STATUS OF THE SIEMENS PARTICLE THERAPY* ACCELERATORS

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Abstract

Siemens has earned contracts to deliver Particle Therapy systems to be operated in Marburg and Kiel, both in Germany, and a third one in Asia. The accelerator consists of an injector (7 MeV/u protons and light ions) and a compact synchrotron able to accelerate proton beams up to 250 MeV and carbon ions up to 430 MeV/u. These beams can be slowly extracted and delivered to a choice of fixed-angle horizontal, semi-vertical and vertical beam-ports. In this report a status of the design and the first installation in Marburg is given.

INTRODUCTION

The Siemens particle-therapy accelerator system follows the lines of modern light-ion therapy accelerators like HIT (the 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 beams from a number of ion sources (2 or 3) are pre-accelerated by a Linac, a synchrotron and high-energy beam-transport (HEBT) system to deliver the beam to the various beam-ports. The main parameters are given Table 1. Descriptions of the accelerator system at an earlier stage can be found in [3].

Table 1: Main parameters of the PT facility.

Parameter	Value
Proton energy range	50-250 MeV/u
Carbon energy range	85-430 MeV/u
Ramping time	< 1s
Extraction time	< 10s
Max. number of p/C extracted	$2\cdot10^{10}/1\cdot10^{9}$
Intensity variation	0.001-1
Ion species	p, He, C, O
Transverse field for scanning	200×200 mm²

PROJECTS

Since entering the field of particle therapy by delivering parts of 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 and adoptions will only be made, when this is required by 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 produced and installation is progressing fast. The commissioning of the sources and LEBT will have been completed by the time of this conference. The Linac components have been tuned and delivered to site.

The second project is situated in Kiel, Germany, and is set up as a public-private partnership with the University Hospital Schleswig-Holstein. The configuration of the accelerator is shown in Figure 2. Currently, the building is under construction, the components of the accelerator are being produced and installation will start in early 2010.

To strengthen the particle therapy business Siemens recently has acquired the particle therapy branch of Danfysik A/S. In 2004, Siemens had entered a tight cooperation with Danfysik in the design and fabrication of the accelerator integrated in the Siemens particle therapy systems.

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.

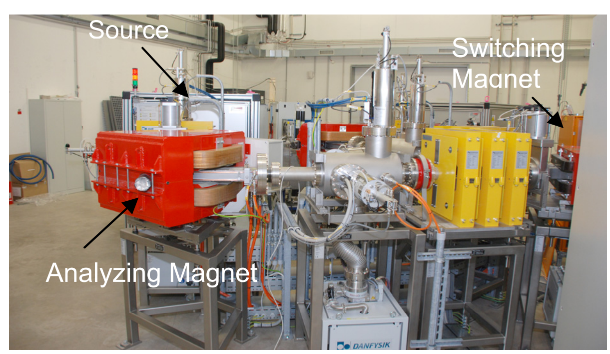

Figure 1: View of one branch of the LEBT in Marburg.

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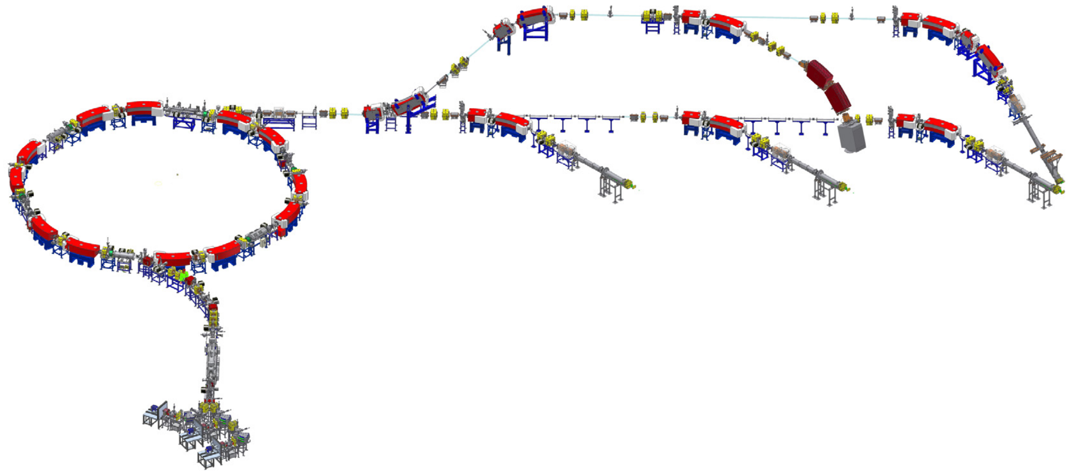

Figure 2: Possible layout of a particle-therapy accelerator, featuring three sources and three treatment rooms with horizontal, vertical and semi-vertical (45°) beam-ports, the last two rooms contain a dual beam-port each.

Figure 1 shows part of the LEBT installation in Marburg, where the beam from sources is momentum analyzed to select the wanted ion species (usually H_3^+ or C^{4+}) on its way to the switching magnet, selecting the source to be used.

The commissioning of the sources and the LEBT in Marburg has been almost completed. Examples of emittances, measured with an emittance scanner (moveable slit and grid), at the location of the RFQ are shown in Figure 3. It could be demonstrated that the specified current within the emittance (180 π mm mrad) has been obtained.

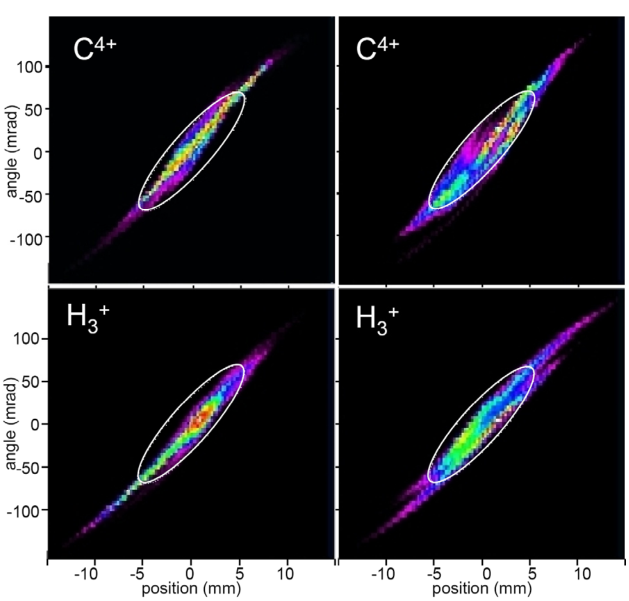

Figure 3: Emittances (left:horizontal, right: vertical) of C^{4+} and H_3^+ beams at the end of the LEBT. The circumscribed emittances correspond to 180 π mm mrad, respectively

LINAC

The linear accelerator consists of a RFQ and an IH-mode drift-tube Linac (DTL) using a design by the IAP Frankfurt for the HIT facility in Heidelberg with only minor modifications. The RFQ accelerates the particles to 400 keV/u whereas the injection energy into the synchrotron of 7 MeV/u is achieved by the DTL, shown opened in Figure 4. After the Linac the beam is stripped by a thin carbon foil and guided by the medium-energy beam-transport to the synchrotron.

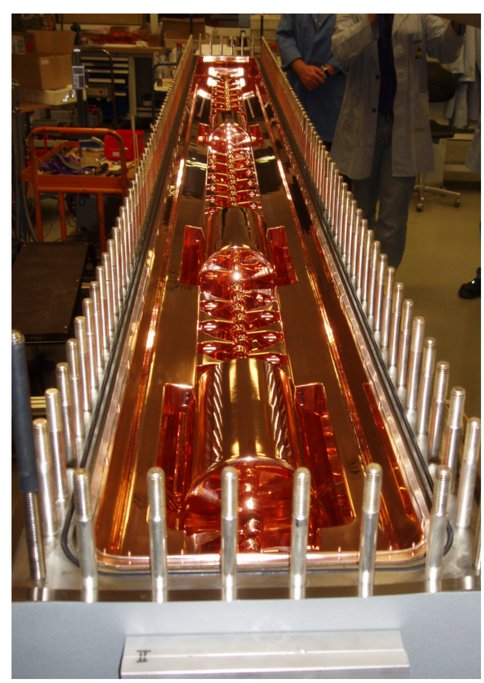

Figure 4: Inside view of the IH-DTL, showing the 4 accelerating sections, separated by quadrupole triplets.

SYNCHROTRON

The synchrotron is a new design (described in more detail in [3] and [5]), featuring a symmetric hexagonal lattice of roughly 65 m circumference with 6 straight sections hosting the injection and extraction systems and the accelerating RF cavity.

For the multiturn injection scheme through a thin electrostatic septum three ferrite bumpers are located within the ring that can produce an injection bump collapsing within a few 10 µs. In this way 10 effective turns can be injected into the synchrotron, sufficient for the specified beam currents.

For the acceleration on the second harmonic a ferrite loaded RF-cavity driven by a solid state amplifier has been designed and successfully tested. Extraction of the beam proceeds using a slow extraction scheme at a third order resonance, using a combination of an electrostatic and two magnetic septa.

HEBT

The high-energy beam transport system delivers the beam from the synchrotron to the different treatment locations. The layout depends on the configuration of required beam ports in the different treatment rooms.

Currently, our system feature horizontal (H), vertical (V) and semi-vertical (SV), i.e. 45° vertically inclined, beam ports. In Marburg the four treatment rooms, starting at the vicinity of the synchrotron, are equipped with the beam ports H, H, H, and SV respectively, whereas in Kiel the configuration is, H, H+V, and H+SV (cf. Figure 2). Here, H+V signifies that a treatment room has two beam ports pointing at the same isocenter, the nominal position of the target volume. This will provide larger flexibility in applying radiation fields from various angles during one fraction.

In Siemens particle therapy systems treatment delivery uses the raster-scan method. Here the Bragg-peak is scanned over the tumor volume. Longitudinally one can only move from spill to spill by changing the extraction energy in the synchrotron, but transverse fast scanning can be achieved with fast "scanner magnets". To have quasi-parallel scanning, these scanner magnets need to be located at least 6m away from the isocenter. Together with a focusing quadrupole doublet needed to obtain small beam diameters at the isocenter a fairly long straight beamline from the last bend to the isocenter is needed.

Whereas this has not been an issue for horizontal and semi-vertical (45°) beam outlets, as used in the Marburg project, vertical beams designed along these lines would require an excessive building height.

Therefore a scheme has been developed where scanning is done through the last dipole magnet, similar to gantries with parallel scanning (PSI, HIT). In this way, the vertical beam line could be designed with the same height as the semi-vertical one. In order to reduce the total weight and cost of the last 90° bend, it is realized with three 30° dipole magnets in a layout shown in Figure 5. The "vertical" scanning in the dispersive plane is done before the first magnet. The "horizontal" scanner is placed between the second and the third dipole, so that only one 30° magnet had to be designed with a large gap. This arrangement provides quasi-parallel scanning and the same variation of beam sizes as in the horizontal and semi-vertical beam-ports.

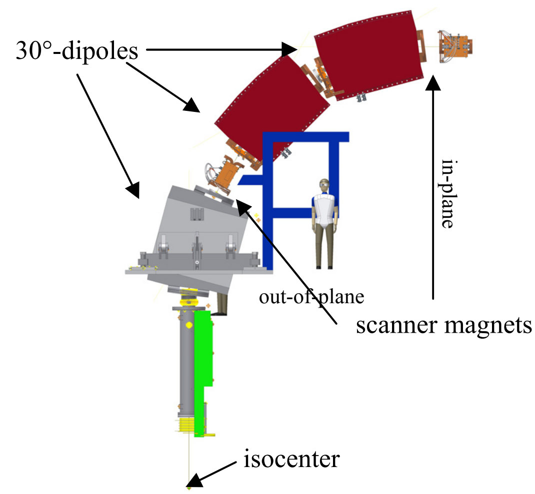

Figure 5: Layout of the last section of the vertical beamline.

CONTROL SYSTEM

The control system used for the Siemens particle therapy accelerators is a variant of the one developed for the HIT facility in Heidelberg [6], however, changes induced by different beamline configuration as well as other hardware interfaces have been implemented.

CONCLUSION

We have given an overview of the particle therapy accelerator, designed for series production, and have given a brief account of the status of the different projects.

The authors acknowledge the assistance, interest and support from staffs at GSI and HIT. We also appreciate the countless contributions from many other colleagues within Siemens and cooperating companies.

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