DESIGN OF A 200MHZ PROTON RFQ

Z.Y. Guo, C. Zhang, X.Q. Yan, J.X. Fang, Y.R. Lu, C.E. Chen
Institute of Heavy Ion Physics, Peking University &
Key Laboratory of Heavy Ion Physics, Ministry of Education, Beijing, China

Abstract

A 200MHz RFQ was designed to accelerate proton beam to over 2.0MeV. A four-rod type structure with mini-vanes was adopted and a 200MHz 400kW tetrode amplifier will be used as its RF power source. The basic consideration was presented. The design of particle dynamics was performed with PARMTEQM and the preliminary results were given.

1 INTRODUCTION

Since the principles of radio frequency quadrupole (RFQ) linac were proposed by Kapchinsky in 1969 [1], RFQ has been accepted worldwide due to its capability of focusing and accelerating a lower-energy high-intensity ion beam efficiently at the same time. Typically, it can capture over 80% of a high-intensity beam and accelerate the ions from tens of KeV to several MeV within a shorter length.

Recently using RFQ to accelerate intensive proton beam has become a common interest. As injector, RFQ is the major component for high power proton accelerators (HPPA), which are very important to many applications like accelerator-driven systems [2], spallation neutron sources [3,4] and neutrino factories etc. [5]

On the other hand, proton RFQ can also be used alone as a lower-energy accelerator, which has been mainly used for neutron applications, for example, neutron radiography [6]. This paper will give a preliminary design of a 200MHz proton RFQ accelerator, which will be constructed at Peking University and used for some neutron applications.

2 BASIC CONSIDERATION FOR THE DESIGN OF 200MHZ PROTON RFQ

There are mainly three kinds of equipments to produce neutron beams, which are reactors, accelerators and radioisotope sources. Reactors can produce very high thermal neutron fluxes (10^6-10^9 n/s·cm^2) but cannot be removed, radioisotope sources are easy to remove but its neutron fluxes are very low. Accelerator-based neutron generators may have both advantages. Their thermal neutron fluxes can reach a level of 10^5-10^6 n/s·cm^2, and they could be transportable or easy to set up in a small building.

When a proton RFQ is used as a neutron generator, two reactions can be selected. One is the ^{9}Be(p, n) reaction with threshold energy about 2.0MeV, and another is the ^{7}Li(p, n) reaction with threshold energy about 1.88MeV. Hence, the output energy of RFQ should be typically between 2.0MeV and 3.0MeV. In order to obtain higher neutron flux, enough beam intensity is necessary. For example, in the case of 2.5MeV, the output beam current had better exceed 4mA.

There are three kinds of RF power sources used for RFQ so far. Klystron and planar triode are often adopted with higher frequency, typically 350 or 400 MHz. The output power of planar triode is limited, which duty factor is usually quite low. Klystron can give high output power, but its dimension is big, its power consumption and cost are quite high, too. The tetrode can operate with higher duty factor and give enough average output power, but the working frequency is usually lower than 250MHz. For example, the tetrode TH781 manufactured by Thomson Tubes Electroniques (now THALES) can deliver 400kW peak power with 16% of duty rate and pulse duration 1.4ms at 200MHz [7].

For a 200 MHz proton RFQ, its cavity can be built basically as four-vane type or four-rod type. Considering the simplicity and the experiences from our 1MeV Integral Split Ring RFQ with mini-vanes, we prefer to choose the four-rod type with mini-vanes (see Fig. 1), which electrodes have better rigidity and are suitable to cool with water for high duty factor.

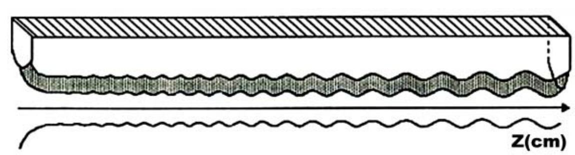

Figure 1: The sketch map of mini-vane

As a preliminary design, the duty factor of the 200MHz RFQ was chosen as 10%, then the output peak beam current should be 40mA. In practice, the beam transmission of RFQ is basically between 80% and 100%, so the input peak beam current should be 50mA. Considering the sparking problem and the limit of RF power source, the electrode voltage of 74 kV has been chosen. So the main design parameters of the 200MHz RFQ are determined (see Table 1).

3 PRELIMINARY RESULTS OF THE BEAM DYNAMICS DESIGN

On the basis of the given design requirements, beam dynamics design was carried out to get good performance of the output beam. The software package used is PARMTEQ Version 2, which includes the RFQ design codes RFQuick, Curli, Pari, and the beam dynamics calculation code PARMTEQM. Compared with the older version, PARMTEQM takes the effects of image charge and higher-order multipole fields into account.

Table 1: Design parameters of the 200MHz RFQ

Particle	H^+
Frequency	200MHz
Output Energy	2.0-3.0MeV
Peak beam current	50mA
Electrode voltage	74KV
Duty factor	10%
Peak RF power consumption	<400kW
Tran. norm. emittance, rms	0.2π mm-mrad
Electrode type	mini-vane

For better transverse and longitudinal capture efficiency, the design procedure is usually to divide the whole RFQ into four separate sections, i.e. radial matcher (RM), shaper (S), gentle buncher (GB) and accelerator (A) [8]. If the length of the first three sections is long enough and other parameters are appropriate, the beam transmission can exceed 90%, but it will also lead to a longer RFQ cavity. That means higher RF power consumption. So we have to weigh the advantages and disadvantages of different simulation results. Several design schemes were compared and one criterion was set up, which is that the beam transmission T should be greater than 85% and the RFQ's length L should be less than 400cm. Table 2 gives two preliminary schemes of the 200MHz 2.5MeV proton RFQ.

Table 2: Preliminary design results of the 200MHz RFQ

Main parameters	**Scheme 1**	**Scheme 2**
Input energy (MeV)	0.050	0.050
Energy after Shaper (MeV)	0.075	0.070
Energy after GB (MeV)	0.465	0.480
Output energy (MeV)	2.5	2.5
Modulation parameter	1-2.399	1-2.359
Accelerating efficiency	0.664	0.654
Focusing parameter	7.076	6.782
Aperture after GB (cm)	0.280	0.290
Final synchronous phase	-30°	-30°
Beam Transmission (%)	86.4	88.9
RFQ's Length (cm)	376.3	391.8

In the first scheme, the beam transmission T is 86.4% and the RFQ's Length L is 376.3cm. In the second one, however, T is 88.9% and L is 391.8cm. To some degree, T is in contradiction to L. According to the practical condition, some parameters concerned, such as the energy after shaper and GB, aperture after GB and modulation parameter, should be adjusted to get an optimum design.

The PARMTEQM simulation result of the scheme1 is showed in Fig. 2. And its detail parameters of every section are listed in Table 3.

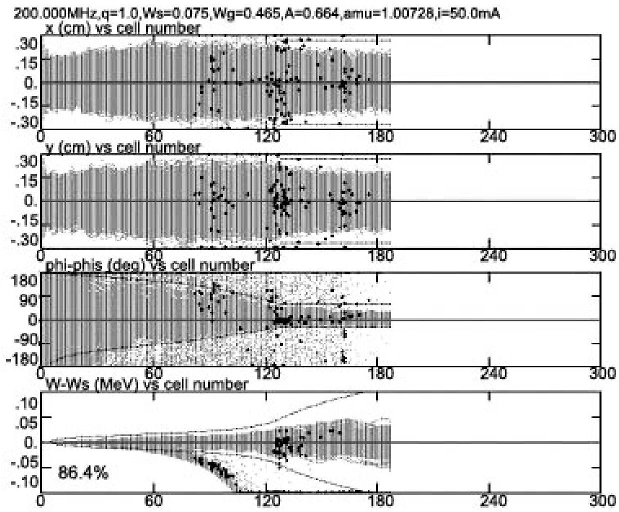

Figure 2: PARMTEQM simulation result of the scheme1

Table 3: Detail parameters of the scheme1

	RM	S	GB	A	
W (MeV)	0.050	0.050	0.075	0.465	2.500
m	1.000	1.000	1.109	2.399	2.399
a (cm)	2.238	0.500	0.475	0.280	0.274
Φ_s (deg)	-90	-90	-70	-30	-30
V (kV)	0.074	0.074	0.074	0.074	0.074
A	0	0	0.057	0.664	0.697
B	0.354	7.076	7.076	7.076	7.076
L (cm)	0	3.1	60.2	134.8	376.3

4 CONCLUSION

The high current proton RFQ accelerator has attracted special attention in the world due to its wide applications. On the basis of two low-frequency heavy-ion RFQs built in the past ten years [9], The RFQ Group at Peking University is designing a 200MHz proton RFQ. At present, its beam dynamics design has been performed and some preliminary but useful results have been given. Further study will be focused on a final scheme with good features. The calculation of RF electromagnetic field, thermal analysis and cold model experiments will be started successively.

5 ACKNOWLEDGEMENT

The authors wish to thank Prof. Tang Guoyou for his helpful discussions on neutron physics and technology.

6 REFERENCES

[1] I.M. Kapchinsky et al., "A Linear Ion Accelerator with Spatially Uniform Hard Focusing", SLAC-TRANS-0099 (1969), 17

[2] M. Comunian et al., "TRASCO RFQ Design", Proceedings of EPAC 2000, Vienna, Austria, 927-9

[3] A. Ratti et al., "Conceptual Design of the SNS RFQ", Proceedings of the XIX International Linac Conference (Chicago, IL, August 1998), 276-8

[4] R Duperrier et al., "Design of the ESS RFQs and Chopping Line", Proceedings of EPAC 2000, Vienna, Austria, 930-2

[5] P-Y. Beauvais et al., "Status Report on the Saclay high-Intensity Proton Injector Project (IPHI)", Proceedings of EPAC 2000, Vienna, Austria, 283-5

[6] R.W. Hamm, "Compact Ion Linear Accelerators for Neutron Radiography", Proceedings of the 3rd World Conference on Neutron Radiography (Osaka, Japan, May 14-18, 1989), 231-8

[7] Thomson Tubes Electroniques.

[8] R.H.Stokes et al., "The Radio Quadrupole: General Properties and Specific Applications", Proceedings of the 11th International Conference on High-Energy Accelerators (Geneva, Switzerland, July 7-11, 1980), 399-405

[9] C.E. Chen et al., "Progress of RFQ for Ion Implantation at Peking University", Proceedings of EPAC 2000, Vienna, Austria, 2594-6