TESTS OF A LIGHT-ION GANTRY SECTION AS AN EXAMPLE OF PREPARATIONS FOR THE THERAPY FACILITY IN HEIDELBERG

H. Eickhoff et al., GSI Darmstadt

Abstract

For the planned cancer therapy facility at the Clinics of Heidelberg a light ion gantry system is foreseen, that is compact and fulfills the requirements of the 'intensity-controlled' rasterscan treatment modality. The last section of this gantry including the scanner-magnets and the 90^0 bending magnet has been constructed and first beam tests have been performed. A brief description of the layout of the Heidelberg treatment facility is given and both the gantry design and results of the gantry-section tests are described .

1 INTRODUCTION

Preparations for the realization of a dedicated cancer therapy facility [1] at the University clinics of Heidelberg have started. The accelerator and beamline sections of this facility will be built by industries with supervision of GSI, aiming at first patient treatments in 2006. The facility is designed to treat more than 1000 patients per year with the intensity controlled rasterscan method [2], developed at GSI and successfully applied with carbon ions to more than 120 patients treated since 1998 within the GSI therapy pilot project.

This treatment method demands fast, active energy-variation to achieve different penetration depths and intensity- and beam-width-variation to minimize the treatment time.

The main requirements of the dedicated facility were intensively discussed with radiotherapists and biophysicists and can be summarized as follows:

- treatment both with low and high LET-ions
- relatively fast change of ion species
- 3 treatment areas to treat a large number of patients
- integration of an isocentric gantry
- ion-species : p, He, C, O
- ion-range (in water) : 20 - 300 mm
- ion-energy : 50 - 430 MeV/u
- extraction-time : 1 - 10 s
- beam-diameter : 4 - 10 mm (hor., vert.)
- intens. (ions/spill) : $1*10^6$ to $4*10^{10}$ (dependent upon ion species)

Fig. 1 shows the layout of the first underground floor of this facility with the accelerator sections and treatment places. The accelerator chain consists of an injector linac, accelerating the ions to an energy of 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 (HEBT) to 3 treatment places; for 2 of them (H1, H2) horizontal beam lines are foreseen , the third beam line is installed within an isocentric gantry, allowing beam entrance channels with angles between 0^0 and 360^0. A 'quality assurance place' (QA) is located at the end of the HEBT to perform various research activities and further improvements of the treatment method. All places are equipped with the installations requested for the rasterscan treatment method.

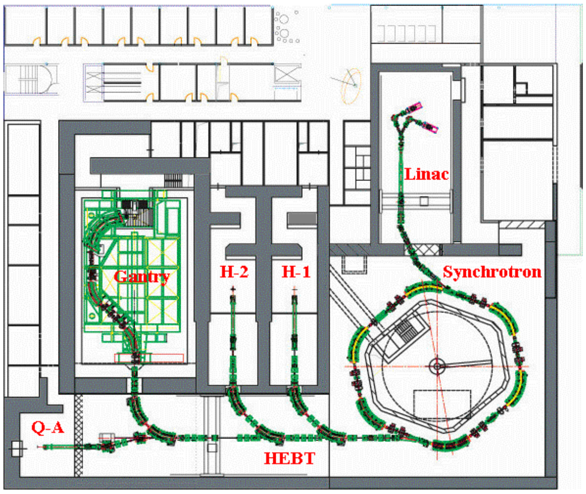

Fig. 1: Layout of the first underground floor, housing the accelerator complex

The building consists of 3 floors; the accelerator complex is located on the first and a major part of the additional technical installations on the second underground level. On ground level offices are located as well as the upper part of the gantry cave, that extends over all 3 floors.

2 THE HEAVY ION GANTRY

In order to have full flexibility of entrance channels a heavy ion gantry is strongly requested for the Heidelberg facility, capable to transport protons and light ions up to oxygen with energies corresponding to penetration depths in tissue between 20 and 300 mm. Intensive discussions with physicians lead to an isocentric gantry design, including the integration of rasterscan components in both planes.

After extended ion optical calculations the layout of the beam transport system was fixed, characterized by two 45^0 magnets after the gantry entrance, 8 quadrupoles for matching the beam parameters and a 90^0 bending magnet at the gantry exit.

As the total gantry has to be compact, the two scanner magnets are located in front of the 90^0 bending magnet. This layout allows a gantry structure with less than 20 m length and 6.5 m radius. For all magnets a normal-conducting design is chosen.

Up to now no heavy ion gantry system has been built; therefore design studies of the mechanical structure were performed by industrial firms; one possible structure is shown in Fig. 2.

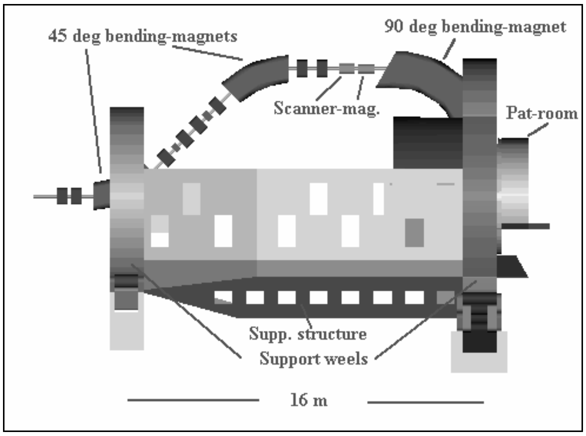

Fig.: 2 View of the gantry assembly (the upper structure elements are excluded to show the magnet elements)

The total gantry weight including a massive counter weight, all magnets and supports is about 600 tons. FEM calculations for the structure result in a maximum angle dependent deformation of about 0.3 mm, which leads to an estimated beam position variation at the isocenter of about 1.5 mm, mainly due to steering of the last focusing quadrupole. Although reproducable positioning errors can be handled by means of appopriate steerer settings a fast on-line position correction with the scanner magnets, that is successfully in operation at the GSI pilot project, will probably be used in addition.

One of the challenging component of the gantry is the last 90^0 dipole in front of the treatment area. Various investigations took place in order to define the design and the properties of this magnet [3,4].

The dipole-aperture is designed to allow the requested irradiation field of 20 * 20 cm. The laminated magnet is of a window frame type with a bending radius of 3.65 m, corresponding to a maximum flux density of 1.8 T for the maximal magnetic rigidity of 6.6 Tm.

The position and dimension of the airslots are determined within 2D- and 3D-computer simulations and improve the field-homogeneity for high field operation (see Fig. 4).

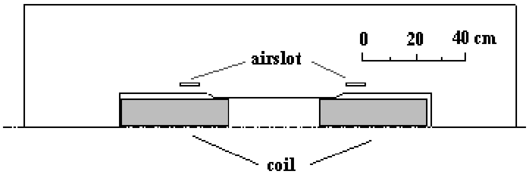

Fig. 3: Cross section of the 90^0 dipole magnet

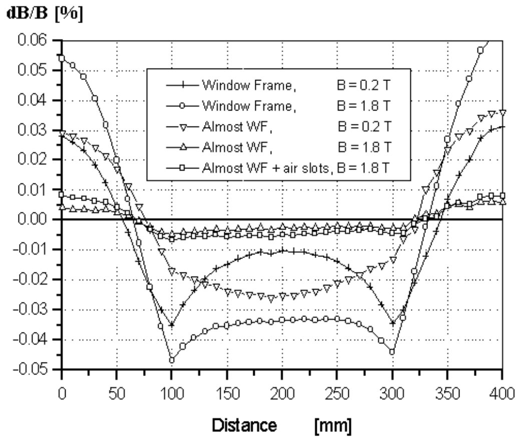

Fig. 4: Simulation of the field homogeneity of the 90^0 magnet ('good field region' from 100 to 300 mm).

The 90^0 bending magnet is equipped with edge angles both at the entrance (30^0) and the exit (21^0). The exit edge angle allows a nearly parallel beam both in horizontal and in vertical direction as shown in Fig. 5.

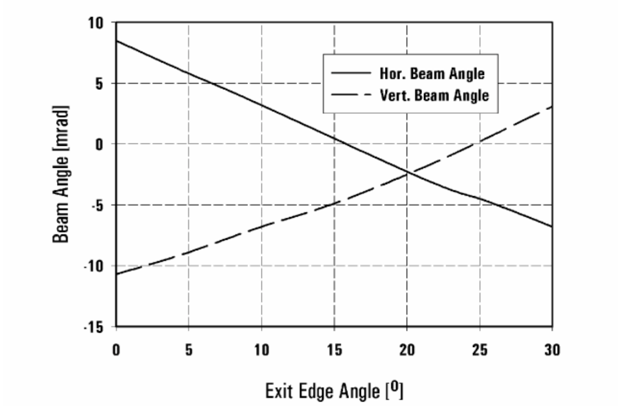

Fig. 5: Beam angle after the dipole as a function of the edge angle.

On both sides of the dipole yoke mirror plates are installed to reduce the strayfield. At the entrance this is essential in order to avoid coupling of the dipole field and the scanner magnet fields; at the exit it is required, as the flux density at the isocenter has to be less than 10 Gauss in order to avoid removals of patient's pacemakers, when patients with pacemakers are treated.

3 TESTS OF THE GANTRY-SEGMENT

As a part of the HGF-strategy funds for investigations on ‘Multifield irradiation techniques’ beam tests of the last gantry section, including the scanner magnets and the 90^0 bending magnet in a horizontal setup have started in 2002.

Fig. 6 shows the gantry segment during the installation phase in a GSI expermental cave with the 90^0 dipole magnet in front and the scanner magnets and quadrupoles close to its entrance, seen from the isocenter position.

Before the installation of the whole segment took place intensive field measurements of the 90^0 dipole were performed, covering both the field homogeneity and its dynamic behaviour.

Fig. 6: Gantry segment (the upper yoke of the 90 degrees dipole and its mirror plates not yet installed)

As an example Fig. 7 shows the various time constants near the flat top for the excitation current and the corresponding field behaviour in the central and edge region of the magnet for a current step from zero to maximum current. A Hall probe is foreseen to allow field regulation of the power supply, in order to assure operation with stable conditions after 4 s.

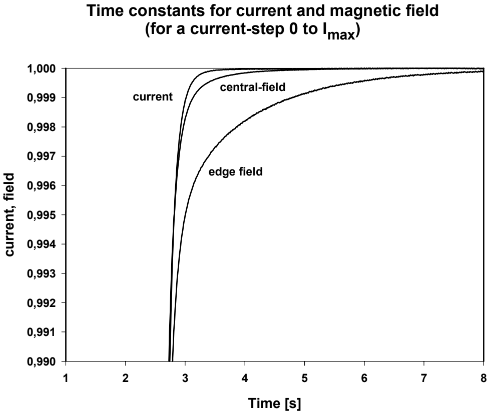

Fig. 7: Measurements of the dynamic behaviour of current and fields.

Within a beam time in april of this year first tests were performed to investigate the beam-performance of the gantry arm, using a special beam diagnostic set up at the ISO-center [5].

For energies of carbon ions between 50 and 400 MeV/u the beam positions and beam profiles in both planes were measured for various settings of the horizontal and vertical scanner magnets.

Fig. 8 shows the results, indicating that for both planes the requested irradiation field of ±100 mm is achieved. It is also demonstrated that the dependence of the beam position from the scanner excitation is very linear.

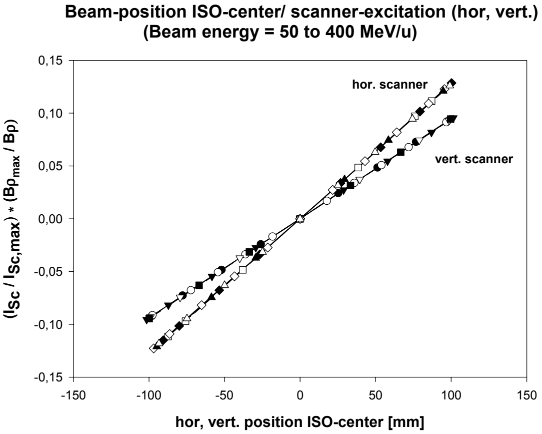

Fig. 8: Measurements of the beam position at the isocenter as a function of scanner excitations.

For the beam profile a slight variation of the beam symmetry between the center and the outside regions has been measured (see Tab. 1); this behavior has been predicted in beam simulations and has to be considered within the treatment plan or by according variations of beam focusing.

Energy (MeV/u)	**150**	**300**
hor. width (2σ, x=0, y=0 cm)	2.8 mm	1.6 mm
vert. width (2σ, x=0, y=0 cm)	3.1 mm	1.8 mm
hor. width (2σ, x=10, y=10 cm)	3.0 mm	1.7 mm
vert. width (2σ, x=10, y=10 cm)	4.1 mm	2.6 mm

Tab. 1: Measurements of the ISO-center beam-profile at the central and outer region of the treatment area.

During several short beam times up to the end of 2002 additional experiments are foreseen including the adaption of the rasterscan control system aiming at a therapy close operation.

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