BEAM DYNAMICS DESIGN AND ERROR STUDY OF THE 5MeV RFQ

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Abstract

An RFQ, which will be operated at 352 MHz frequency and 6% duty factor and will accelerate 50mA proton beam from 80keV to 5MeV, has been proposed as an injector of the verification facility of Accelerator Driven System (ADS) for Radioactive Clear Nuclear Power System in China. The RFQ general layout and beam dynamics simulation and error study are described in the paper.

1 INTRODUCTION

In November 2000 it was considered to construct an RFQ as an injector of the verification facility of ADS in China. Since then we started to do the conceptual design of the RFQ. According to the design requirements, the RFQ will be operated at 352MHz frequency and 6% duty factor .The RFQ will accelerate 50mA of peak proton beam current from 80keV to 5MeV and deliver it to the DTL, which keeps the same frequency of the RFQ. The RFQ transverse acceptance is sufficient to accelerate beams up to 50mA output current with a normalized emittance less than 0.2π-mm-mrad (rms) and with a transmission efficiency of greater than 95%. The RFQ power consumption needed is near 900 kW. The design requirements of our RFQ are listed in Table 1.

Table 1: Design requirements of our RFQ

Particle	H+
Energy input/output	80keV/5MeV
Peak beam current	50mA
Tran. norm. emittance, rms	0.2π-mm-mrad
Duty factor	6%
Frequency	352MHz
Beam transmission	>95%
Peak RF power consumption	<900 kW

2 BEAM DYNAMICS DESIGN

According to the beam dynamics design, our RFQ is divided the usual four sections: the radial matcher, the shaper, the gentle buncher and the accelerator. The first six cells is the radial matching section, where the proton beam is gradually matched to the time dependent transverse focusing system. The next 93 cells is the shaper section where the bunching process is initiated with a slow decrease of stable phase from -90 to -83.1 degree and with a slow increase of modulation parameter m from 1 to 1.1038. The next 139 cells is the gentle buncher section, where the stable phase is decreased to -38 degree, the parameter m is increased to 1.794, the proton beam is brought to 514keV and fully bunched. At the end of the gentle buncher section, where the beam has achieved its minimum bunch length, space charge forces on the beam are at a maximum and the aperture (a=2.05mm) is at a minimum. The final 173 cells is the accelerator section. In order to shorten the RFQ length and to get more accelerating efficiency, in this section the stable phase and parameter m are not constant. The stable phase is gradually varied from -38 degree to the end of -29 degree and the parameter m is slowly varied from 1.794 to the end of 1.943. And the proton beam is accelerated to 5MeV at the end of RFQ. In the accelerator section, that corresponds to more than 3/4 of the total structure length. Our RFQ has a total of 411 cells and a length of 7.13 meters, corresponding to 8.3 times the wavelength in free space. In order to extend the mode distant respect to the closest quadrupole modes and to sure the operation stability, the segmented resonantly coupled four vanes structure [1,2] has been chosen for our RFQ. The RFQ has three of coupled segments and two of coupled gaps. In our case the operating mode is more than 2MHz distant respect to the closest quadrupole modes, and the dipole modes are outside the range of the main quadrupole band. The inter-vane voltage is kept constant of 68kV along the structure, while the average aperture R_0 is increased so to allow a higher electrode modulation keeping the necessary aperture a. This choice allows to shorten about 0.6 meter RFQ length and to save the RF power, near 54kW, without a ramp of the inter-vane voltage. The main parameters of our RFQ are shown in Fig.1 and listed in Table 2.

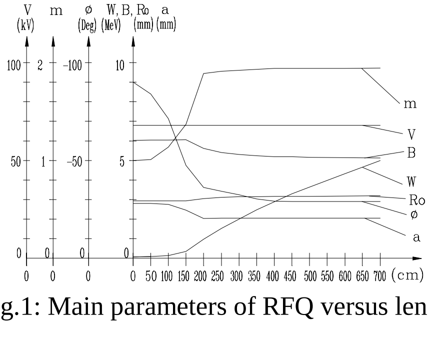

Fig.1: Main parameters of RFQ versus length

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[*] from China Institute of Atomic Energy

[**] from Peking University

Table2: Main parameters of our RFQ

Inter-vane voltage	68 kV
Tran. focusing parameter B	6.08-5.116
Modulation parameter m	1-1.943
Stable phase	-90— -29 Deg.
Beam transmission	> 95%
Max. surface field	< 33 MV/m
Dissipated power (SF*1.3)	0.627 MW
Peak beam loading power	0.246 MW
Total peak RF power	0.873 MW
Average aperture	2.93-3.19 mm
Minimal aperture	2.05 mm
RFQ length	713 cm
Number of coupled segment	3
Number of coupled gap	2

The beam simulation of the RFQ had been performed by codes of PARMTEQM and LIDOS.RFQ. The beam transmissions are 95.6% and 97.7% by PARMTEQM (with 10000 macro particles) and LIDOS.RFQ (with 50000 macro particles) respectively. The simulation results are rather similar. Fig.2 shows the beam simulation results by PARMTEQM.

In our RFQ design there are some features as follows:

- The inter-vane voltage kept constant along the structure, so it is easier to adjust the field distribution along the length.
- The inter-vane voltage (68kV) is low. And the parameter m and stable phase are specially varied in the accelerator section, so a more reasonable power dissipation and length of RFQ had been achieved.
- Due to the adopting a long and segmented resonantly coupled structure, the operating frequency is 2MHz distant respect to the closest quadrupole modes.
- The beam transmission is high (>95%) and the increment of rms emittance along the z is low (<10%).

3 ERROR STUDY

An error study of the 5MeV RFQ was carried out. The calculated sensitivity to initial beam alignment, mismatch, emittance and inter-vane voltage variation is shown in from Fig.3 to Fig.9. Fig.3 shows the transmission versus the displacement of the input beam. Fig.4 shows the transmission versus the beam steering errors into the RFQ. Fig.5 shows the transmission versus vane voltage factor which means real voltage values over design voltage values. If the vane voltage factor is less than 0.95, the beam transmission is sharply reduced. In order to maintain the high beam transmission in RFQ, the voltage factor must be kept more than 0.95. Otherwise the beam transmission is low. Fig.6 shows the effect on transmission if the input beam is not at the correct energy of 80keV design value. Fig.7 and Fig.8 show the transmission versus the input beam emittance and current respectively. Observably, the emittance and current are lower and lower, the transmission can be get higher and higher. In order to get a good transmission, the emittance is as low as possible. Fig.9 shows the transmission versus the tilt factor. On the basis of the simulation a tolerance of about ±2.5% per meter tilt with respect to the nominal field is required for good performance of the RFQ. From the error study we can conclude that a high beam transmission is preserved in case of different error sources.

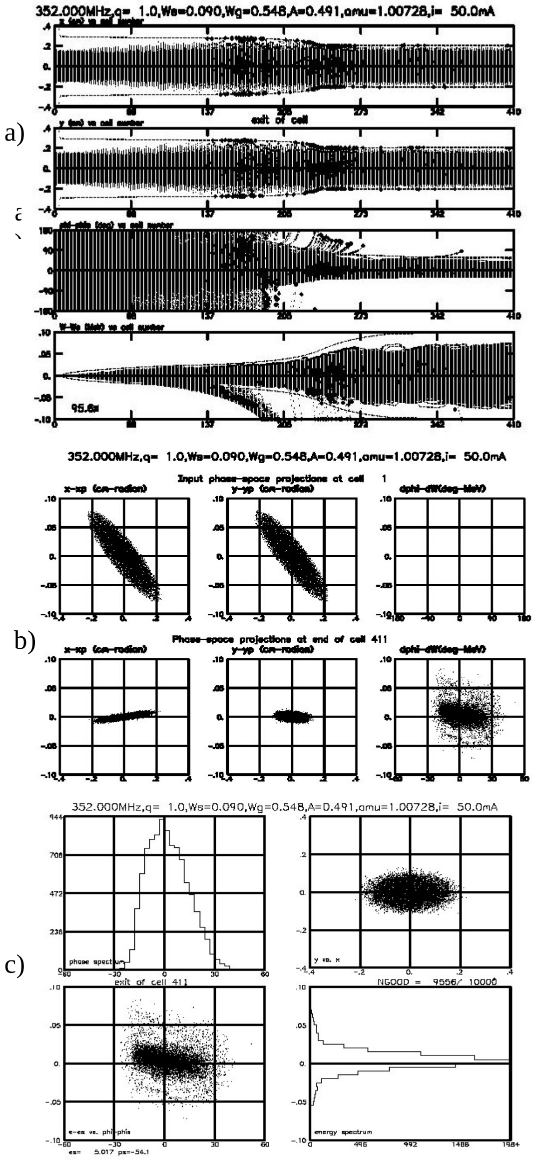

Fig.2: Beam simulation of the RFQ for 50mA current

Notes: In Fig.2, (a) shows the PARMTEQM simulation of the RFQ using 10000 macro particles. From top to bottom are: x, y, phase and energy coordinates versus cell number. Bold black points indicate the lost particles in RFQ. (b) shows the phase-space projections at input of cell 1 and output of cell 411. (c) shows the beam profile and phase spectrum at output of cell 411.

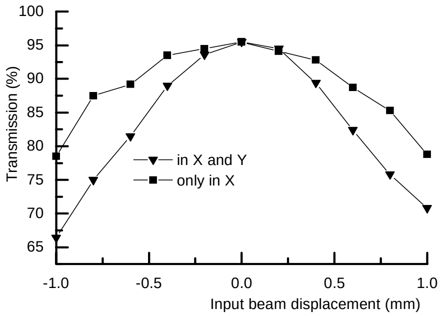

Fig.3: Transmission vs input beam displacement

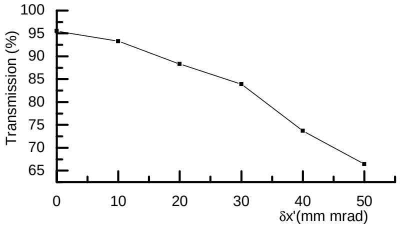

Fig.4: Transmission vs beam angle

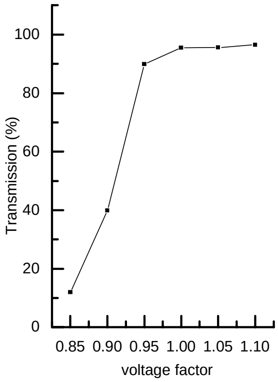

Fig.5: Transmission vs voltage factor

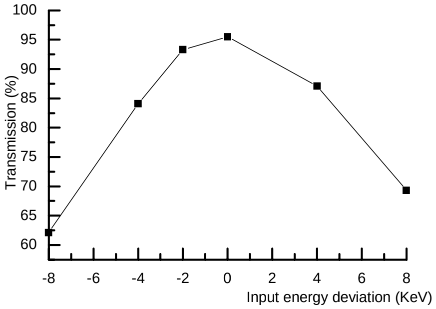

Fig.6: Transmission vs input energy deviation

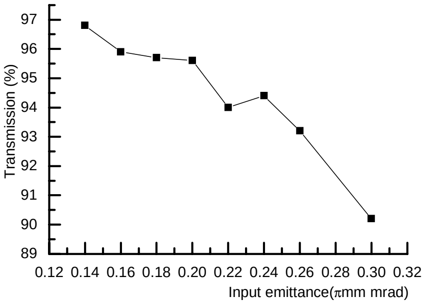

Fig.7: Transmission vs input emittance

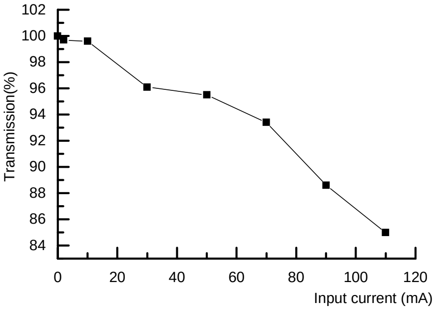

Fig.8: Transmission vs input current

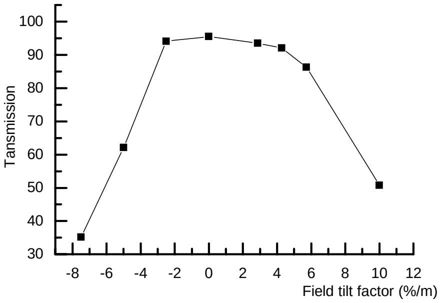

Fig.9: Transmission vs field tilt factor

4 ACKNOWLEGMENTS

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