Design Studies of an RFQ-Injector for a Medicine-Synchrotron[1]

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Abstract

An accelerator facility for radiotherapy of cancer tumours with ions is proposed for the Radiologische Universitaetsklinik in Heidelberg. Design studies have been done for the injector-complex [1] in front of the Synchrotron with respect to the construction and operation costs as well as to a comfortable handling of the machine [2]. After the source section and a LEBT path the beam will be injected into the RFQ at an energy of 8 keV/u to be accelerated to 400 keV/u with an electrode voltage of 70 kV and an expected power consumption of 100 kW. The RFQ layout, featuring a special parameter design, has been investigated with an extended version of the PARMTEQ code. The length of the RFQ will be approximately 1.45 m, the operation frequency is 216.816 MHz, same value as in the following IH drift tube Linac. For beam matching reasons, the combination of drift tubes with the RFQ electrodes at the high energy end is examined in detail by beam dynamic simulations and model measurements.

1 INTRODUCTION

Cancer therapy by heavy ion beams is subject of research activities at GSI in Darmstadt since about 25 years. The tumor radiotherapy started with the successful irradiation of first patients in December 1997. Now it is planned to build an accelerator facility for applications in clinical areas, design studies have been done at GSI.

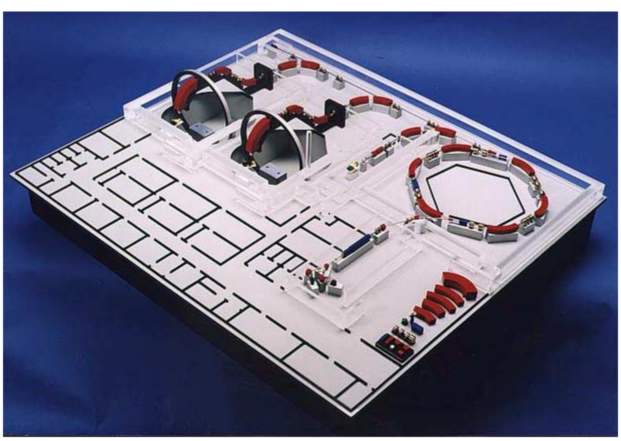

Figure 1: Model set up of the heavy ion cancer therapy facility.

We worked out a design concept for the RFQ section of the machine. Essential part of our efforts has been the matching of the beam parameters to the acceptance of the IH-DTL. A new concept of beam bunching behind the RFQ and measurements on a model set up is discussed.

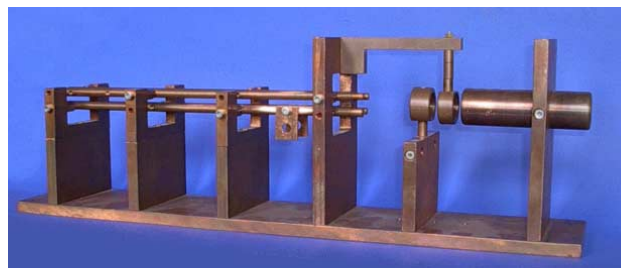

Figure 2: Model set up of the RFQ drift tube combination.

2 RFQ DESIGN

The layout of the electrodes has been done in accordance with the following beam parameters:

Input energy	8 keV/u
Input emittance	$\varepsilon_{x,y}$=150 π mm mrad
Current	max. 2 mA H^+
Output energy	400 keV/u
max. beam angle at the exit	±20 mrad (in both planes)
Phase width at IH entrance	$\Delta\varphi \leq \pm 15°$

Table 1: RFQ beam parameters.

Particularly the small phase width of ±15° at the IH entrance puts special requirements to the particle dynamics of the RFQ. The design presented in [3] has been done by an optimization code, reducing the phase width to the smallest possible value by varying both, the electrode parameters of the RFQ and the gap voltages of the following drift tubes. The latest version of this design is shown in figure 3 where we have done some modifications to shorten the length of the RFQ and to improve the homogeneity of the output distribution (fig. 4).

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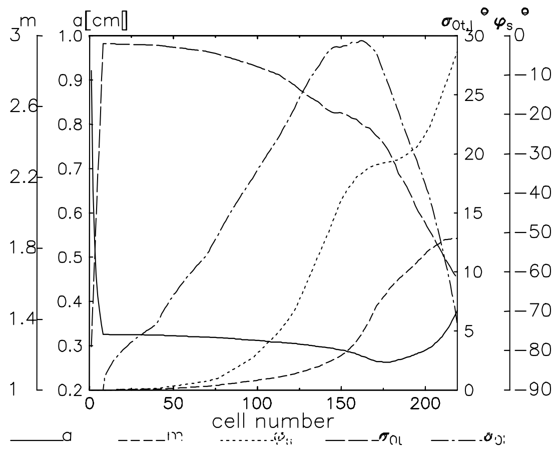

Figure 3: Design parameters of the RFQ.

The growing aperture at the end of the electrodes leads to a decreasing focusing strength, which guarantees the maximum beam angle of 20 mrad at the exit of the RFQ. Furthermore there is an unusual increase of the ideal phase to nearly 0° corresponding to take a maximum advantage of the HF voltage, but a minimum of longitudinal focusing. This means that the beam is already drifting longitudinally within the RFQ electrodes, which allows the bunching in a distance of only 6 cm.

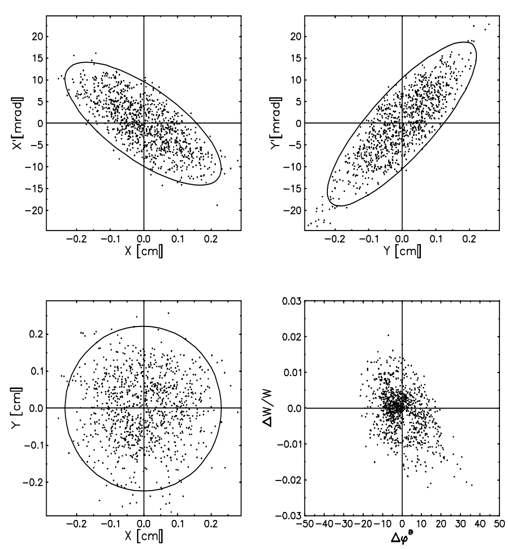

Figure 4: Particle distribution at the exit of the RFQ.

3 THE TRANSITION BETWEEN RFQ AND DRIFT TUBE

To do detailed investigations on the dynamics in the distorted field distribution between electrodes and drift tubes, a new subroutine for the IAP version of the PARMTEQ code has been written to calculate the particle dynamics in an arbitrary potential distribution. The generation of the potential has been done externally by solving the Poisson equation with the method of successive overrelaxation. The boundary conditions and phase relations between the components are displayed in figure 5.

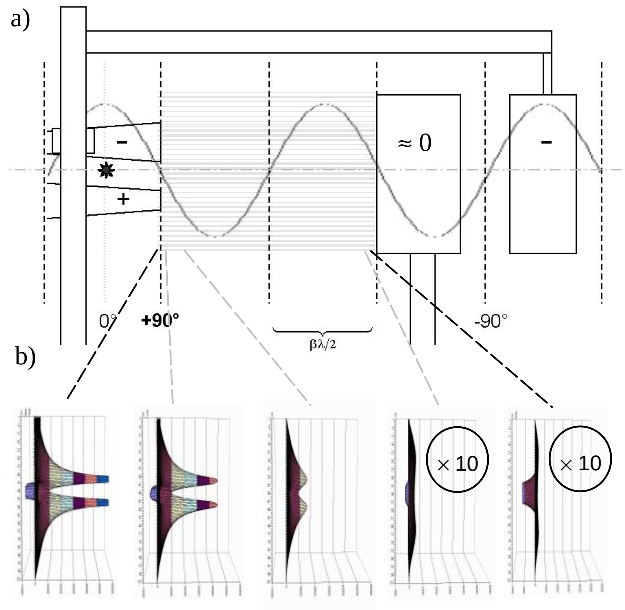

Figure 5: a) Area of interest (shaded) and its boundary conditions: -10 resp. 60 kV electrode voltage, -1,2 kV at the first drift tube (calculated by MAFIA), b) generated static potential in different planes (factorized by 10 in the last two planes).

The transformation of the beam has shown only negligible effects on its dynamics in comparison to calculations, which have been done simply with a field-free drifting. Due to the rapidly decreasing field magnitude behind the electrodes the distorted field in between this gap is not critical.

4 BEAD-PERTURBATION MEASUREMENTS

Dynamic simulations have shown a minimum phase width at the IH entrance with a total gap voltage of U_B = 87 kV (fig. 6).

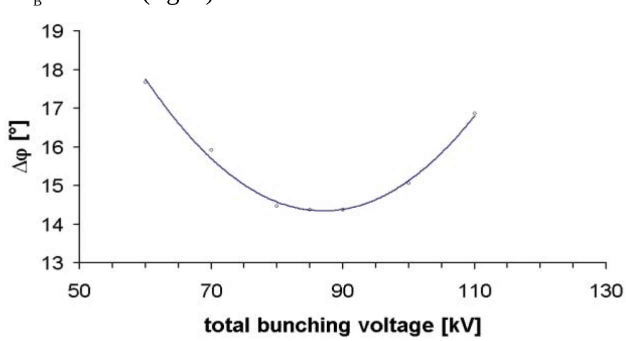

Figure 6: Simulated phase width.

This is 1.24 times the voltage U_Q of the RFQ electrodes. The final concept of two bunching gaps has one extra stem supporting the first drift tube between RFQ and the end flange of the tank (fig. 2). This stem is not tuned to the RFQ frequency and therefore can be treated as on ground potential.

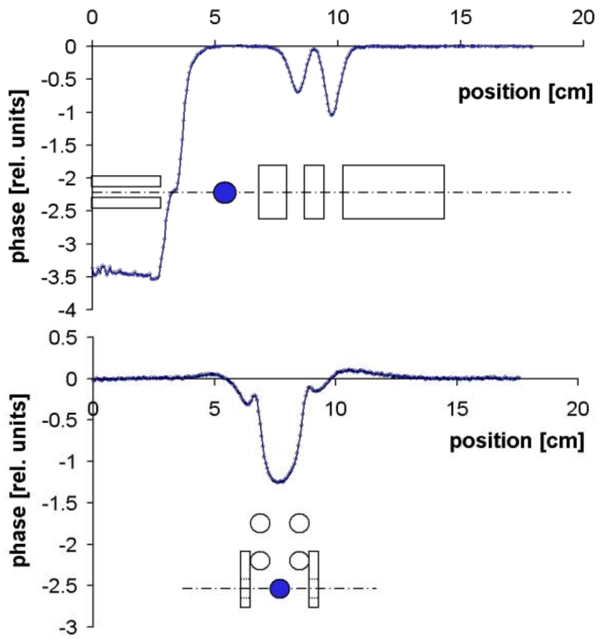

Figure 7: Bead-perturbation measurements on the model set up to compare the electrode with the buncher voltage.

Bead-perturbation measurements have been done on the model set up (fig. 2) in good accordance with MAFIA calculations and resulted in a voltage ratio between electrode and buncher of U_B/U_Q =1.23 corresponding to 86.1 kV total bunching voltage with 70 kV at the RFQ electrodes.

5 FLATNESS

The buncher section attached at the end of the RFQ has an effect on the voltage distribution (flatness) of the electrodes. It forms a big capacity, which increases the voltage at this end of the structure.

Figure 8: MAFIA plot of the RFQ structure (16 stems).

To investigate these effects in detail we have done MAFIA simulations for a 16-stem RFQ structure as it is proposed for the final design. Figure 9 shows calculations for three different structures for upper and lower electrodes each. First calculation has been done with equidistant stems and shows about 20% unflatness.

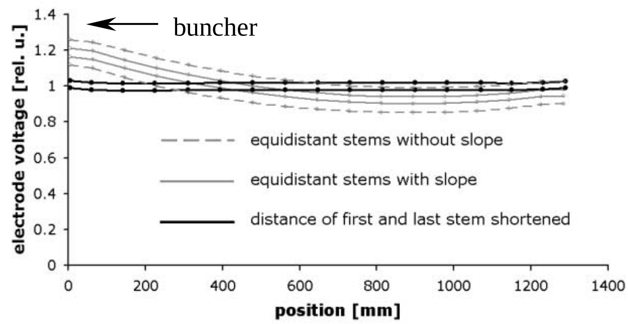

Figure 9: Simulations of the flatness with MAFIA.

The second calculation has also been done with equidistant stems but with the slope at each stem (fig. 10) to reduce the voltage difference between upper and lower electrode from 14% to 4%.

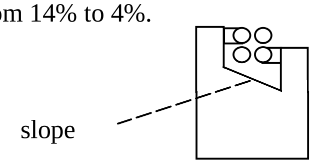

Figure 10: Scheme of a RFQ stem.

A very flat field distribution of about 1.1% unflatness can be achieved for example by a shorter first and last stem distance as it has been done in the last simulation. It is also conceivable to flatten the field by movable ground plates between the first and the last two stems used also for tuning the resonator to resonance frequency.

6 CONCLUSIONS

A new concept of a RFQ drift tube combination as part of the injector complex of the Therapy-Synchrotron in Heidelberg has been elaborated. Measurements on a modified model set up with 16 stems are planed for the near future to confirm the calculated HF properties of the resonator and to determine the exact height in which the tube is connected with the last stem which determines its voltage.

The “Wissenschaftsrat” has now approved the project; the official start to build the machine will be in the near future.

7 REFERENCES

[1] B. Schlitt, A. Bechtold, U. Ratzinger, A. Schempp, "Design of the 7 MeV/u, 217 MHz Injector Linac for the Proposed Ion Beam Facility for Cancer Therapy at the Clinic in Heidelberg", Proc. LINAC2000.

[2] B. Schlitt, U. Ratzinger, "Design of a Carbon Injector for a Medical Accelerator Complex", Proc. EPAC98, 2377.

[3] A. Bechtold, A. Schempp, U. Ratzinger, B. Schlitt, "Development of an RFQ-Injector for a Therapy-Synchrotron ", Proc. EPAC2000, 2500.