RIA RFQ BEAM DYNAMIC STUDIES

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Abstract

In this paper we present an analysis of the beam dynamics of a possible RFQ for the Rare Isotope Accelerator (RIA) driver linac [**?**]. The highest frequency linac structure will be 805 MHz. Two linac design have been considered; a 14^{th} harmonic based lattice beginning with 57.5 MHz structures and a 10^{th} harmonic based lattice with 80.5 MHz structures. As a consequence, we have investigated an 80.5 MHz and a 57.5 MHz RFQ. Both RFQs are designed for U^{28+} with an input energy of 12.4 keV/u. The output energy is 169 keV/u for the 57.5 MHz RFQ and 292 keV/u for the 80.5 MHz RFQ. To increase the total beam power of the driver linac, the RFQ must be capable of accelerating two charge states (28,29) simultaniously. Two charge state acceleration increases the longitudinal emittance significantly. Therefore, one major design issue was the minimization of the longitudinal emittance. To optimize the RFQ accelerator subject to a variety of design criteria (emittance growth, tank length, transverse acceptance) an optimization program has been developed. We present a new method of generating RFQ parameter curves (i.e. modulation and synchronous phase) and of optimizing RFQ accelerators.

1 INTRODUCTION

One of the most challenging features of the proposed RIA driver linac is simultaneous acceleration of different charge states to increase the total beam power [2][3]. The multi-charge state acceleration leads to an increase of the longitudinal emittance. The output emittance after the RFQ should be smaller than 1.25 πkeV/n·ns for both uranium charge states.

In the proposed front end design, a multi-harmonic buncher will pre-bunch the beam and a following single harmonic buncher will equalize the velocities of the two uranium charge states (28,29) delivered from an ECR ion source. Figure 1 shows the longitudinal phase space of the bunched uranium beam in front of the RFQ.

An optimization program ('RFQopt') using the PARMTEQ code [4] has been developed in order to optimize the RFQ electrode geometry.

2 OPTIMIZATION PROGRAM

The main idea of the optimization program 'RFQopt' is to represent the RFQ parameter curves (i.e. modulation and synchronous phase) with smooth functions like polynomials. In general, the smoother the parameter changes are

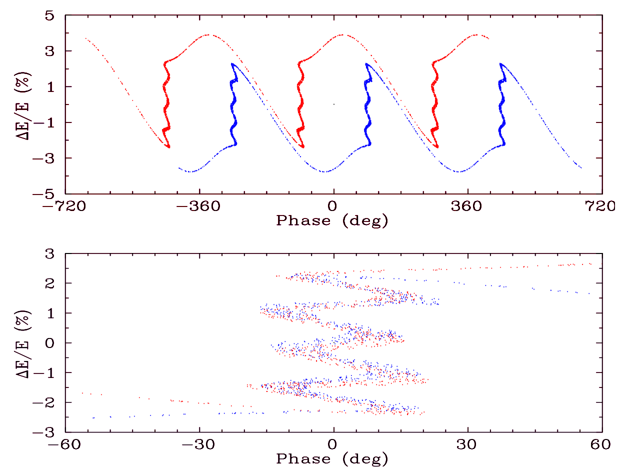

Figure 1: Top: Longitudinal input phase space at the entrance of the RFQ (red=U^{29+}, blue=U^{28+}). Bottom: Phase space scaled to the RFQ frequency.

the more stable the RFQ design is against small deviations from the ideal design.

Each parameter curve consists of several polynomials of 4^{th} order. Several free parameters are neccessary to determine the coefficents of the polynomials. The program 'RFQopt' starts with an arbitrary set of free parameters $p[k]$, $k = 1...n$. The polynomials and the PARMTEQ input file are then calculated from this data. The user can define an assessment function b which describes the quality of the solution. b can be for example a function of the tank length, longitudinal emittance, transverse emittance growth and transmission.

Then one parameter p is changed keeping all other $n-1$ parameters constant. This leads to a different value b_k for the function b and the partial derivative can be calculated:

$$\partial b/\partial p[k] = (b_k - b)/(p_{\texttt{new}}[k] - p[k])$$

After the partial derivatives have been calculated for all n parameters, 'RFQopt' changes all parameters in the direction of the steepest gradient. Depending on the sign of the partial derivative the sign and/or the step width will be changed. This procedure continiues until all limits for the user given step widths are reached. This means that 'RFQopt' has found a local maximum in the n-dimensional parameter space.

For the reason of simplicity a rectangular distribution of the longitudinal input phase space has been chosen to approximate the pre-bunched beam.

The following parameters have been kept constant during the oprimization process:

- frequency: 57.5/80.5 MHz
- input energy: 12.4 keV/u
- output energy: 169/292 keV/u
- vane voltage: 75/60 kV
- transverse input emittance: 120 πmm·mrad
- space charge

3 THE 80.5 MHZ RFQ

Figure 2 shows the modulation and the synchronous phase as function of the cell number. Due to the optimization process these parameter curves are very smooth. One of the major design criteria was the minimization of

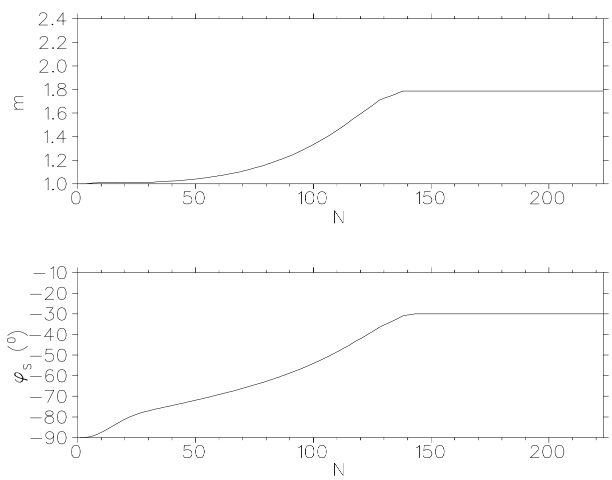

Figure 2: Modulation and synchronous phase of the 80.5 MHz RFQ.

the RFQ induced longitudinal emittance growth. Figure 3 shows a contour plot of the longitudinal output emittance as function of the energy and phase width of the input beam. The acceptable area is plotted in red. Within this area the emittance is smaller than 1.25 πkeV/u·ns. The distance between the lines is 0.125 πkeV/u·ns. For the simulations, two uranium charge states (28 and 29) have been used simultaniously. With an assumed phase spread of $\pm 38^\circ$ and an energy width of $\pm$2.3%, we expect a longitudinal output emittance of 0.81 πkeV/n·ns for two charge states and 0.65 πkeV/n·ns for a single uranium charge state. The beam dynamic for each charge state is very similar. The main source for the emittance growth is the shift in phase of the particle distribution for different charge states. Figure 4 shows the longitudinal phase space at the end of the 80.5 MHz RFQ for uranium ($U^{28,29+}$).

The transverse beam dynamic is nearly the same for two uranium charge states. We expect an emittance growth of 1.04 in the horizontal and 1.07 in the vertical plane. The transverse acceptance at 12.4 keV/u is about 180 πmm·mrad which corresponds to 0.9 πmm·mrad normalized. The final synchronous phase is -30°. The focusing B is 4.88 and has been kept constant to provide a constant capacitance along the electrodes.

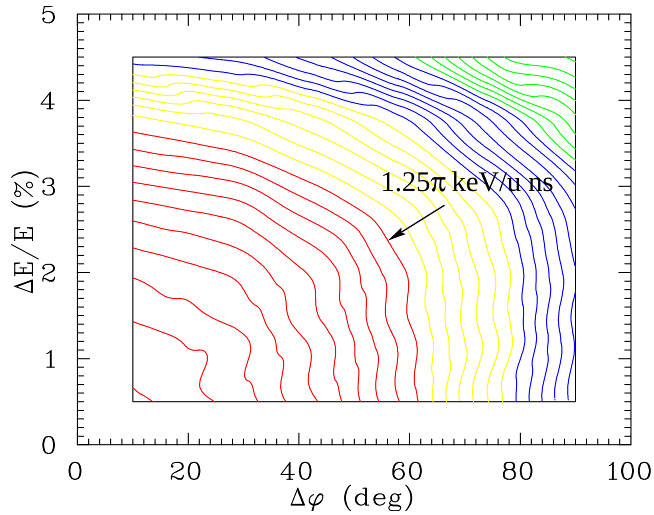

Figure 3: Contour plot of the longitudinal emittance (80.5 MHz) as function of the energy and phase width of the input beam. The beam consists of two uranium charge states (28,29). The acceptable area is plotted in red. In this area the output emittance is smaller than 1.25 πkeV/n·ns (98% particles).

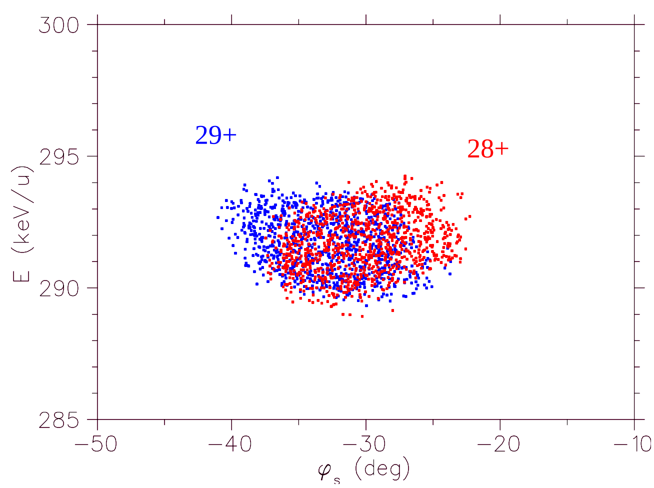

Figure 4: Longitudinal phase space at the end of the 80.5 MHz RFQ with two uranium charge states (28,29).

4 THE 57.5 MHZ RFQ

We designed a 57.5 MHz RFQ to compare it with the 80.5 MHz solution. In general, we used the same design criteria as for the higher frequency. The main differences are the lower final energy of 169 keV/u and the higher electrode voltage of 75 kV. The focusing B is about the same. Figure 5 shows the modulation and synchronous phase as function of the cell number. Figure 6 shows a contour plot of the longitudinal output emittance as function of the energy and phase width of the input beam. The acceptable

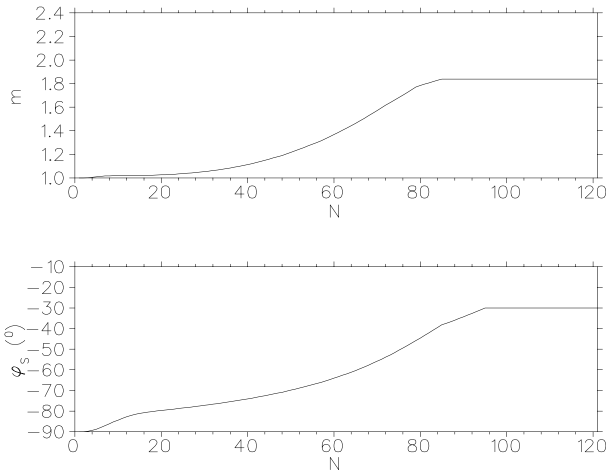

Figure 5: Modulation and synchronous phase of the 57.5 MHz RFQ.

area is shown in red. Within this area, the longitudinal

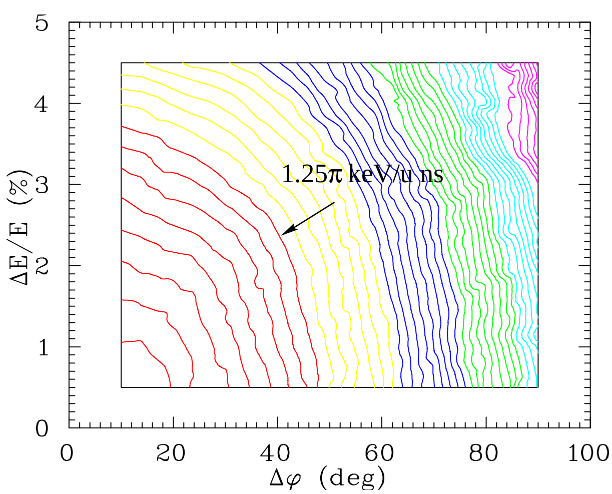

Figure 6: Contour plot of the longitudinal emittance (57.5 MHz) as function of the energy and phase width of the input beam. The beam consists of two uranium charge states (28,29). The acceptable area is plotted in red. In this area the output emittance is smaller than 1.25 πkeV/n·ns (98% particles)

output emittance is smaller than 1.25 πkeV/u·ns for both uranium charge states. With an assumed phase spread of $\pm 38°$ and an energy spread of $\pm 2.3\%$ we expect a longitudinal output emittance of 1.17 πkeV/u·ns. This is about 40% larger than for the 80 MHz solution. The ratio between this two values is mainly determined by the ration of the two frequencies.

The transverse acceptance (normalized) is 1.35 πmm·mrad which is about 40% larger than for 80 MHz. The main reason for this is the higher voltage.

Figure 7 shows the longitudinal phase space at the end of the 57 MHz RFQ with two uranium charge states.

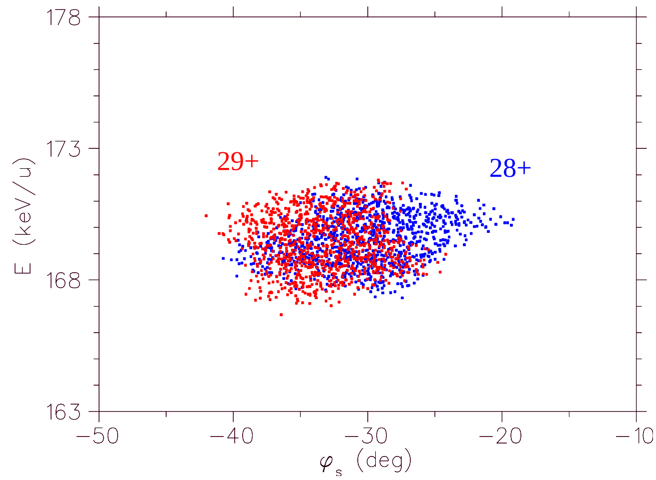

Figure 7: Longitudinal phase space at the end of the 80.5 MHz RFQ with two uranium charge states (28,29).

5 COMPARISON AND SUMMARY

An 80.5 MHz and a 57.5 MHz RFQ have been designed for the RIA driver linac. The simulations showed that there is no significant penalty in using a specific frequency. It is possible to fulfill the requirements for the RIA driver with an 80 MHz RFQ. The 57.5 MHz solution leads to a larger transverse acceptance but the longitudinal emittance is about 40% larger than for the 80 MHz solution.

Parameter	**57.5 MHz**	**80.5 MHz**
Voltage (kV)	75	60
Electrode length (cm)	287	518
Input energy (keV/u)	12.4	12.4
Output energy (keV/u)	169	292
Ave. aperture (mm)	6.9	4.64
Vane tip radius (mm)	5.7	4.0
Tr. acceptance (πmm·mrad)	1.29	0.92
long. emittance (πkeV/u·ns)	1.17	0.81
max. Focusing	5.03	4.88
synchronous phase	-30°	-30°
max. modulation	1.84	1.79

Table 1: Comparison of important resonator properties of the 4-rod and the IH RFQ.

6 REFERENCES

[1] http://srfsrv.jlab.org/ISOL

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[3] J. Kim et al., Design Study of a Superconducting Linac for RIA, Proceedings of the PAC 2001, Chicago, USA

[4] www.lanl.gov