COMMISSIONING OF THE CARBON BEAM GANTRY AT THE HEIDELBERG ION THERAPY (HIT) ACCELERATOR

M. Galonska[a], S. Scheloske[a], R. Cee[a], K. Höppner[a], C. M. Kleffner[b], A. Peters[a], T. Haberer[a]
[a] *Heidelberger Ionenstrahl-Therapiezentrum, D-69120 Heidelberg, Germany*
[b] *GSI Helmholtzzentrum für Schwerionenforschung mbH, D-64291 Darmstadt, Germany*

Abstract

The Heidelberg Ion Therapy Facility (HIT) is the first dedicated proton and carbon cancer therapy facility in Europe. It uses full 3D intensity controlled raster scanning dose delivering method. The ion energy ranges from about 50 up to 430 MeV/u corresponding to ion penetration depths of 20 to 300 mm in water.
The HIT facility comprises the only heavy ion gantry worldwide designed for the beam transport of e. g. carbon ions up to an energy of 430 MeV/u corresponding to a magnetic rigidity of 6.6 Tm. The gantry rotating angle of 360 degrees enables patient treatment from arbitrary directions.
This paper gives a brief outline on the commissioning activities so far.

INTRODUCTION

Fig. 1 shows the HIT accelerator consisting of an injector linac accelerating ions to 7 MeV/u. The injector is followed by a compact synchrotron which provides protons and carbon ions with variable energy to the four high energy beam transport lines.
The first two beam lines guide the ion beam to horizontally fixed raster scanning systems for patient treatment (H1 and H2 in Fig. 1). Treatment in the first room started successfully in November 2009, while in H2 an enhanced version of the medtech equiqment is under commissioning. The clinical operation will start fall 2010. A third horizontal target station is built for quality assurance, development, and research (Q-A in Fig. 1).

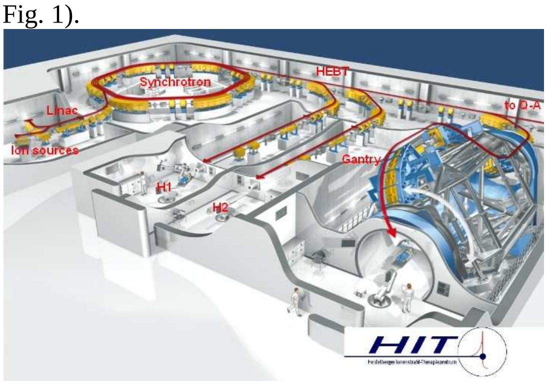

Fig. 1: Overview of the HIT accelerator

Finally, HIT comprises the worldwide first heavy ion gantry with integrated beam scanning capability. While the first proton and carbon beams were transported to the isocenter in January 2008, the commissioning was interrupted in order to focus on the start of the clinical operation in the horizontally fixed treatment lines. In February 2010 comissioning restarted after some optimizations in the cable tray chain. The commissioning aims at the efficient provision of the pencil beam libraries for the raster scanning dose delivering, i.e. up to 4 ions (^{1}H, ^{12}C, ^{4}He, ^{16}O), 255 energy steps, 6 beam foci (3.5-20 mm FWHM) and 10 (15 later) intensities (10^{6}-10^{10}), summing up to ~ 90.000 combinations.

THE HEAVY ION GANTRY

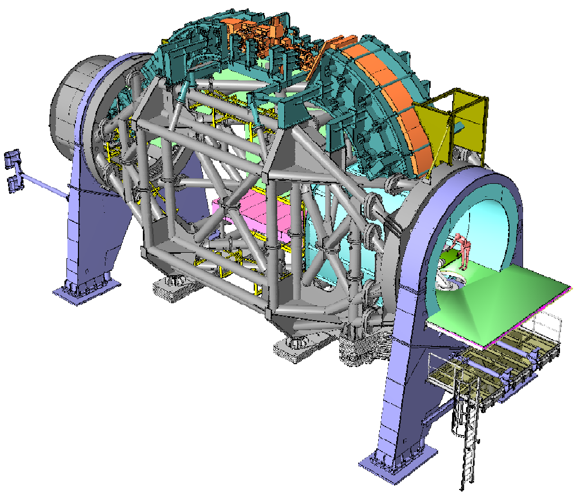

*Fig. 2: Drawing of the heavy ion gantry at the HIT including mechanics, beam line components and patient treatment room (**MT Mechatronics**)*

- First and only heavy ion gantry worldwide
- Raster scanning included
- Optimum dose application by patient treatment from arbitrary directions
- About 450 t of rotating parts
- Length / diameter: 25 m / 13 m
- Construction and integration by MT Mechatronics (former MAN Technology) finished by the end of 2007
- See also [1]

COMMISSIONING (ORGANISATION)

Schedule
Commissioning of the heavy ion gantry takes place in the time slots between patient treatment (5 days a week), and installation work on further treatment equipment in the second horizontal treatment room.

On average there are about three shifts a week (8 hours per shift) for gantry commissioning which will be finished for protons and carbon beams in fall of this year.

Commissioning team

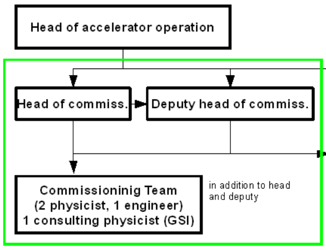

Fig. 3: Organisation chart, green framed: main commissioning team consisting of 6 members (beam adjustment, data supply, and theory)

The head of accelerator operation is in charge for supervision of the project, and in especially supervision of the preparation of the gantry beam times concerning the functionality of all components involved: e. g. mechanics (e. g. enabling of gantry rotation etc.), beam diagnostics (e. g. installation of viewing target at the gantry exit etc.), control system and so on. This work is partly supported by the main commissioning team, for instance by bug reporting to the HIT and external expert teams.

The main commissioning team (green framed in Fig. 3) is in charge for the scheduling and planning of the beam time experiments concerning ion beam adjustment, ion optics, data supply of the magnetic structure, and theory.

Besides the preparation of the gantry beam line by the HIT expert teams there are generally on-call experts during each shift.

Communication

In order to achieve a substantial progress in commissioning shift by shift an elaborate documentation and scheduling system is inevitable. This reporting system includes:

- A weekly meeting of the commissioning team for presentation and discussion of the results achieved during experiments and planning of following beam times
- A detailed written record of each session presenting results, conclusions, and drawbacks
- A data collection of measurements on a network storage
- Records posted to the HIT E-Log [2]
- Bug reporting to HIT and external experts concerned by encoutered problems

ION BEAM CHARACTERISTICS

The gantry commissioning started again in February 2010 with a carbon ion beam. Fig. 4 gives an overview of the gantry beam line with the beam diagnostic devices while Tab. 1 outlines the reference value and the small margin (25 % rel. deviation) of the beam width and the maximum allowed position deviation ot the pencil beam.

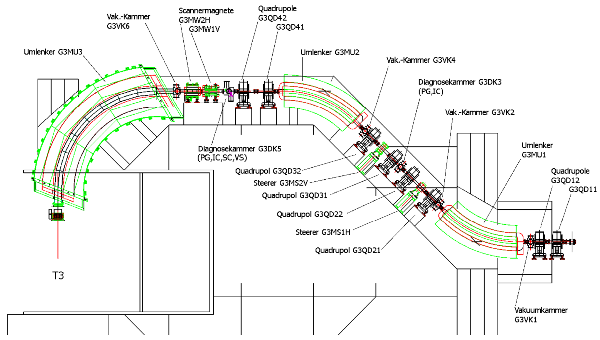

Fig. 4: Gantry beam line with beam diagnostic devices

energy step	reference focus [mm]	FWHM range [mm]	max. position deviation [mm]
1	9.8	7.4-12.3	± 1
1	10.7	8.0-13.4	± 1
1	12.1	9.1-15.1	± 1
1	13.4	10.1-16.8	± 1
255	3.4	2.6-4.3	± 1
255	5.5	4.1-6.9	± 1
255	7.8	5.9-9.8	± 1
255	9.8	7.4-12.3	± 1

Tab. 1: Reference value of the beam width (FWHM, carbon) with margin (25 % rel. deviation), and maximum position deviation for the minimum and maximum ion beam energy and focus steps 1 to 4

The beam width in the HEBT changed since the first gantry commissioning at the beginning of 2008 due to a change in synchrotron extraction. Therefore the high energy beam transport to the gantry and the ion beam characteristics (beam widths) behind the gantry had to be re-adjusted. Beam size and position, are measured with a viewing target and camera mounted on the (rotating) exit of the gantry (Fig. 5).

The ion beam adjustment follows the pattern:

1) the beam size and position variation over the gantry angle is reduced by optimisation of the ion beam at the gantry entrance point, i. e. beam size and angle for a single ion beam energy (Fig. 6, see also [3][4]). Since the vertical beam emittance depends on the beam energy (due to adiabatic damping) the matching at the entrance point depends on the ion beam energy as well;

2) the beam size behind the gantry is adjusted by the last gantry quadrupole doublet, the control values of which can be set and stored individually for different gantry positions.

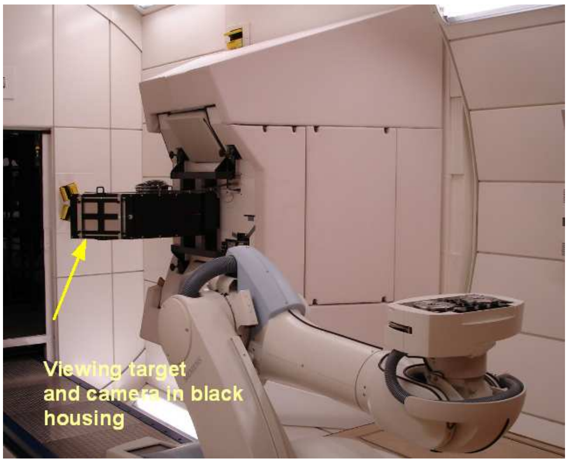

Fig. 5: Viewing target and camera in black housing at the gantry exit

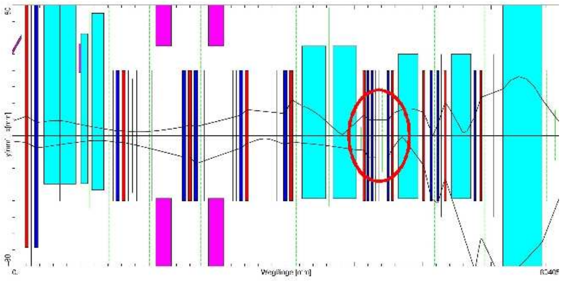

Fig. 6.: Beam envelopes along the HEBT and gantry, red marked: envelope at the gantry entrance point

In order to reduce the commissioning efforts these quadrupoles are the only lenses which should be set corresponding to the gantry angle although this is technically possible for other magnets as well.

This given procedure ensures that the beam size ranges (up to now almost) in a 25 % limit compared to the beam sizes needed for patient treatment for 89, 251, and 430 MeV/u, i. e. for the minimum, maximum and one medium carbon energy. Fig. 7 shows the measured beam size (FWHM) over a full gantry rotation.

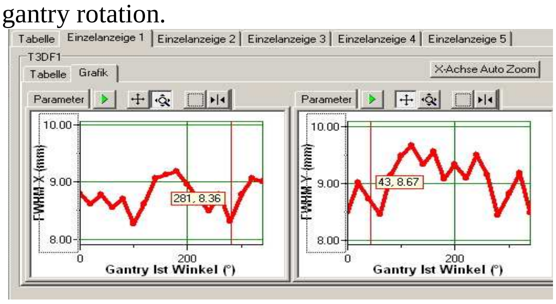

Fig. 7: Beam width (FWHM, left: horizontal, right: vertical) over a full gantry rotation, energy step 255 (430 MeV/u), focus step 3 (9.0 mm), diagnostic tool: viewing target behind the gantry

For a single energy the control data for the accelerator components is calculated from physical input parameters. The data supply model accounts for scaling of the control data with the magnetic and electric rigidity for different energies. Other energy dependend effects have to be compensated by manually adjusting components according to the beam energy, i. e. quadrupoles, dipoles, steerer in the HEBT. The focusing strength of the last gantry quadrupoles even has to be set individually for different energies, set values of beam width, and gantry angle.

In order to minimize the commission effort only a few number of input parameters are set manually; i. e. for a few energy steps, and gantry angles, while missing data (physical and control data for the power supplies) is created by means of a polynomial fit between these nodes. Fig. 8 shows an example for the input setting of a correction to the quadrupole focussing strength as a function of the gantry angle. The position of the maxima/minima in the fit curves clearly reveals the periodic structure of the input parameter corresponding to the gantry angle.

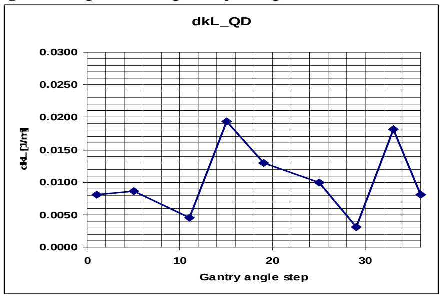

Fig. 8: Correction to a quadrupole focussing strength as function of the gantry angle step (1 step ≡ 10°) with fit (line) between the base points (dots) for a fixed energy and focus step

OUTLOOK

The next steps in the beam commissioning include the adjustment of the beam size for several medium energy steps. After this, the magnet settings for intermediate energies and gantry angle dependend focussing strengths will be calculated from the polynomial fit curves for the whole variety of needed beam properties, i. e. 255 energy steps, 4 beam radii and 36 gantry angles. This is giving a total number of 36720 combinations for one ion species, excluding 10 intensitiy steps and intermediate gantry angles.

The results concerning the beam position are still preliminary. With the settings so far the beam position varies within a few mm on the viewing target as well as in the MWPCs on the gantry. These variation will be reduced by further modification of the matching at the gantry entrance point and, as a further option, by gantry angle depended corrections of the beam position in the near future, and later on by position control of the rasterscanning technique.

It can be concluded that the described procedures provide an efficient way of setting the ion beam properties in a reasonable time.

ACKNOWLEDGEMENT

The authors would like to thank the GSI therapy accelerator team for commissioning of the HIT accelerator, which was finished for the horizontal treatment rooms by the end of 2007 [5]. The accelerator was handed over to HIT on the 30th of April 2008. Thanks to the HIT staff for many helpful discussions, preparation, and maintenance of the accelerator parts which are necessary for the gantry commissioning.

REFERENCES

[1] R. Fuchs et al., Proc. of the 11th EPAC 08, Genoa, Italy

[2] J. Mosthaf et al., Proc. of the 12th ICALEPCS, Kobe, Japan, 2009

[3] C. M. Kleffner, U. Weinrich, Proc. of the 11th EPAC 08, Genoa, Italy

[4] U. Weinrich, documentation to the gantry commissioning, 2008, unpublished

[5] D. Ondreka et al., Proc. of the 11th EPAC 08, Genoa, Italy