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

C.Kleffner, U. Weinrich, GSI, Darmstadt, Germany

Abstract

The HIT facility comprises the only carbon ion gantry worldwide. This gantry is especially unique in offering fully flexible beam transport to the patient for carbon ions up to an energy of 430 MeV/u. It includes a full 3D-beam scanning system and full medical treatment environment. The gantry can be rotated by 360 degree so that the beam may be directed at the patient from arbitrary directions. Commissioning with beam of the gantry was successfully started in January 2008 when the first proton and carbons beams were transported into the gantry treatment room.

Based on theoretical calculations for rotation independent settings of the beam optics, the beam commissioning aims for an efficient practical way to realize the full variety of required beam properties (2 ion types, 10 intensities, 255 energy steps, and four beam sizes) in the isocenter independent of the gantry angle. The presentation will report on the concept and progress of the beam commissioning process.

INTRODUCTION

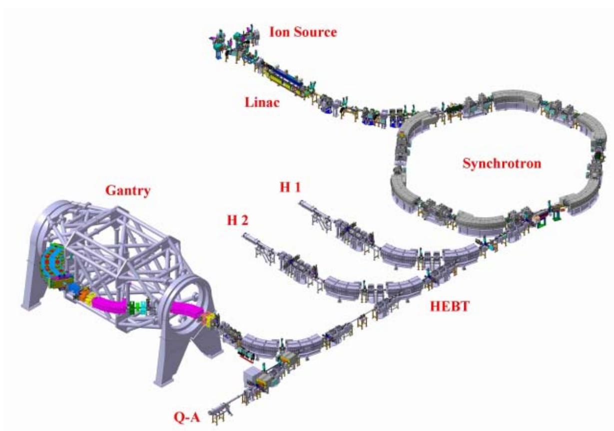

Figure 1**:** Detailed Overview over the accelerator part.

Figure 1 shows the overview of the HIT accelerator. The accelerator chain consists of an injector linac, accelerating the ions to an energy of up to 7 MeV/u, followed by a compact synchrotron with a circumference of about 65 m. The beam is distributed by the high energy beam transport line HEBT to the four beam stations. Station one and two are fixed horizontal beam stations for patient treatment. In station three the beam is guided along an isocentric gantry allowing irradiation from all directions. The fixed beam station number four is used for quality assurance, development and research activities. All places are equipped with rasterscan treatment equipment for a full 3D volume conformal irradiation.

The accelerator part of the dedicated cancer therapy facility in Heidelberg has been commissioned with beam all along the year 2007. The first turn in the synchrotron could be reached on the 7th of February. The first beam in the horizontal place was then already measured on the 23rd of March. As can be seen in Figure 2 with the RF-knock-out method a flat spill structure was reached.

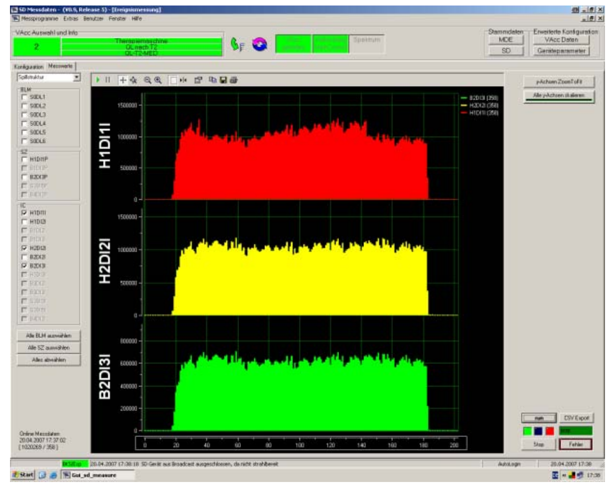

Figure 2: Spill structure along the HEBT in April 2007.

Bringing the carbon and proton beam performance and flexibility to a quality which enables patient treatment lasted until the 16th of December [1]. Figure 3 shows the horizontal beam profile over time for a spill interruption of 1 second. The spill interruption feature enables the treatment of in one isoenergetic slice transversally separated tumour regions within one synchrotron cycle.

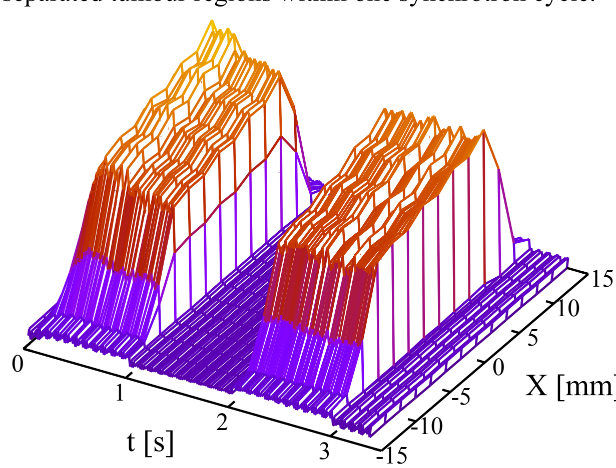

Figure 3**:** Horizontal beam profile over time for a spill with interruption.

Afterwards the staff of the operating society HIT GmbH was trained, the documentation finished and the minor defects eliminated. GSI has rendered over the accelerator on the 30th of April 2008. The now available key parameters of the facility are:

- carbon and proton beam in 2 fixed beam treatment rooms and 1 quality assurance place
- fast change between carbon and protons
- choice of ion-energies: 255 steps
- range of ion energies: 50 - 430 MeV/u
- penetration depth: 20 – 300 mm
- extraction-time: ≤ 5 s
- choice of beam diameters: 4 steps
- range of beam-diameters: 3.5 - 20 mm FWHM
- choice of ions/spill: 10 steps
- range of ions/spill: $1 \cdot 10^6$ - $1 \cdot 10^{10}$
- spill interruption: possible

The main effort in the project is now focused on the commissioning of the treatment technique equipment and the necessary tests to get the permission for patient treatment.

THE HEAVY ION GANTRY

In order to have full geometrical flexibility of the entrance channel of the beam into the patient a gantry has been built which is able to transport protons and light ions up to carbon with energies corresponding to a penetration depth in tissue between 20 and 300 mm. In July 2003 the order was placed to the company MAN Technologie (now MT Mechatronics) for the construction of the structure and the integration of the components [2].

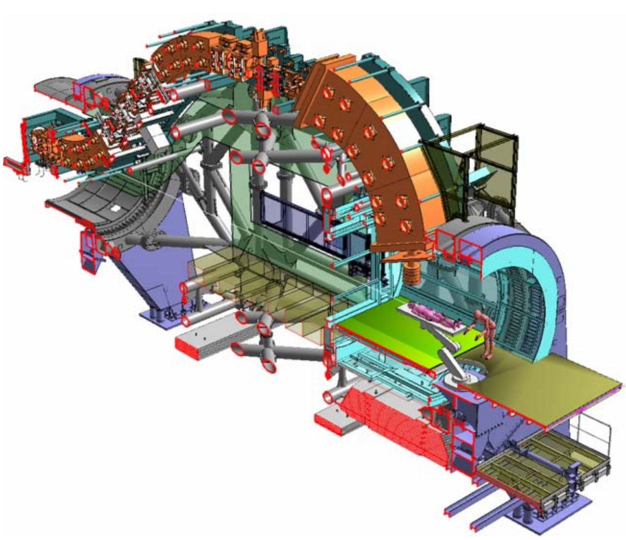

Figure 4: Cut of the gantry showing also the beam line components.

There are two main stands holding the rotating part via two large bearings. The total weight of rotating parts in the final layout amounts to 570t out of which 140t are due to the beam transport components and about 120t due to the beam absorber. In addition there are 130t of room fixed components such as the main Gantry supports. The functionality has to be maintained for up to 300 000 rotations over the envisaged life cycle of 25 years. The 3D volume conformal rasterscan method requires reproducible beam positions for all gantry angles. Given the weight of the components to be integrated it was necessary to perform extensive FEM – calculations to optimise the supporting structure to the required stiffness without increasing too much the total weight of the system. [3].

The whole installation process of the gantry including the alignment procedure and the commissioning with was finished by the end of 2007 [4].

BEAM PERFORMANCE

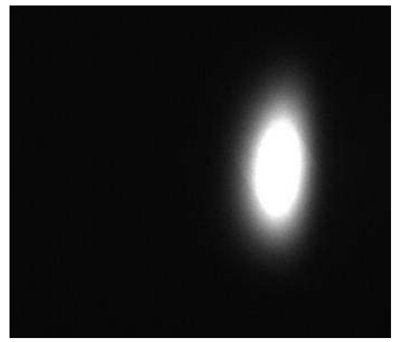

Figure 5: First beam measured in the isocenter of gantry patient room on the 4th of January 2008.

Beginning of January 2008 the commissioning with beam of the gantry was started. Already on the 4th of January the first proton beam was transported to the isocenter. One day later this was also achieved for the carbon beam. So for the first time worldwide carbon beam has been successfully transported through the gantry.

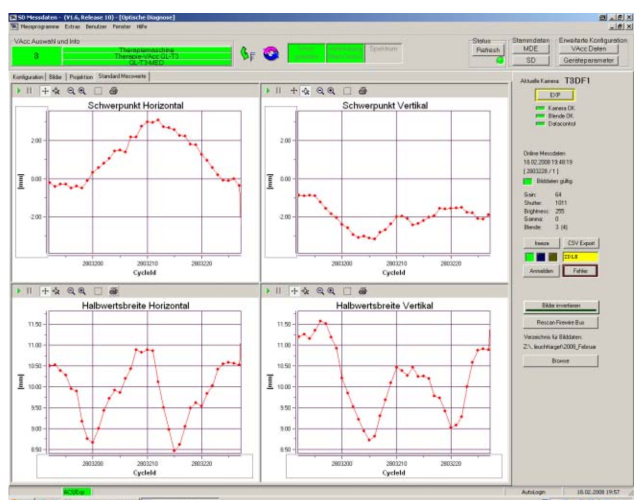

Figure 6: Beam position and focus behaviour over a full gantry rotation

During the following weeks the variety of the carbon beam settings was improved. First of all it was shown that the required four Fokii could be reached for the maximum and the minimum carbon beam energy. Then a procedure was developed which assures that the beam size remains within 25% tolerances of the FWHM for all gantry angles without any quadrupole change in the High energy beam transport line or the gantry. First the beam size is measured over many gantry angles (Figure 6). Then the angle dependent variation is reduced with the beam envelope optimisation at the gantry entrance point (Figure 8) while the average beam size is adjusted with the last gantry quadrupole doublet.

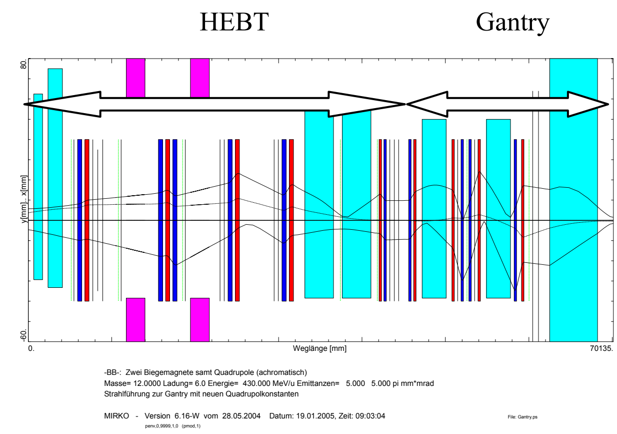

Figure 7: Beam envelopes along HEBT and Gantry.

The goal of less than 25% focus variation was achieved for the lowest and highest energies as can be seen in Table 1. On the 13th of March the beam commissioning was interrupted and no further commissioning work was possible due to cabling problems in the flexible cable tray of the gantry. Major optimisation of the cable tray arrangement has to be done.

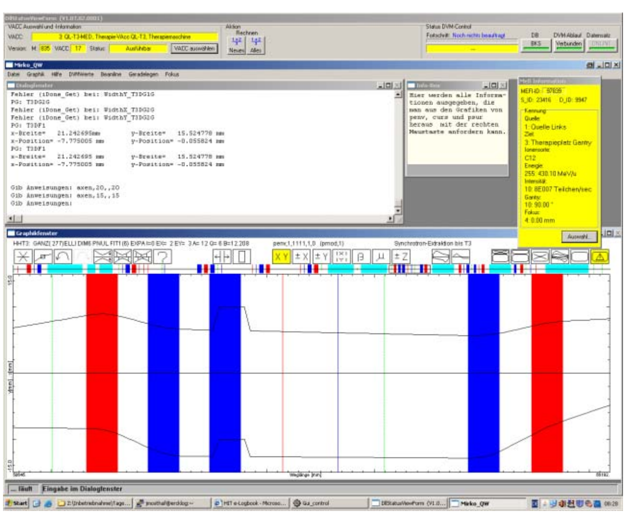

Figure 8: Matching of the beam envelopes at the gantry entrance point.

The vertical beam emittance in the HEBT is energy dependent due to adiabatic damping. The horizontal beam emittance in the HEBT, however, remains rather constant for the full energy range, since it is dominated by the extraction process. In order to achieve a rather gantry angle independent focusing it was therefore necessary to match the beam envelopes at the Gantry entrance point corresponding to the energy. The already achieved beam performance for carbon beam in the gantry is summarised in the following table. The mentioned beam size variation cover all beam sizes for all angles.

Table 1: Achieved carbon beam focus performance

Energy step	Target Focus [mm]	Horizontal Focus [mm]	Vertical Focus [mm]
1	9.8	9.6 - 10.0	9.6 - 10.0
1	10.7	10.2 - 11.0	10.2 - 11.4
1	12.1	11.7 - 12.9	11.9 - 13.1
1	13.4	12.6 - 14.4	12.2 - 14.8
255	3.4	3.1 - 4.1	2.9 - 3.9
255	5.5	4.7 - 6.5	5.1 - 6.1
255	7.8	6.9 - 8.9	7.2 - 8.8
255	9.8	8.5 - 10.9	8.7 - 11.7

OUTLOOK

The next step in the beam commissioning will be to reach the same performance at several other medium energies which will allow reaching the 25%-tolerance band for all energies via interpolation. There exists also a strategy to reduce the angle dependent deviations below 15% by using four interpolation points at different gantry angles.

Concerning the beam position the results are rather preliminary. It was shown, that the settings could be found which maintain without any further action the beam position within a few millimetre at the isocenter. This can be further improved by optimising the beam entrance into the gantry, by using gantry angle dependent interpolation and profiting from the active beam position control of the raster scanning technique.

From the still preliminary results of the beam commissioning it can already be concluded, that the gantry beam will reach focus and position performance very close to the fixed beam stations and certainly sufficient for patient treatment. Furthermore it can be stated that this performance will be reached with a reasonable amount of effort for beam commissioning.

REFERENCES

[1] D.Ondreka et al., The Heidelberg Ion Therapy (HIT) Accelerator Coming into Operation, Presentation TUOCG01 at this conference
[2] U. Weinrich et al.: The Heavy Ion Gantry of the HICAT Facility. EPAC 2004
[3] U. Weinrich: Gantry Design for Proton and Carbon Hadrontherapy Facilities, EPAC 2006
[4] R. Fuchs et al.: Assembly of the Carbon Beam Gantry at the Heidelberg Ion Therapy (HIT), Presentation TUPP133 at this conference