INTENSITY UPGRADE PROGRAMME FOR THE HIT INJECTOR LINAC

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Abstract

The Heidelberg Ion Beam Therapy Centre (HIT) is a worldwide unique radiation therapy facility and the first installation of its kind in Europe. It is equipped with three treatment rooms and has the potential to irradiate over 1000 patients per year. To guarantee a time-saving quality assurance and to be well prepared for future clinical requirements the currently limited beam intensity (ions per second) should be increased. In an endeavour to provide optimum conditions for the patient treatment an intensity upgrade programme for the injector linac has been initiated. It affects primarily the Radio-Frequency-Quadrupole (RFQ) but also other linac components. The largest influence on the linac transmission is expected by a new RFQ design with optimised electrodes, which will be soon commissioned on a test bench. The update programme is accompanied by machine studies. First improvements are presented and the status of the programme is given.

INTRODUCTION

Over the last two years the HIT accelerator [1, 2] was commissioned by GSI Darmstadt [3, 4], while the subsystems were running under the responsibility of the HIT operating team. In parallel the implementation of the medical equipment took place. In December 2007 the pencil beam library reached therapy quality for two out of three treatment places.

The accelerator provides a set of intensity levels for the coarse preadjustment, whereas the exact dose is defined by the intensity controlled rasterscan technique. During this early state of operation the maximum available beam intensity allows us to deliver $8 \cdot 10^7$ ions / s for carbon and $3.2 \cdot 10^9$ ions / s for protons. With respect to the patient treatment these intensities are sufficient but for an effective quality assurance it will be important to reach the final particle numbers (C: $5 \cdot 10^8$ ions / s, p: $2 \cdot 10^{10}$ ions / s). Taking into account the variable spill-length the intensity has to be increased by a factor of 2.5 for carbon and 4 for protons.

The main contribution of particle losses is caused by the poor transmission of the beam through the RFQ. The upgrade programme therefore concentrates on a redesign of this linac part. In parallel we have carefully examined other linac components with the goal of optimising their performance. Starting with the ion source we have found some approaches for improvements.

ION SOURCE

We are operating two 14.5 GHz ECR ion sources of the type Supernanogun [5]. During the commissioning of the low energy beam transport system (LEBT) the design values for the beam emittance could not be fully reached. Moreover the source did not achieve long term stability for carbon operation at the specified current output of 200 μA in the past months. We are hence planing to adopt modifications resulting from recent experiments with ECR ion sources [6]. They have shown that a remarkable intensity gain can be obtained by varying the microwave frequency within a narrow range around the centre frequency. Furthermore we intend to investigate the performance of an extended extraction system consisting of three electrodes.

SOLENOID

Our beamlines from the sources to the RFQ include three solenoids of identical construction. Two solenoids are located straight behind the ion source, the third one serves as focusing element in front of the RFQ. Regarding the radial field component as a measure for the field homogeneity values of up to almost 5 mT appear (Fig. 1). The resulting beam steering investigated during the LEBT-commissioning was identified as one of the reasons for a reduced transmission. We ordered a new solenoid to replace the one in front of the RFQ demanding from the supplier a maximum relative radial field component on axis of $1 \cdot 10^{-3}$. This time it was especially taken care that the single coil-windings are adjusted exactly in parallel before they are casted. This resulted in a decrease of the radial field component by nearly one order of magnitude. As could be shown by measuring activities during the last shutdown we could substantially diminish the steering effect with this measure.

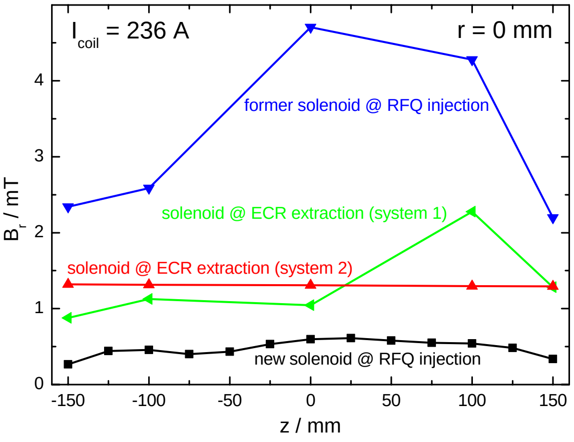

Figure 1: Radial field component in the LEBT-solenoids.

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RFQ

In carbon routine operation the transmission of the 400 keV/u four-rod RFQ and the 7 MeV/u IH drift tube linac (IH-DTL) amounts to 30%. From the commissioning we know that particles are already getting lost in the RFQ whereas the (intensity reduced) beam is then accelerated through the IH-DTL with a high efficiency. The losses can be partly attributed to the beam properties behind the LEBT which differ from the design conditions. But apart from that, the RFQ holds optimisation potential.

With the support of GSI the design of a new RFQ was initiated. The modifications concentrates on the RFQ-tank and the RFQ-electrodes with emphasise on the input radial matcher (IRM). The new RFQ will be tested under real conditions on a test-bench in Risø, Danmark, in a collaboration with Danfysik A/S and Siemens AG Medical Solutions before it will be installed in our beamline.

Tank

During the installation phase of the linac we detected a misalignment of the electrodes using a simple telescope. A precise laser tracker measurement of the tank's fiducialisation points, performed to investigate the phenomenon in detail, revealed a deflection of the tank in vertical direction. As the electrodes and the tank are firmly connected to each other via the groundplate and the stems this implicates a deflection of the electrodes as well. We came to the conclusion that an insufficient tank rigidity in combination with stress acting on the tank during the alignment procedure due to the four point suspension are the principal reasons for the problem.

The new tank therefore implements several modifications (Fig. 2). The rigidity was improved by increasing the wall thickness from formerly 4 to now 6 mm and by welding a u-rail onto the bottom of the tank. To avoid contaminations during the galvanisation process it is equipped with wholes. The suspension was reduced to three points with two points located on a cross brace at the low energy end and one centered point at the high energy end.


courtesy NTG, Gelnhausen

Figure 2: New RFQ-tank upside down with 6 mm wall thickness, reinforcement rail and three point suspension.

Electrodes

After the commissioning of the linac and the measuring activities during the last summer shutdown it became obvious that the real beam differs considerably from the design beam with respect to emittance and phase space orientation. This makes it impossible to match the beam into the RFQ acceptance.

One of the decisive factors for the acceptance of an RFQ is its first section, the IRM. At GSI it was proven that the acceptance of an RFQ can be increased only by optimising this section of the electrodes [7]. Applying the same approach, a new design of the IRM was carried out by GSI. In Fig. 3 the comparison between old and new IRM is illustrated. The new shape diverges from the circular arc and the length has been expanded from 8 to 16 RFQ-cells. The acceptance ellipse of the new design is optimised to the measured phase space distribution.

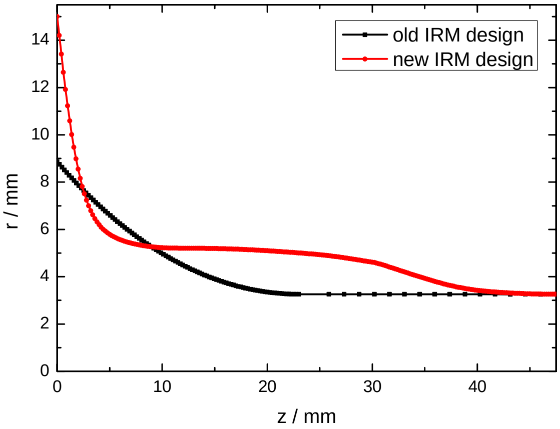

Figure 3: Comparison between old (black squares) and new (red dots) input radial matcher.

We took the opportunity of the electrode reconstruction to select a better raw material. Instead from a copper-tin alloy the rods are now made from anoxic copper (SE-Cu) with a purity of 99.9% and a conductivity of $57 \cdot 10^6$ S/m. With this we expect a higher quality factor of the RFQ ($Q \approx 3500$ instead of now 2500) moving the working point of the RF-amplifier into its optimum range of operation.

MACHINE STUDIES

Since the beginning of 2007 the linac delivers routinely beam for the commissioning of the consecutive accelerator sections (MEBT, Synchrotron, HEBT, Gantry) and the medical equipment. For the accelerator experts the opportunity to perform machine studies arises between the commissioning shifts. Except for an emittance measurement device the beamline is well equipped with beam diagnostic instruments. With respect to the RFQ there is a capacitive phase probe available in the intertank section between RFQ and IH-DTL which is directly flanged to the IH-tank. By operating the IH-DTL in the transport-mode we are able to investigate the behaviour of the RFQ. In this mode the RF of the IH-DTL is switched off and the internal quadrupole triplets are matched to the output energy of the RFQ (400 keV/u). Using this transport-mode allows us to observe pure RFQ effects and to use the phase probe of the intertank section whose signal competes with the interfering RF-signal out of the IH-tank. Although the phase probe amplitude is not only dependent on the beam intensity but also on the bunch length it can serve to some extend as current measurement in the intertank section. Additionally we can measure the beam current with a beam transformer and a Faraday-Cup behind the IH-DTL.

Applying the transport mode we measured the amplitude of the phase probe behind the RFQ and the current on the beam transformer behind the IH-DTL as a function of the RFQ control voltage. The result for a 750 μA H_2^+-beam is plotted in Fig. 4 (top). Both curves show two distinct maxima with a local minimum in between. The first maxima can be found at 6.15 V (transformer) resp. 6.21 V (probe) which coincides with the current working point. The second maxima with lower amplitudes are located between 6.60 and 6.65 V. We carried out the same voltage scan in the accelerating mode (IH-RF switched on). The transmission maximum was not found at one of the two maxima but in the local minimum around 6.4 V. This yielded in an intensity gain of 8% with respect to the current injected into the synchrotron. More investigations are necessary to understand this correlation. For the carbon beam (130 μA, Fig. 4, bottom) the behaviour is more evident. Only one maximum in the range of the working point 9.45 V can be found. The measurement in the accelerating mode confirms this result. Here we can be sure that we are operating at the optimum RFQ voltage within an accuracy of ±0.05 V.

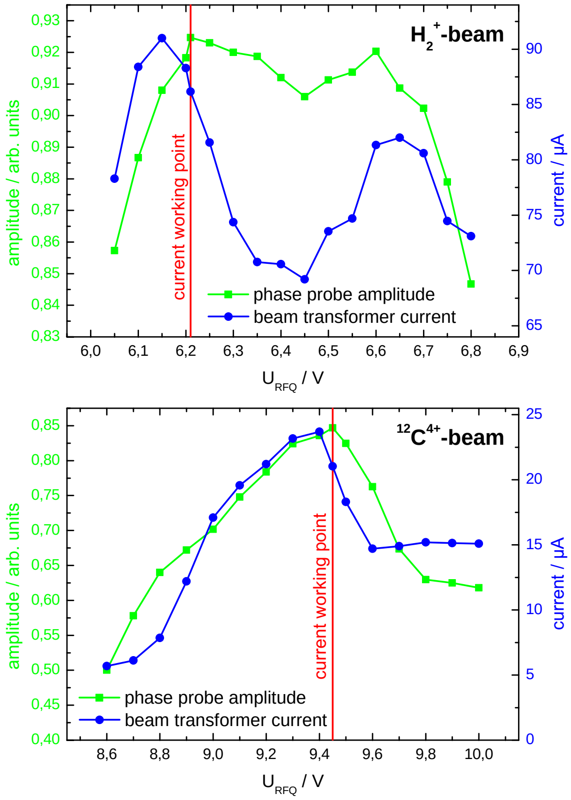

Figure 4: Phase probe amplitude behind the RFQ and current measured with the beam transformer behind the IH-DTL as a function of the RFQ tank voltage for an H_2^+-beam (top) and a $^{12}C^{4+}$-beam (bottom).

Such studies will be important for the on-site verification of the commissioning results of the new RFQ. Moreover it is necessary for the future operation to have the opportunity to react on shifts of the working point caused e.g. by changes in our subsystems.

OUTLOOK AND CONCLUSION

The machining of the RFQ-electrodes has recently been finished. The delivery of the complete RFQ including RF-tuning is scheduled for August 2008. Subsequently the RF-conditioning and the beam commissioning will take place at Danfysik A/S. The tank will presumably be installed at the HIT linac during the summer-shutdown 2009.

Transfering the simulated transmission gain to the current value a final transmission of up to 60% can be expected from the combination of all implemented measures.

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