SURVEY AND ALIGNMENT OF THE WORLD'S LARGEST GANTRY FOR CANCER THERAPY

Andreas Schnegg, Holger Wirth, Metronom Automation GmbH, Mainz, Germany
Ina Pschorn, Gesellschaft für Schwerionenforschung mbH (GSI), Darmstadt, Germany

Abstract

At the last IWAA at SLAC, Metronom and GSI have presented the concept for the Survey and Alignment at the new Heavy Ion Cancer Therapy facility at Heidelberg, Germany [1]. Now, we want to present the procedures to align the largest heavy ion gantry of the world for cancer therapy.

This large gantry allows to rotate the whole beam transportation system around the patient, in order to minimize radiation damage in the tissue surrounding the cancer. The impressive gantry has a total weight of 600 tons, the rotating parts have a weight of 420 tons and the beam transportation system itself has a weight of 140 tons. The gantry is 25 meters long and 13 meters in diameter.

We want to present the biggest challenge for the survey and alignment team: to perform the acceptance measurements of the rotating parts, which means to check the position of each component on different rotation angles. Basis for this measurement was a real 3D-network over three different levels of the building and, amongst other techniques, the deployment of industrial climbers to install the reflectors to the components.

THE HICAT PROJECT

The University Hospital of Heidelberg has built in co-operation with GSI Darmstadt and subcontractors a new Heavy Ion Cancer Therapy (HICAT) accelerator. It is the first clinical Irradiation facility for heavy ions in Europe. Its capacity enables the treatment of 1000 patients per year. An intensity-controlled raster scanning technique will be used to optimize the use of the favorable depth dose distribution of ions. The benefit for the patient is a gentle treatment with a high chance to destroy the tumors and prevent further cancer growth. The health insurance companies have agreed to bear the expenses of the treatment.

The therapy accelerator consists of a linear accelerator with two sources, a synchrotron and three treatment rooms with a circumference of 65 m. The third treatment room contains a rotatable, worldwide unique isocentric gantry which allows radiation treatment from all directions. The project start was in 2003, fiducialization and assembly of the accelerator began in 2005 and the alignment of the 150 components started 2006.

Figure 1: HICAT accelerator

The biggest challenges of the HICAT project:

- Survey and alignment of the entire machine including gantry had to be offered for a fixed price three years before starting on.
- Acceptance test measurements of the gantry structure and of each component in different angle positions of the gantry.
- To set up a real 3D-network in the three-storied gantry hall with high precision
- Very tight project plan concerning time and costs

SURVEY AND ALIGNMENT

First of all we had to define a global HICAT coordinate system in all beam leading rooms of the HIT building. For this we measured all these rooms in the first reference measurements, set up a basis network and fit the accelerator in the building. Through the local and temporal separated assembly, local high-precision reference networks were measured, short times before the alignment of the components, and settled on the basis reference network. For these networks we had to install up to 500 wall and floor monuments. In order to avoid offset problems we have a consistent nest design for all fixed points (wall, floor and component).

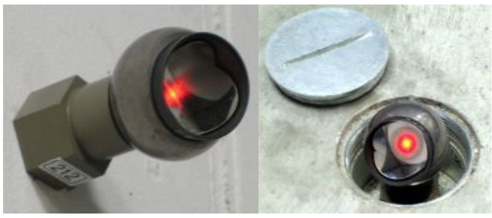

Figure 2: Wall and floor monument

For the network measurements we operated with Laser Tracker (Faro SI-2) and Digital Level (Leica DNA 03). The evaluation of the combined network adjustment was arranged with the Metronom TASA and SLAC LEGO software. We achieved a standard deviation of the fixed reference points ≤ 0.02 mm.

The transfer measurement (fiducial points were representing the beam axis) of each component were also performed with Laser Tracker, therefore at least four permanent nests have been installed an each component.

For the 3D alignment on site with Laser Trackers we pursuit the concept to calculate the position of the (virtual) beam axis on every alignment step. Therefore we integrated the necessary data structures and transformation methods into the TASA software. The allowed positioning error for the beam axis transversal and vertical are 0.1 to 0.3 mm and the allowed tilt error of the roll angle are 0.1 to 0.5 mrad depending on the component. With this alignment concept we achieved the goal to keep the components in tolerances. Furthermore the alignment itself, especially of the larger components (e.g. the 60° synchrotron dipoles), was easier and faster with exact deviations after each alignment step.

ISOCENTRIC GANTRY

The worldwide first ion beam gantry is commissioned at the Heidelberg Ion-Beam Therapy Centre. It is an isocentric gantry system, i.e. the beam is bent by two 45° dipole magnets and a 90° dipole magnet and delivered always perpendicular to the gantry axis. The supporting structure keeps angular elastic deformations within tight limits [2].

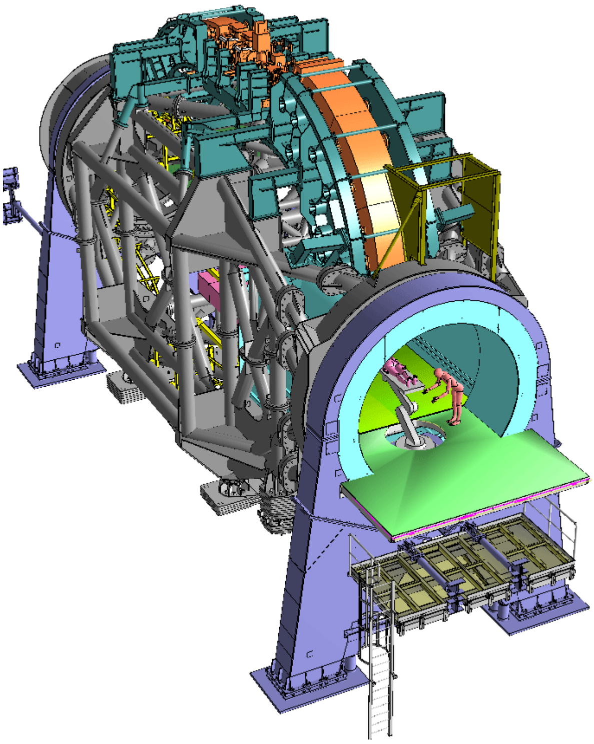

Figure 3: Layout of the gantry structure in 0° [2]

The gantry system spans all three levels of the HIT (Heidelberg Ion-Beam Therapy Centre) building. All beam line elements of the gantry are located in-plane. The beam scanning system integrated on the gantry is unique. Aiming for a “small” diameter of the gantry, the scanning magnets are mounted on the section parallel to the gantry axis, just in front of the final 90° bending magnet [3].

The elaborate construction allows the exact positioning of the ion beam in an optimum angle to the patient with a maximum deviation of 0.5 mm.

After the “warm-up”, alignment of the horizontal part of the accelerator and the two horizontal fixed beam treatment rooms, we have to face the challenge of the alignment of the monstrous gantry. In the following the procedures to align the large isocentric gantry will be described.

Tasks for the survey and alignment of the gantry

- Conceptual design and development of a survey and alignment strategy
- Alignment of the rotating axis, the gantry structure and all components
- Acceptance test measurements (6-DOF) of each component in different angle positions of the gantry

Conceptual design

For the survey and alignment in the three-storied gantry hall we had to develop special adapters to enable measurements. For the Laser Tracker we used moveable brackets on tracks and steel balconies that the instruments could be installed in different positions and levels. Tilt adapters were necessary to increase the vertical working range. Extended net points (points for plumbing) were needed for the measurement of the reference network in the gantry hall.

Figure 4: LT on moveable bracket with tilt adapter

Last but not least we needed special techniques to install the reflectors to the components including industrial climbers to permit the measurements.

Figure 5: Industrial climber on the gantry

With these preconditions we had to do a line-of-sight simulation to ensure that all components on the gantry could be seen with the Laser Tracker. Furthermore it has to be a detailed simulation of all possible lines of sight in all different angle positions of the gantry (every 30°). With this CAD-simulation the position and number of the stations and fiducial points of each component on the gantry was defined.

Alignment of the gantry

Three main steps had to be done for the gantry alignment and between the alignments we had to ensure with network measurements the quality of the reference network.

First of all the two main bearing supports had to be aligned to the rotating axis with an accuracy of 0.1 mm. Therefore we measured the bearings itself and calculated the deviation of the middle point and the tipping of the bearing.

The second step was the alignment of the gantry structure. Which also had to be aligned to the rotating axis with an absolute tolerance of 0.1 mm. Therefore fixed points on both sides of the structure were measured. Also the deformations along the rotating axis were detected and compared with the calculated and expected bending of gantry structure.

The third step was the alignment of the gantry components itself. All components were aligned in the 90° position with tight positioning tolerances for the beam axis, transversal and vertical, of 0.1 mm and an allowed tilt error of the roll angle of 0.1 mrad. Without the concept of the position calculation of the (virtual) beam axis on every alignment step it would not have been possible to align the great and double fixed components on the gantry. For example the 90° dipole has 24 adjustment jacks! For the alignment of this dipole we needed two days with the result that the (virtual) beam axis of the dipole itself had a deviation under 0.15 mm.

Acceptance test measurements

For the acceptance test the position of each component had to be controlled in different angle positions of the gantry. Every 30° the position and orientation of the components were measured and calculated. For one acceptance test (12 positions of the gantry every 30°) we needed six days with two Laser Tracker teams. The installation of the instruments followed the line-of-sight simulation and therefore we could measure every component in each angle position of the gantry. The beam reproducibility in the isocenter with all influences (!) is ±0.5 mm.

For the complete acceptance test we needed 50 stations. After three iterations (alignment and acceptance test measurements) the deviation of each component could be reduced to less than 0.3 mm in all different angle positions of the gantry.

LASER-ALIGNMENT

Additionally to the survey and alignment of the beam components special lasers (line- and crosshair laser) inside the treatment rooms had to be aligned with an accuracy of 0.2 mm referring to the beam line. These lasers will be used to visualize the beam and the isocenter (treatment point) and to adjust the patient before the treatment starts.

Metronom Automation has developed a so called “laser phantom” which will be temporarily installed in the intersection point of the lasers. The phantom will be aligned to the isocenter by determining the pose (6-DOF) with a laser tracker and adjustment of the position and orientation. If the phantom is installed the lasers can be aligned in respect to four pins with markers on it. The pins are rectangular to the laser lines and define the necessary reference planes.

With the laser phantom the alignment procedures have been sped up by factor 2 to 3 compared to conventional methods. Furthermore it was the only way to align the lasers in the gantry treatment room where no stable wall is available for the installation of alignment marks.

REFERENCES

[1] Holger Wirth, Ina Pschorn, “A New Heavy Ion Cancer Therapy Facility”, 2006

[2] MT Mechatronics GmbH, “Rotating beam delivery system”, 2007

[3] GSI information, “Rotating beam delivery system”, 2007