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

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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 up to a magnetic rigidity of 6.6 Tm, equivalent to an energy of C-ions 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 aimed at the patient from arbitrary directions.

Commissioning of the gantry with beam was started in January 2008, when the first beams were transported into the treatment room. The design and assembly of this gantry with a rotating mass on the order of 600 tons was a real challenge to the project partners involved, in particular the supplier MT Mechatronics. Given the tight tolerances for the position of the beam line components the survey and alignment procedure was difficult, since also the elastic deformation for the different rotation angles had to be taken into account.

This presentation will report on the experiences and results of the assembly and alignment phases. Furthermore, the final performance reached for precision and reproducibility of the beam line components will be presented.

INTRODUCTION

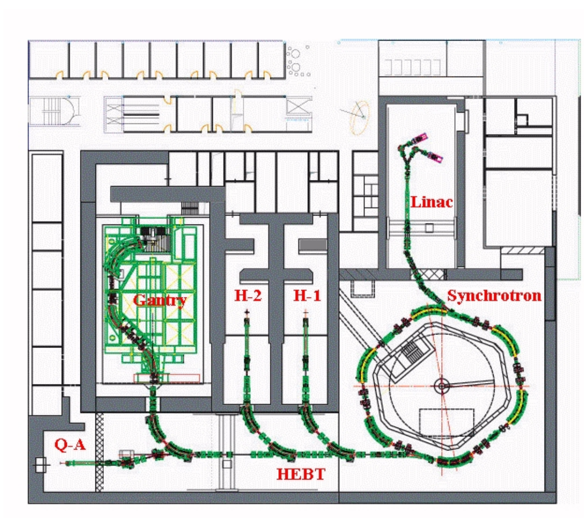

Figure 1: Layout of the first underground level housing the accelerator complex.

Figure 1 shows the layout of the first underground floor of the HIT facility with the accelerator sections and the treatment places. 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. Two fixed horizontal beam stations will be used for patient treatment. In one station the beam is guided along an isocentric gantry allowing irradiation from all directions. Another fixed beam station will be used for quality assurance, development and research activities. All places will be equipped with rasterscan treatment equipment for a full 3D volume conformal irradiation.

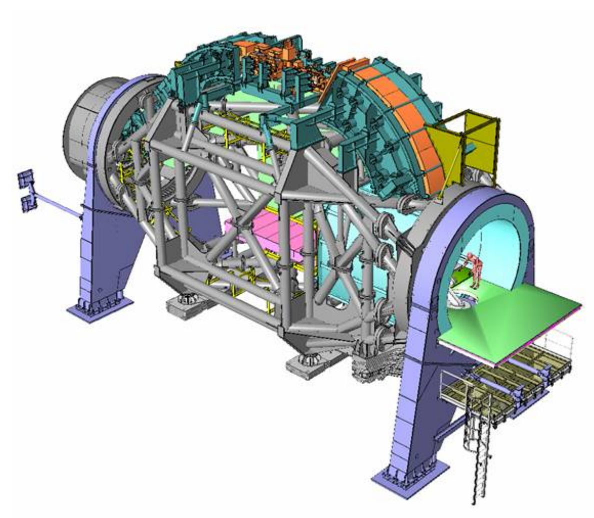

Figure 2: Overview of the isocentric ion gantry.

The accelerator part of the dedicated cancer therapy facility in Heidelberg has been commissioned to a performance which enables patient treatment [1]. The GSI has handed over the accelerator to the operating society HIT GmbH. The actually achieved beam parameters of the facility are:

- carbon and proton beam in fixed beam stations
- 2 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
- 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: $1 \cdot 10^6$ - $1 \cdot 10^{10}$

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.

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].

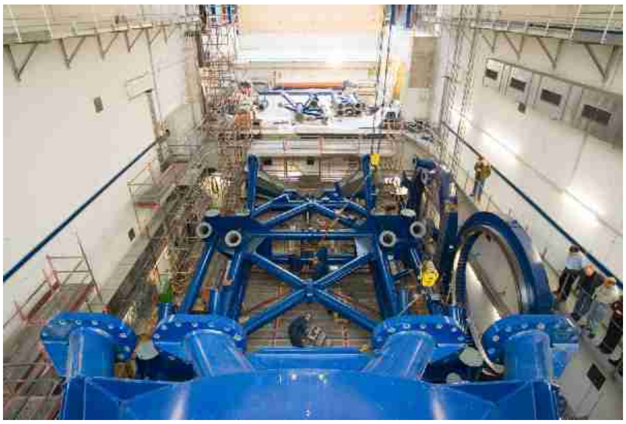

Figure 3: Assembly of the main structure.

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 15 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 [3].

ASSEMBLY OF THE GANTRY

The gantry hall is roughly 26 m long, 15 m wide and 16 m high. It contains two cranes with in each case 25 tons of carrying capacity which can be synchronised. For the transport of the components into the gantry a large part of the building wall and roof had to be kept open. The first larger components of the gantry were delivered in summer 2006 into the gantry hall. It was the main bearing stand which was the assembled in place.

In January 2007 the main components of the gantry were delivered and the assembly started. Until end of March 2007 the assembly of the supporting structure and the integration of the beam line components took place. On the 21st of April the gantry was for the first time successfully rotated. During all the summer a lot of effort was spend to connect all the cables and tubes to the magnets and the vacuum and diagnostic components. In addition the survey and alignment took place so that finally the main gantry itself was handed over for operation purpose to the university hospital on the 31st of August 2007.

Figure 4: Main structure seen from below.

Due to the related complexity at the border line to both – the building and the treatment technique - the last assembly work took place in the patient environment. A significant part of the room walls is inserted in the gantry itself and therefore supported by the fixed bearing stand. The gantry nozzle not only includes the end of the 90°-dipole and the beam exit window but also the technical equipment to verify the patient position. Furthermore some security measures were included to avoid unwanted collisions during gantry or robot movements. The patient room was handed over to the hospital at the 4th of December 2007.

Figure 5: View of the patient room.

Beam commissioning started successfully in January 2008 [4]. Unfortunately mid of March 2008 severe problems on cable isolation in the flexible cable tray of the gantry were discovered. An analysis of the situation revealed several weak points of the design of the cable tray which are actually being eliminated.

Figure 6: Flexible cable tray.

ALIGNMENT OF THE GANTRY

In order to achieve a very reliable and precise beam position the magnets in the gantry have to be precisely positioned. Another important requirement is that the position will be reached in a very reproducible manner. This can only be assured when the mechanical stress remains well within the elastic deformation region.

A third requirement is that the magnets have to maintain their position and orientation for the different gantry angles. It was therefore agreed, that a survey of all relevant beam line components has to take place in steps of 30° for the full 360° angle potential of the gantry. As tolerance band for the total error budget among others the following values were derived from beam position estimations:

± 0,3 mm radial position for the quadrupoles
± 0,4 mrad tilt around tangent for the 45°-dipoles
± 0,2 mrad tilt around tangent for the 90°-dipol

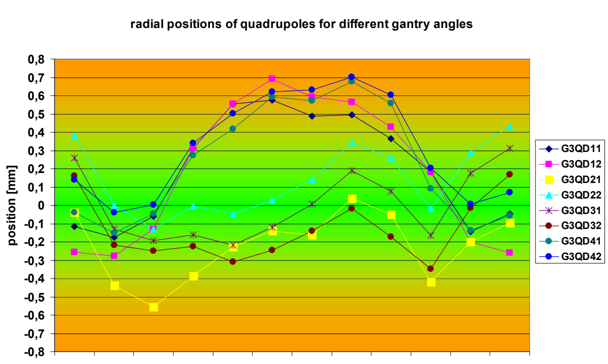

Figure 7: Radial positions of gantry quadrupoles.

The survey and alignment procedure was complex and some iteration was necessary until finally the full set of information was correctly achieved.

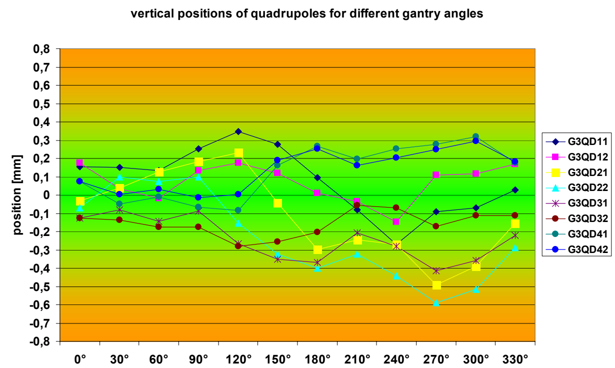

Figure 8: Vertical positions of gantry quadrupoles.

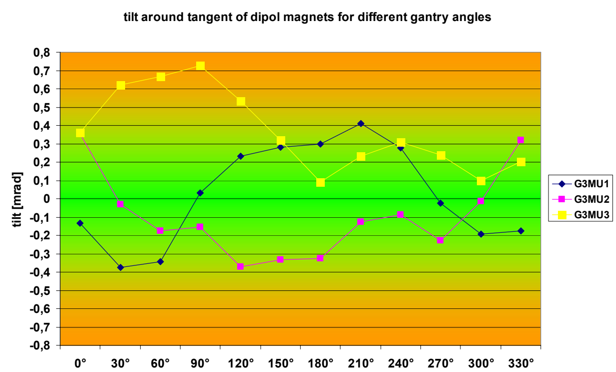

Figure 9: Tilt around tangent of gantry dipole magnets.

The given tight tolerances for the total error could not be reached as can be seen in the figures Figure 7, Figure 8 and Figure 9. The commissioning with beam, however, revealed that the mechanical properties are good enough to produce reliable operation settings via the use of beam position correction elements [4] Part of this can be explained that adjacent quadrupoles undergo the same mechanical movements.

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