RFQ Matching of Current Dominated Ion Beams

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Abstract

In spite of the fact that the RFQ is used with great success to bunch and accelerate all kinds of ions, there are still problems with matching current dominated ion beams from the ion source to the entrance of the RFQ. It is almost impossible to completely fill an RFQ to its theoretical current limit and the combination of large beam slope with large radius makes matching difficult. The gas load from the ion source into the RFQ should also be reduced. A new scheme of ion optics is proposed here for the entrance region of the RFQ, in order to: (1) avoid beam losses to the tapered end sections of either vane or rod structures; (2) reduce the diameter of the entrance aperture; and (3) relax the matching conditions required from the ion injector. This scheme requires decelerating the incoming ions between the entrance aperture and the radial matching section by a DC potential. Numerical simulations will be presented and different configurations for achieving this matching will be proposed.

1. INTRODUCTION

All existing RFQ ion accelerators operate with ion currents far below the theoretical limit as given by the focusing capability of the RF-quadrupole structure [1]. It has been shown by numerical simulations [2] that, for current dominated beams, losses to the tapered end sections cannot in principle be avoided, if the full focusing limited current is being injected. The strong beam spreading behaviour of low-velocity, high-current ion beams requires a relatively large aperture in the entrance flange of the RFQ vacuum chamber, which then reduces the vacuum inside the RFQ by the gas load from the ion source. A better vacuum would allow the RFQ to operate at higher RF-power or with reduced breakdown from sparking.

In addition to a large radius, the ion beam entering the RFQ must have a large slope at the entrance aperture. This makes matching by means of electrical or magnetic lenses difficult.

2. REDUCTION OF BEAM SPREAD BY ACCELERATION

The ion beam transport between the entrance flange of an RFQ and the tapered end of the RF structure suffers from the beam spreading by the mutual Coulomb repulsions of the ions. No space charge compensation techniques can be applied, due to the presence of RF fields in this region. The only way to reduce the spreading for a beam of given current is to reduce its space charge by increasing its velocity. Since the velocity is fixed by design at the beginning of the RF structure, it can be increased only by applying a negative high voltage to the entrance aperture, which then decelerates the ion beam between this aperture and the RF structure.

In order to simulate the effect of such a bias voltage, the program IGUN [3] is used, neglecting the action of the RF fields. These become important only in the vicinity of the RF structure and mostly cause the ion trajectories to begin radial oscillations in the directions perpendicular to the beam axis.

For a 10 mA/30 keV N^+ beam with the entrance aperture and RF structure at DC ground potential, the beam spreading is shown in Fig. 1. The tapered electrode contour and the location, radius and position of the entrance aperture are taken from a standard commercially

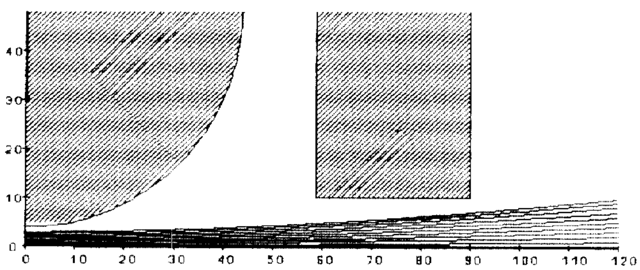

Figure 1. Beam spreading at the entrance of an RFQ

supplied RFQ [4] but should not be considered to be crucial in this context. It is obvious that the beam spreading almost completely fills the aperture, proving the significance of the simulation. For this calculation, the ion beam is injected at the entrance of the constant radius section of the RF structure in the reverse direction, e.g. the ion beam is travelling from the RFQ to the aperture with trajectories initially parallel to the axis, with a homogeneous space charge and zero emittance, but with defined energy and current.

If the entrance aperture of the RFQ is then biased with a DC potential of -50 kV, the results are seen in Fig. 2. The increase of the ion velocity towards this aperture reduces the beam spreading behaviour. The reduction is further enhanced by the lens action in this gap, which provides focusing. As a result, the beam radius is reduced by almost a factor of 2 in the aperture as compared to Fig. 1 and the beam divergence is much less.

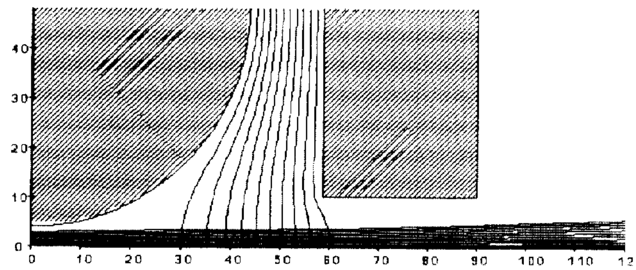

Figure 2. Reducing beam spread by a negative potential on the RFQ entrance flange

This allows reducing the radius of this aperture by a factor of 2, thus reducing the vacuum conductance by a factor of 8. It also greatly facilitates the matching as seen from the source. This becomes obvious when another aperture is supplied at ground potential to decelerate the beam back to the design energy (see Fig.3). As a result, the beam has larger radius and smaller divergence at this grounded electrode, where it has to be matched to (in reverse direction) the ion source. This clearly is a big advantage of the proposed ion optics.

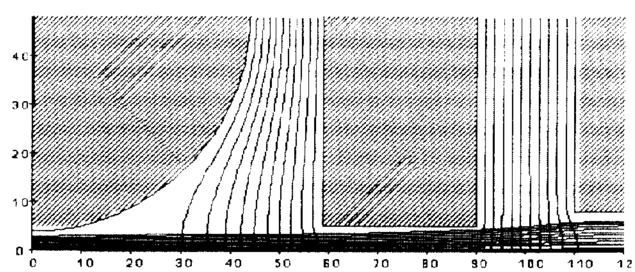

Figure 3. Adding an electrode on ground potential

3. DESIGN OF A COMPLETE INJECTION SYSTEM

The aberrations of this ion optics cause the homogeneous beam inside the RF structure to have a higher current density near the beam boundary when it is at the matching point. This, however, is the natural situation for an ion beam extracted from a plasma source with

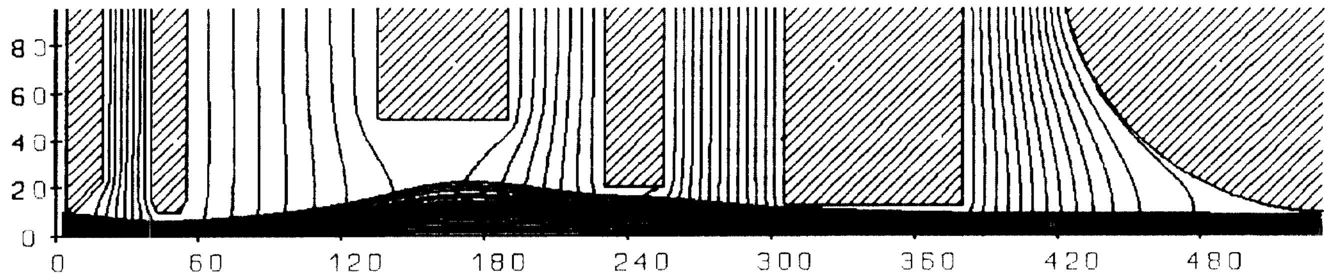

Figure 4. Simulation of a complete injection system for an RFQ using the CHORDIS ion source with a 10 mA/30 keV N^+ beam with electrode potentials (from left to right) of 30,0,30,0,-50,0 kV

some degree of compression. In order to prove this, the CHORDIS [5] ion source was simulated for the required ion current and source potential. The einzel lens was put at source potential in a position such that the ion beam reaches the biased entrance flange of the RFQ with the radius and slope as determined by calculations of the optics in reverse direction (Fig. 3). The result of this simulation is seen in Fig. 4. The grounded electrode between the einzel lens and the entrance aperture does not have much influence on the optics, because it almost coincides with an equipotential line and therefore could be removed.

As an alternate method for the application of beam spread reduction by acceleration, the RF-structure of the RFQ could be put at a positive high voltage, which seems to be possible for the 4-rod-structuce, where the vacuum tank is not an RF cavity [6]. In this case, however, the matching scheme shown in Fig. 4 must be changed, the ion source is then put at 80 kV potential, increasing the spacing of the extraction electrode by a factor of $(8/3)^{3/4}$. This again will facilitate the matching of the extracted ion beam to the (now grounded) entrance flange. The deceleration of the ion beam to an RF-structure at 50 kV potential still may be favourable with respect to the RFQ length optimisation, because bunching of the DC beam is done in a shorter length and the additional acceleration is easily accomodated by the RF-structure [6].

4. CONCLUSIONS

Deceleration of the ion beam between the entrance flange of an RFQ and the vane/rod-structure substantially decreases the beam spreading behaviour with two significant benefits: The aperture in the entrance flange can be reduced by a factor of 2, reducing the vacuum conductance by a factor of 8, and the matching conditions as seen from the source become relaxed. This method improves the matching of current dominated ion beams from an ion source to the RFQ.

5. REFERENCES

[1] M. Reiser, Part. Acc. 8(1978)167
[2] R. Becker and N. Zoubek, Proc. LINAC-84, GSI-84-11
[3] R. Becker, W.B.Herrmannsfeldt Proc. ICIS-91, to be publ. RSI
[4] R.W. Hamm, priv. communication
[5] R. Keller et al., Proc. ISIAT/IPAT-83, Kyoto (1983)
[6] A. Schempp, priv.communication