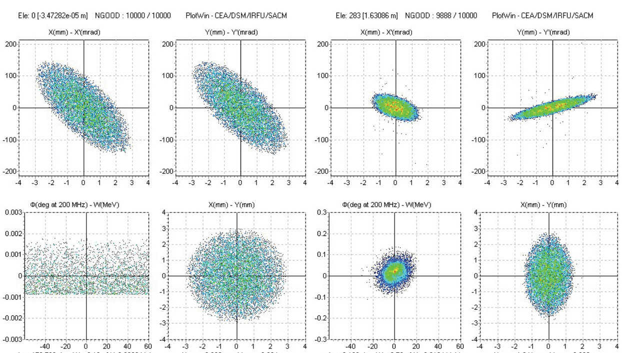


(a) configuration plot



(b) input beam (c) output beam

Figure 3: The figure (a) shows the configuration plot of the beam in the RFQ, the figure (b) shows input beams which have 4D water-bag distribution at cell zero and (c) shows the output beam profile at the last cell

Beam dynamics is calculated by TOUTATIS code. The transmission rate of this configuration reached 98.9% without emittance growth. The result is shown in Fig. 3(a) as a configuration plot and Figs. 3(b)(c) as the phase space plots.

CAVITY DESIGN

In the beam dynamics simulation, the vane tip voltage along the beam axis plays a key role. The focusing force mainly depends on the tip voltage difference between adjacent tips separated by a few millimeter. It means that the V_0 distribution is quite sensitive to aperture modulation of the tip. And the electric field near the beam axis is greatly affected by V_0 distribution which depends on geometrical cavity structure.

The absolute value of the voltage difference can be controlled by modulating the strength of stored power. But distribution of relative voltage value is determined by the geometrical structure of the cavity only. Therefore, the following procedure has been done.

- Adjust other parameters except V_0 (constant).
- Simulate the field by using the geometrical structure obtained from the output of the beam simulation.
- Applying V_0 distribution obtained from the above and proceed beam simulation again.

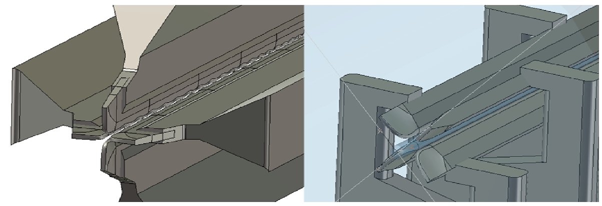


Figure 5: Two types of geometrical structure

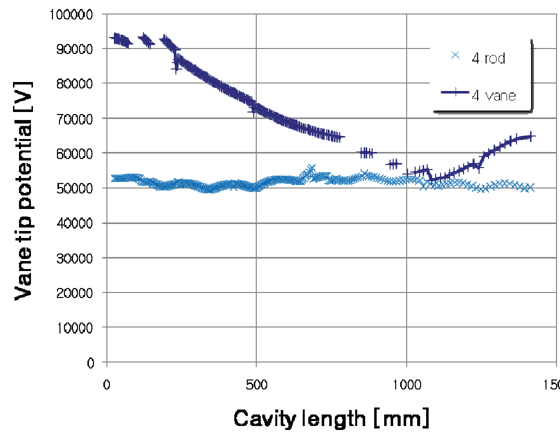


Figure 6: V_0 distributions of two RFQ structure

CONCLUSIONS

A simulation of RFQ for C^{4+} which is capable of accelerating up to 300 keV/u has been done by using TOUTATIS. To adjust resonance frequency and Q value, the geometrical structure was built and tested in MWS. As a result, design parameters of applied V_0 distribution was determined.

REFERENCES

[1] TOUTATIS, "A 3D RFQ Code", CEA
[2] CST. Microwave Studio; http://www.cst.com