DESIGN STUDY OF A HEAVY ION RF LINAC FOR MEV IMPLANTER

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Abstract

A preliminary design study is done for the design of a 4-rod RFQ linac. A modified PARMTEQ code is able to predict the transmission of an multiply charged ion beam and also to see what happens when injection energy is varied from the design value. Space-charge limited current is also checked, though our linac is not intended to be used for accelerating more than few mA of an ion beam. A 1/3 scale cold-model is constructed for the RFQ to check the resonant frequency, Q-value, and the field distribution. The number of electrode-supporting structure is six and the length of the electrodes is 793 mm. Our target is to optimize the dimension of the RFQ structure and operate the resonator in 100 MHz inside a 200 mm diameter tank. A 1/3 scale cold-model of spiral resonator is also build and its resonant frequency, Q-value, and on-axis field distribution are measured. This resonator is going to be placed downstream of the RFQ and operated as a post accel./decelerator in the same resonant frequency as the RFQ but in different phase condition.

Introduction

RFQ has its several appealing points to be recognized by industrial accelerator users as a high current and high energy accelerator in ion implantation application. Compared with conventional electrostatic accelerators, implanter's weight is going to be less heavier and radiation shield is much easier in RFQ linac design. Those points should be greatly appreciated and be carefully studied for the design of a successful commercial RFQ machine. We have been working on 4-rod RFQ for several years and accumulated quite a deal of experiences as we developed a proton accelerator.[1] Rod type structure has been selected because the diameter of the vacuum tank of the RFQ can be made smaller and the maintenance and tuning of this RFQ is expected to be much simpler than vane-type RFQ.

Rough Design Work

Unlike high-intensity light-ion RFQ , a particular attention is needed when doing the parameter search of a heavy ion RFQ in low beta regime. Transmission efficiency of the RFQ is restricted mainly by the acceptance of the linac not by the space-charge limits. Users are happy at moment if we could offer beam current at order of one mA and RFQ does not present much difficulty handling this amount of current load. Other important considerations are associated with mechanical and engineering difficulties and consequently the manufacturing costs. The length of the electrodes and the operating frequency must be optimized to guarantee the mechanical rigidity of rod-RFQ structure within the tolerance of assembly requirements.

Ion Source Emittance

An effective intrinsic normalized emittance, e_n is found as follows,

$$e_n = 2\, r_s \left(kT / Mc^2 \right)^{1/2} \quad [\text{ m-rad }] \,, \qquad (1)$$

where r_s is the beam radius at the emitter surface, kT is the source temperature - typical value is 3 eV - and M is the mass of ions.[2] e_n is roughly 1 mm-mrad for boron when r_s is 3 mm. An unnormalized emittance at energy 25 KeV is then approximately 0.045 cm-rad for this case. The acceptance of RFQ must then be larger or at least comparable to this value to accommodate a large portion of incoming ion particles. In PARMTEQ simulation, 10 % larger value of the above estimate is used for the input emittance.

PARMTEQ Simulation

RFQ parameters are listed in table 1. We intended to get most efficient parameters considering the length of RFQ, power requirement, and beam transmission. At moment this involves a long and repetitive work on computer and requires some experience to reach at satisfactory results.

Table 1
Design RFQ Parameters

Frequency	33.3 MHZ
Characteristic bore radius	0.8 cm
Focusing strength	6.79
Inter-electrode voltage	54.9 kV
Mass of ion	11 AMU
Charge state	1
Injection energy	25 keV
Output energy	1 MeV
Total length	310 cm
Number of cells	144

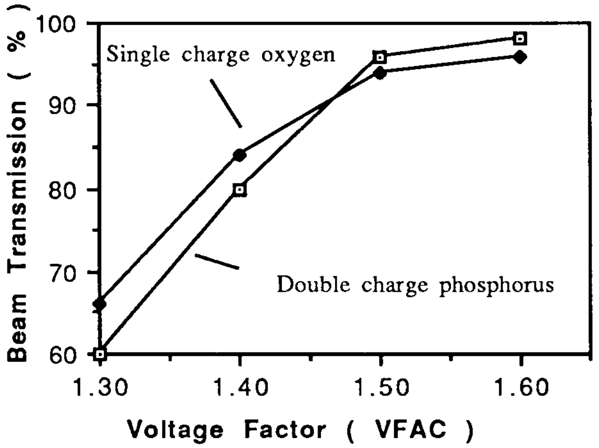

Fig. 1. Beam transmission of $^{31}P^{++}$ and $^{16}O^{+}$ in fixed structure and fixed operation frequency of a RFQ.

The beam transmission of $^{11}B^{+}$ is 92 % when the inter-electrode voltage is increased by 10 % of the design value in the dynamics calculations. Fig. 1 shows the beam transmission of $^{31}P^{++}$ and $^{16}O^{+}$ beam in the same RFQ. The results are that if we tolerate the transmission efficiency, a range of ion species can be accelerated by adjusting the input power. Fig. 2 is the transmission efficiency of $^{11}B^{+}$ beam as a function of injection energy. The results shows that our RFQ has a rather broad acceptance with regard to the variation of injection energies.

Space Charge Limits

The current limits are checked with LINACS.[3] The parameters are from the 110 th cell - supposedly at the end of the gentle buncher section - of the RFQ : the aperture, a =0.527 cm; the modulation, m=1.962; the output energy at the end of the cell, W_0=0.282 MeV; and the maximum field=10.47 MV/m. Fig. 3 shows both longitudinal and transverse current limits as a function of modulation parameter.

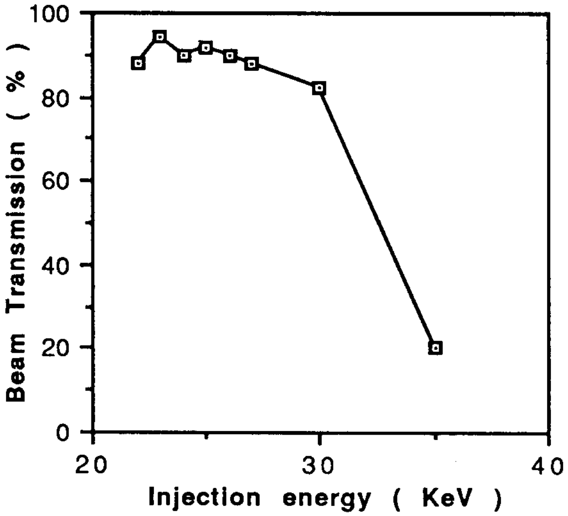

Fig. 2. $^{11}B^{+}$ beam transmission as a function of injection energy. The design injection energy is 25 keV.

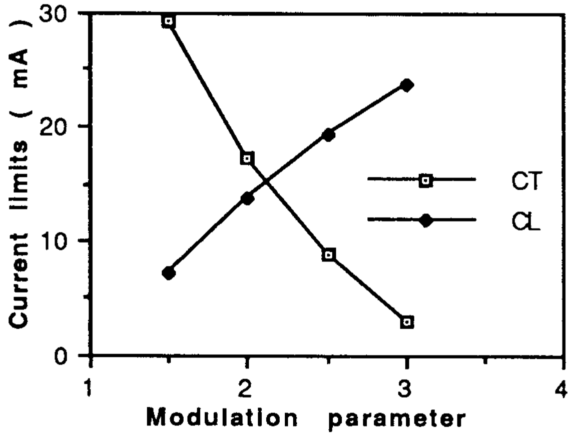

Fig. 3. Transverse (CT) and longitudinal (CL) space charge current limits as a function of modulation parameter.

Model Study of RFQ

4-rod RFQ presents relatively less rigorous engineering difficulties compared with 4-vane RFQ, nevertheless still there are important subjects we have to work and improve on . Those are structural rigidness and cost performance. Our 100 MHz 4-rod proton RFQ was only 75 cm long so it was not too heavy and sufficiently rigid with just 4 supporting structures. For a heavy ion RFQ with output energy reaching 100 KeV/nucleon, the resonator must be operated much lower frequency and its length becomes around 200 cm. If the structure is made with just 4-supporting posts, the droop of an cantilevered electrode will not be negligible and cannot be kept under machining and assembly tolerances. On the other hand, with 6-supporting post, the height of the post must be made much larger than that with 4-supporting post structure. The results are increase in the construction cost of the vacuum tank due to its larger diameter. The purpose of this model study is to search for the final dimension of the RFQ in reasonable size and to check its RF characteristics.

Droop of Electrode

The maximum displacement of electrode droop, Y can be estimated from the following equation,

$$Y=w\,L^4\,/\,(\,8\,E\,I\,) \qquad (2)$$

, where w is weight distribution, L is length, E is Young's modulus, and I is the second moment of system.[4] The cross-section of a RFQ is approximated by a rectangle of 24 by 60 mm, and its orientation is tilted 45 degree. Material is C1020-1/2H copper. The result is that when one end of an 50 cm long electrode-rod is fixed to the post, the maximum displacement becomes approximately 30 microns. This is less than but unfortunately comparable to what we expect for machining or assembly tolerances, 50 microns.

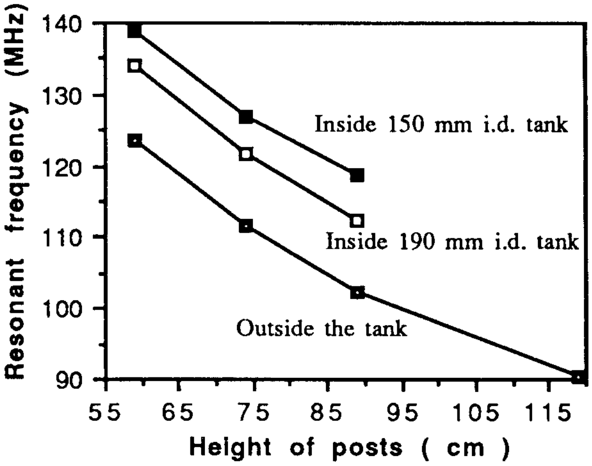

Fig. 4. Resonant frequency of 4-rod RFQ as a function of the height of the posts.

RF Characteristics

Fig. 4 shows the resonant frequencies of our 4-rod RFQ as a function of the height of the post in three different surrounding conditions: inside 190 mm diameter tank, inside 150 mm diameter tank, and outside the tank. The number of the post is six - this means a pair of RFQ electrode is supported by three posts. The width and thickness of the post are 80 mm and 15 mm, respectively. The posts are evenly spaced at 150 mm from each other. The electrode is un-modulated and its length is 793 mm. The aperture radius is 2.7 mm. RF contact between the tank and the base-plate of the RFQ assembly is made by commercially available "RF shield fingers". Note that the center of the aperture coincides with the center of the tank only in the case where post height is 59 mm and the diameter of the tank is 150 mm, otherwise they are eccentric.

We have developed an automated field measurement system which comprises of a HP-4195A, a workstation, and a stepping motor system. The principle is usual Slater's bead-pull method but our system is much simplified taking advantage of HP-4195A's high resolution performance. Fig. 5 is a typical on-axis longitudinal electric-field distribution obtained from the experiments. The perturber's length is 10 mm and it is made just to fit in the aperture of the RFQ model. The results are that the variation of field along the axis is within 5 %. To achieve this degree of flatness, the electrode alignment tolerance must be as good as 0.05 mm.

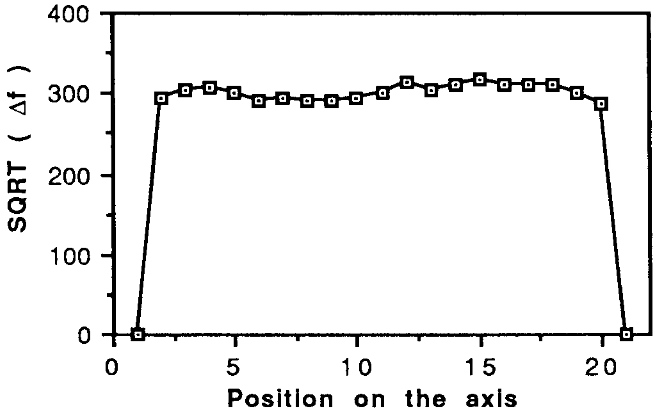

Fig. 5. Typical on-axis electric field distribution of 4-rod RFQ 1/3 scale cold-model. The resonant frequency is 94.72 MHz.

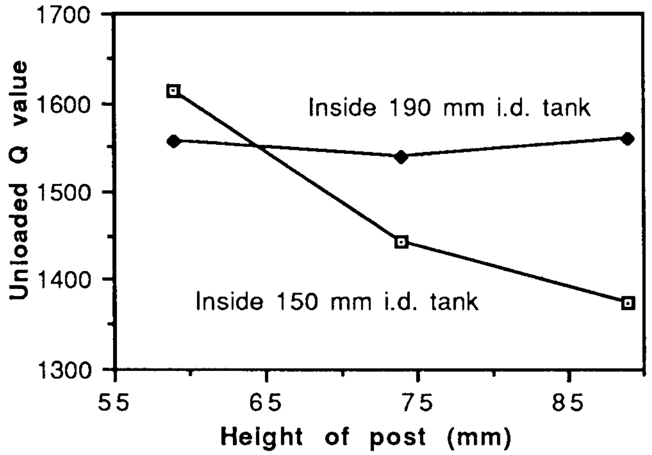

Fig.6. Unloaded Q-value as a function of post height.

Fig. 6 shows the unloaded Q-values as a function of the post height in 150 mm and 190 mm diameter tank. The size of posts, the distance between the posts, and the other conditions are the same as described above. The tendency is that the Q-value is basically irrespective to the height of the post, but will deteriorate as the electrodes come close to the wall of the tank.

Model Study of Spiral Resonator

Properties of spiral resonators have been studied elsewhere and we just followed their guidelines for building of our model.[5,6] A schematic drawing of a 1/3 scale spiral resonator is shown in fig. 7. The dimension of each parameter is defined and the experiment results are listed in table 2. On-axis field distribution is not presented here due to space limitation.

Concluding Remarks

There are still many other considerations to be given before the construction of a full scale machine. The RFQ's acceptance and its length, for instance, are probably the most important parameters to be optimized. The cooling of the RFQ structure presents the another engineering challenge for a stable operation of the accelerator.

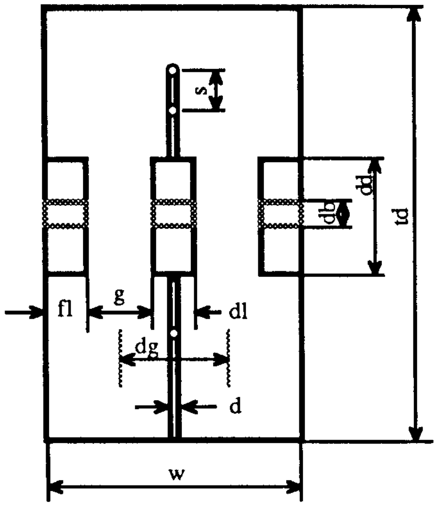

Fig. 7. Schematic drawing of 1/3 scale spiral resonator.

Table 2
Dimensions (in mm) and The Properties of 1/3 Scale Spiral Resonator.

	#1	#2	#3	#4
Gap length, g	7.0	7.0	7.0	7.0
Diameter of drift tube, dd	24.	32.0	24.0	32.0
Bore diameter, db	8.0	8.0	8.0	8.0
Gap-gap length, dg	18.0	18.0	18.0	18.0
Length of drift tube, dl	11.0	11.0	11.0	11.0
Length of field cutoff tube, fl	7.5	7.5	0.0	0.0
Separation pitch, s	18	18	18	18
Diameter of tube, d	7.0	7.0	7.0	7.0
Width of resonator, w	40	40	25	25
Diameter of tank, td	200	200	200	200
Length of spiral	660	660	660	660
Resonant frequency (MHz)	106.10	100.70	105.15	101.15
Unloaded Q value	1240	1260	880	920

Acknowledgments

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