

LATEST COMMISSIONING RESULTS OF THE SIEMENS PARTICLE THERAPY* RFQ

Stephan Emhofer^x, Henrik K. Andersen⁺, Michael Budde⁺, Franz Bødker⁺, Oleg Chubarov^x, Jesper S. Gretlund⁺, Ingo Hollenborg^x, Henrik B. Jeppesen⁺, Carl Kleffner^x, Vitali Lazarev^x, Michael Maier^x, Carsten V. Nielsen⁺, Christian G. Pedersen⁺, Heiko Rohdjeß^x, Bernhard Schlitt^x, Thomas Sieber^x, Bastian Steiner^x, Kasper T. Therkildsen⁺, Peter Urschütz^x, Søren Vinter Weber⁺

⁺Siemens AS Jyllinge, Denmark, ^xSiemens AG Erlangen, Germany

Abstract

Siemens is currently preparing, installing and commissioning three IONTRIS particle therapy accelerator systems – two in Germany, in Marburg and Kiel, and one in Shanghai, China.

Siemens IONTRIS is based on a synchrotron to accelerate protons and carbon ions for clinical applications up to 250 MeV resp. 430 MeV/u. The injector part consists of an RFQ to accelerate protons and light ions up to 400 keV/u followed by an IH-cavity, wherein the particles reach an energy of 7 MeV/u. The results of the commissioning of the RFQ at a test facility in Denmark will be presented.

INTRODUCTION

The Siemens particle-therapy accelerator system follows the lines of modern light-ion therapy accelerators like HIT (Heidelberg ion beam therapy centre) built by GSI [1] or CNAO [2], designed for providing mainly proton and carbon ion beams with a penetration depth of about 30cm in water-equivalent tissue. The system comprises an injector, where ions from a number of ion sources (2 or 3) are pre-accelerated with a LINAC (RFQ / IH combination), then injected into a synchrotron ($\varnothing \sim 20$ m) followed by a high-energy beam-transport (HEBT) system to deliver the beam to the various beam-ports. The main parameters are given in Table 1. Descriptions of the accelerator system at an earlier stage can be found in [3].

PROJECTS

Since entering the field of particle therapy by delivering the patient environment and treatment delivery system to HIT in Heidelberg, Siemens has acquired three contracts for complete particle therapy systems.

These projects are based on the same accelerator design with adaptations made, when required (e.g. the different configuration of beam ports or the number of ion sources).

The first facility is located in Marburg, Germany and will be operated by the Rhön-Klinikum AG. Practically all parts of the accelerator have been installed. The commissioning of the sources, LEBT, LINAC and MEBT

has been completed and the commissioning of the Synchrotron and HEBT is progressing fast. Proton and carbon ion beams have been successfully accelerated and transported to the first two treatment rooms.

Table 1: Main Parameters of the PT Accelerator System

Parameter	Value
Proton energy range	50-250 MeV/u
Carbon energy range	85-430 MeV/u
Max. number of p/C extracted	$2 \cdot 10^{10} / 1 \cdot 10^9$
Intensity variation	0.001-1
Ion species	p, C ⁶⁺
Transverse field for scanning	200×200 mm ²

The second project is situated in Kiel, Germany, and is set up as a public-private partnership with the University Hospital Schleswig-Holstein and Bilfinger Berger as consortial partner. The configuration of the accelerator is shown in Figure 1. The main components of the accelerator have been manufactured. The installation and commissioning of two ion sources and the LEBT are finished and the commissioning of the LINAC has started. Currently the RFQ is in commissioning.

The third Siemens PT facility is located in Shanghai (China). Production of the components has been started and the accelerator installation will begin in January 2012.

SOURCES AND LEBT

The low-energy beam-transport system (LEBT) allows selecting the beam from currently either two or three ECR ion sources and delivers and matches the beam to the linear accelerator. The beam from the sources is momentum analyzed to select the required ion species (H₃⁺ or C⁴⁺ for clinical use). Subsequently the beam from the source to be used is selected by means of switching magnet. The commissioning of the sources and the LEBT in Marburg and Kiel are completed.

* Siemens Particle Therapy products and solutions are works in progress and require country-specific regulatory approval prior to clinical use.

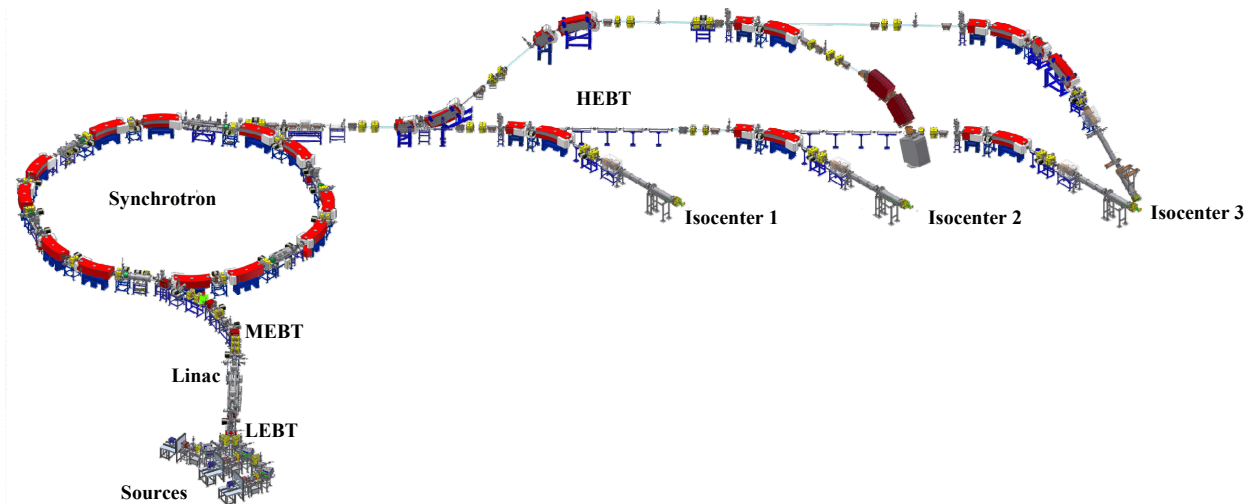


Figure 1: Layout of the particle-therapy accelerator for the Kiel project, featuring three treatment rooms with horizontal, vertical and semi-vertical (45°) beam-ports, the last two rooms contain a dual beam-port each.

LINAC

The linear accelerator consists of a RFQ and an IH-mode drift-tube LINAC using a slightly modified design of the IAP Frankfurt for the HIT facility in Heidelberg. The RFQ accelerates the particles to 400 keV/u whereas the injection energy into the synchrotron of 7 MeV/u is achieved by the IH-DTL. After the LINAC the beam is stripped by a thin carbon foil and guided by the medium-energy beam-transport to the synchrotron.

The commissioning of the LINAC and MEBT in Marburg is completed. For the LINAC a transmission of up to 35% has been achieved, where the majority of the losses are caused by the RFQ. The Kiel RFQ has been pre-tested and adjusted at the Risø test facility in Denmark. The transmission could be raised to about 70% in Kiel.



Figure 2: A picture of the four RFQ electrodes at the radial matcher.

LOW LEVEL TUNING OF THE RFQ

The RFQ (figure 2) was fabricated by NTG in Gelnhausen including the internal alignment and the initial RF-tuning. The unloaded Q-factor was measured to 3300. For the measurement of the flatness a small perturbation device was build, because of the fact, that the smallest industrial capacitors for electronics on the market are in the range of 0.5pF, which would cause a too big frequency shift violating the Slater Theorem. Therefore a device with about 0.1pF was build. Figure 3 shows a technical drawing of this device.

By changing the dimensions also much smaller capacities would be possible, but one has to make a compromise between having a really small ideal perturbation device against the influence of other factors, e.g. frequency change because of temperature shift.

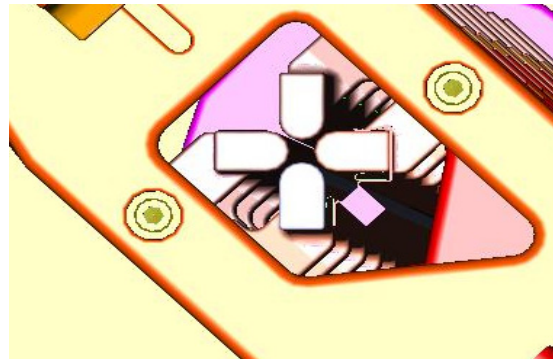


Figure 3: A technical drawing of the perturbation capacitor.

With this device the flatness of the reference electrode pair was measured to with a maximum of +2% and a minimum of -5%.

This flatness along the different cells is shown in figure 4. The lower value in cell 9 is a result of the influence from the frequency tuning plunger in that cell. The lower values at the end (mainly cell 14 & 15) are a result of the rebuncher influence.

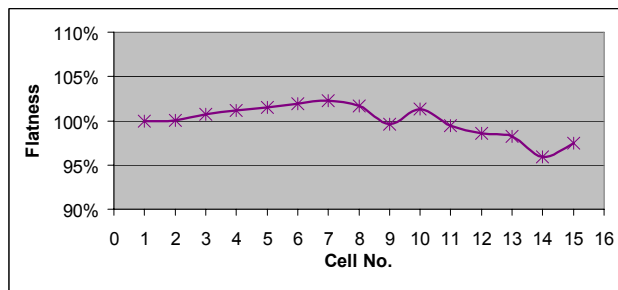


Figure 4: The flatness of the reference electrode pair of the RFQ for the project in Kiel.

RFQ BEAM TESTS

To save time on the customer site, a test facility was built in Risø close to Copenhagen in Denmark. The RFQ for the Kiel project has been pre-tested and its rebuncher adjusted in this test facility. This allows us to reduce the commissioning time in Kiel by several weeks.

To verify the proper voltage and position of the rebuncher two measurement series were performed in Risø. During one measurement series the rebuncher was in dummy position, where the rebuncher has no influence on the beam, during the other measurement series the rebuncher was in its working position. This method is described in deeper detail in [4]. Among the measurements performed with those two different setups was a TOF measurement, where the flight time difference between three different pickups in the beam line is measured.

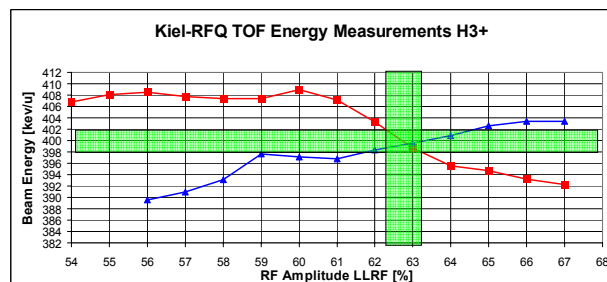


Figure 5: The beam energy as function of the RF-amplitude inside the RFQ cavity with the rebuncher in dummy position (blue with triangles) and in working position (red with squares) are shown. The energy acceptance of the following IH of 400keV/u is indicated by the horizontal green line.

The measurement results are shown in figure 5. While the beam energy with changing RF-amplitude inside the RFQ-cavity shows a typical RFQ behaviour when the rebuncher is in dummy position, the beam energy is

reduced with higher RF-amplitude in the RFQ-cavity when the rebuncher is in its working position. This is a result of phase and amplitude changes in the two gaps of the rebuncher and can be simulated accordingly. The working point of this type of RFQ is where those two lines cross. At the working point the RFQ has the proper energy of 400 keV/u for injecting into the following IH-cavity. This point is at a RF-power-level of 177kW which results in an Rp-value of 28 kΩ. This is close to the predicted value in [5] of 30 kΩ. The transmission could be raised to more than 60% in Risø and currently already about 70% are reached in Kiel, while the RFQ is still in commissioning.

CONCLUSION

We have given an overview on the status of the different projects and have shown the latest results of the RFQ for the Kiel project.

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