DEVELOPMENT OF AN RFQ-INJECTOR FOR A THERAPY-SYNCHROTRON[1]

A. Bechtold, A. Schempp, Johann Wolfgang Goethe-Universitaet, Frankfurt, Germany
U. Ratzinger, B. Schlitt, GSI, Darmstadt, Germany

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 synchrotron injector-complex with respect to construction and operation costs as well as to a save and simple handling of the machine [1]. 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 electrode design, has been investigated with an extended version of the PARMTEQ code. The length of the RFQ will be approximately 1.55 m, the operation frequency is 216.816 MHz 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 simulations with the MAFIA code as well as by measurements on a model set up. The IH structure represents the last step of acceleration before the injection into the synchrotron at 7 MeV/u. As the same injector should also deliver a 2 mA proton beam, space charge effects were examined by beam dynamic simulations.

1 INTRODUCTION

Cancer therapy by heavy ion beams is subject of research activities at GSI in Darmstadt since about 25 years. The tumour 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 and resulted in a ground plan which is shown in fig.1.

Two separate ion sources are intended to deliver H^+ and C^{4+} at 8 keV/u to reduce swhiching time between the two ion species. The LINAC section (fig. 2) consists of the RFQ structure followed by an IH type DTL. The beam will be injected into the synchrotron by multi-turn injection after passing the stripping foil to turn the charge state from C^{4+} into C^{6+}.

Before its application to the patients the beam is passing one of the two gantries which consist mainly of three bending magnets. The gantries are rotating around the patient to make an irradiation out of several directions possible without turning the patient himself which might course an uncontrolled movement of the organ of interest.

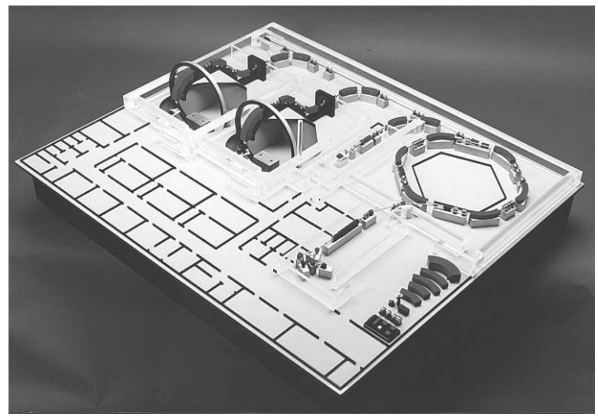


Figure 1: Model set up of the heavy ion cancer therapy facility.

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 first measurements on a model set up are explained.

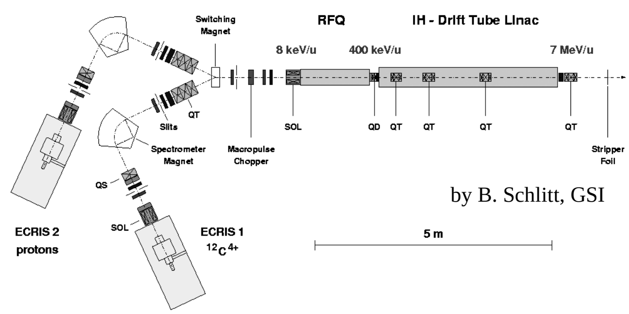


Figure 2: Scheme of the LINAC section.

2 RFQ DESIGN

The electrodes with a length 1,35 m are supported by 16 stems mounted in a distance of 85 mm on the ground plate. The operation frequency of 216.816 MHz will be achieved by a stem length of about 105 mm [2]. As the

[1] Work supported by the BMBF and GSI

duty-cycle is less than 1 % no additional cooling of the electrodes is necessary.

For beam matching reasons, a very small phase width of less than ± 15° is required at the entrance of the IH-structure which is following the RFQ in a distance of 31 cm. To reduce the costs and complexity and to simplify the handling of the machine, we pursued in a first step the idea to do the bunching within the RFQ-electrodes itself. The RFQ-parameters were optimized for a minimum bunch length at the IH entrance by an optimization code.

Unfortunately further investigations have shown, that this design was very sensitive to special input parameters and especially to the particle distribution. The optimization has been done for an input emittance of 150 π mm mrad (fig. 3). But the losses should also be acceptable for 200 π mm mrad as a worst-case-input-emittance.

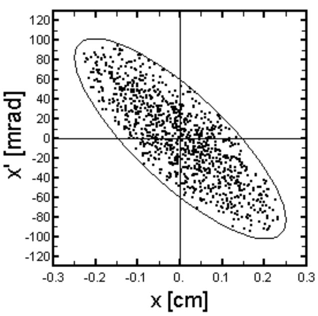


Figure 3: Input particle distribution, ε = 150 π mm mrad (same in y-plane).

As an alternative option the combination of drift tubes with the RFQ at the high energy end was examined [3]. We decided to attach a tube directly to the last stem which forms a bunching gap with the potential of the tank wall.

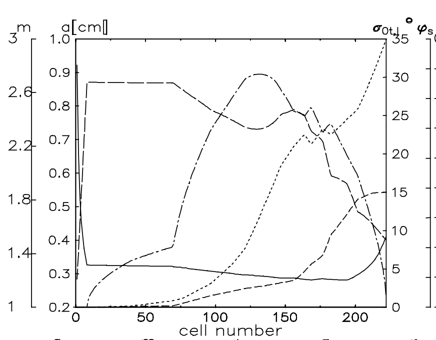


Figure 4: New RFQ design (optimized for bunching with additional drift tubes).

Because of the short distance between electrodes and drift tubes and the need of longitudinal drifting in front of the buncher, the stable phase is kept near zero at the accelerating part of the RFQ-electrodes. This layout (fig. 4) was also optimized for a minimum phase width at the entrance of the IH-structure.

3 COMBINATION OF DRIFT TUBES WITH THE RFQ RESONATOR

The height in which the tube is connected with the stem is decisive for its voltage (fig. 5). Particle dynamics simulations have shown that an amount of 1.14 times the electrodes voltage is needed in case of a single gap of 5 mm for bunching. In this context it is an interesting fact that the voltage of the last (resp. the first) stem at the height of the electrodes measured to the end of the tank is only about 20 % of the actual RFQ voltage between two neighbouring electrodes.

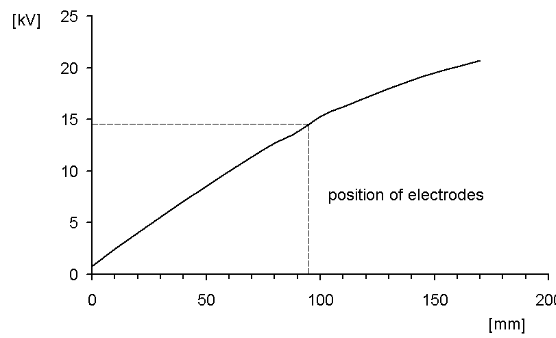


Figure 5: Voltage between the last stem and the tank wall versus stem altitude (RFQ voltage: 70 kV).

Therefore the drift tube had to be mounted to the stem even above the electrodes to be a bit closer to the top of the λ/4-line were the voltage is at its crest. For a further increase of the tube voltage another, more particle dynamical consideration was helpful: Because of the distorted field distribution in between this gap, the transition of the beam from the end of the RFQ electrodes to the entrance of the first drift tube is problematic. So we decided to make this gap $\beta\cdot\lambda$ wide which means that the beam is in between the gap for the duration of a total HF-period and the integral voltage seen by one particle is approximately zero. At the exit of the RFQ the value of $\beta\cdot\lambda$ is 4.1 cm. A final adjustment of the tube voltage can be done by a slight variation of the height in which the fixture of the tube is mounted, but also by a variation of the capacitance of the gap between tube and tank.

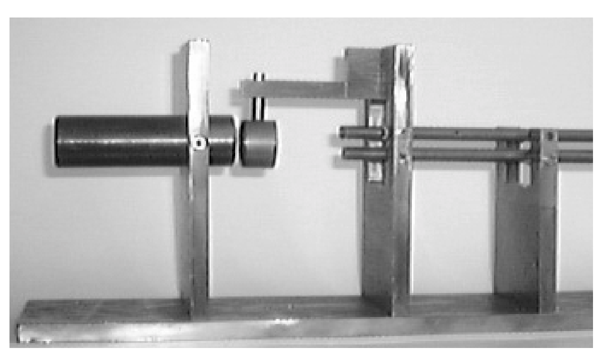


Figure 6: Model set up.

However, further calculations and measurements on the model set up (fig. 6) have shown that the RFQ resonator gets more and more effected by the increased capacitive load. This leads to an inhomogeneous field distribution along the RFQ structure. One possibility to avoid these problems we introduced a second gap so that the voltage of the tube could be halved. This idea resulted in a structure shown by the MAFIA plot of fig. 7.

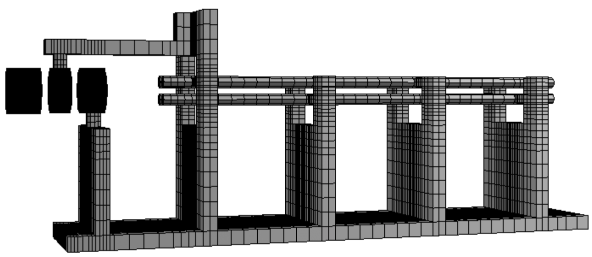


Figure 7: Two bunching gaps (last drift tube is connected to the invisible tank).

The additional tube is sitting on top of an extra stem placed in front of the 'hot' tube and is not resonantly connected to the RFQ structure and on same potential as the end of the tank. Therefore the voltages in the two gaps will be equal. This could be confirmed by simulations with MAFIA. To adjust the gap voltages to the values in demand, the gap width had to be changed from 5 to firstly 7 mm.

4 BEAM DYNAMICS

Figure 8 shows a graphical PARMTEQ output of the beam profile within the RFQ calculated with the above input distribution (Fig. 5).

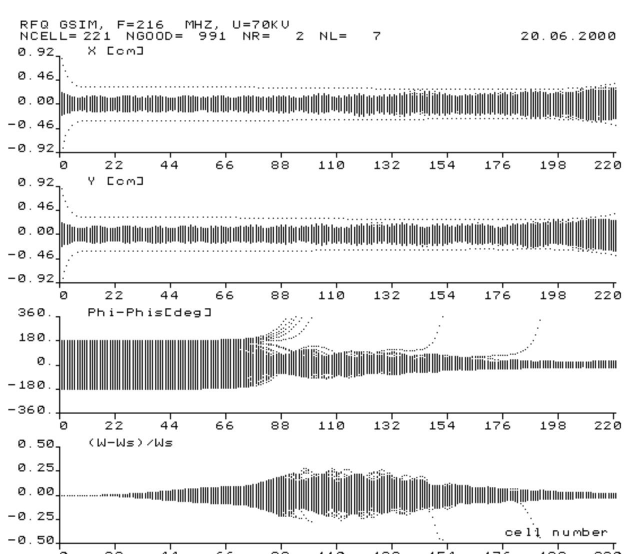
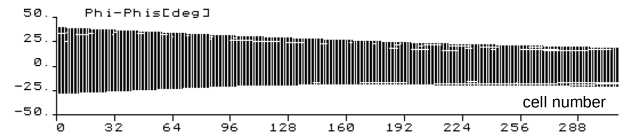


Figure 8: Beam transport within the RFQ electrodes.

As the stable phase in the high energy part of the RFQ is getting high for longitudinal drifting, the separatrix is increasingly small and some particles are getting lost.



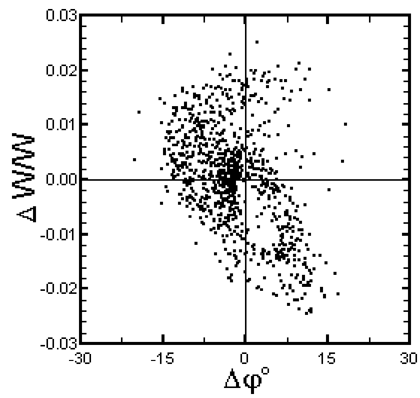


Figure 9: Focus after 31 cm of drifting, $\Delta\varphi_{95\,\%} = \pm\, 14.63°$.

The phase evolution of the beam within the drift of 31 cm behind the two gap bunching section of 40 respectively 45 kV gap voltage (computed by MAFIA) is shown in Fig. 9.

5 CONCLUSIONS

A design proposal for the RFQ-section of the Therapy-Synchrotron in Heidelberg has been prepared. In the course of that we worked out a concept for the combination of drift tubes as a bunching unit directly with the RFQ-resonator. Now measurements on a modified model set up have to be done to confirm the calculated properties of the resonator.

REFERENCES

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[3] U. Ratzinger, E. Malwitz, M. Rau, "Design Study of a Four Vane RFQ for High Duty Cycle Operation", LINAC94, 275.