THE PROPOSED DEDICATED ION BEAM FACILITY FOR CANCER THERAPY AT THE CLINIC IN HEIDELBERG

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Abstract

Starting in 1997 nearly 60 patients have been successfully treated by means of the intensity controlled rasterscan-method within the GSI experimental cancer treatment program. The developments and experiences of this program accompanied by intensive discussions with the medical community led to a proposal for a hospital based light ion accelerator facility for the clinic in Heidelberg. [1]

Major aspects of the design are influenced from the experiences of the GSI cancer treatment program; the requirements of this facility, however, exceed in many fields those of this pilot project.

The main characteristics of this facility are the application of the rasterscan method with active intensity-, energy-, and beamsize- variation in combination with the usage of isocentric light ion gantries. The accelerator is designed to accelerate both low LET ions (p, He) and high LET ions (C, O) to cover the specific medical requirements.

1 INTRODUCTION

The basis of the accelerator concept has to satisfy the demands of the medical community for the treatment procedures. One of the key aspects of the proposed facility is the use of the intensity controlled rasterscan technique (Fig. 1), which is a novel treatment concept, developed at GSI and successfully applied within patient treatments of the GSI pilot therapy program.

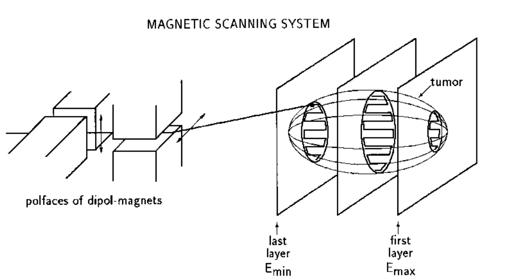

Figure 1: Rasterscan-Method

After acceleratain and slow extraction in a synchrotron the beam enters 2 fast scanner magnets, that deflect the beam both in horizontal and vertical direction to cover the lateral dimensions of the tumor.

Ionization chambers in front of the patient measure the number of ions at a specific irradiation point and control the scanner excitation.

Fast multiwire proportional counters detect the position and beam width at each scanning point. When a required dose limit has been reached the beam extraction is interrupted very fast (< 0.5 ms).

This method demands fast, active energy-variation to achieve different penetration depths and intensity-variation to minimize the treatment time [2].

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

Table. 1: Therapy requirements

- intensity-controlled rasterscan method
- treatment both with low and high LET-ions
- relatively fast change of ion species
- wide range of particle intensities
- integration of isocentric gantries
- 3 treatment areas to treat a large number of patients
- 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.)
- intensity (ions/spill) : $1*10^6$ to $4*10^{10}$
- (dependent. upon ion species)

2 LAYOUT OF THE ACCELERATOR FACILITY

The accelerator facility was designed to meet the medical requirements, considering the experiences at the GSI accelerator facilities used for the successful GSI treatment program over the last years.

Fig. 2 shows the cross section of the first underground floor of the building, which houses the accelerator-sections, the patients preparation areas, local control rooms and various laboratories and offices. Additional space for housing the power supplies and further technical infrastructure is available in the ground floor and the second underground floor of this building.

The accelerator and beam transport sections consist of the following subsections:

<u>a) Injector and low energy beamline</u>

For the ion generation two parallel ECR-sources are foreseen, giving the possibility to switch from proton to carbon treatment within a few minutes.
The ECR source is chosen, as this type provides a very stable intensity over a long time without adjustment of the source parameters.

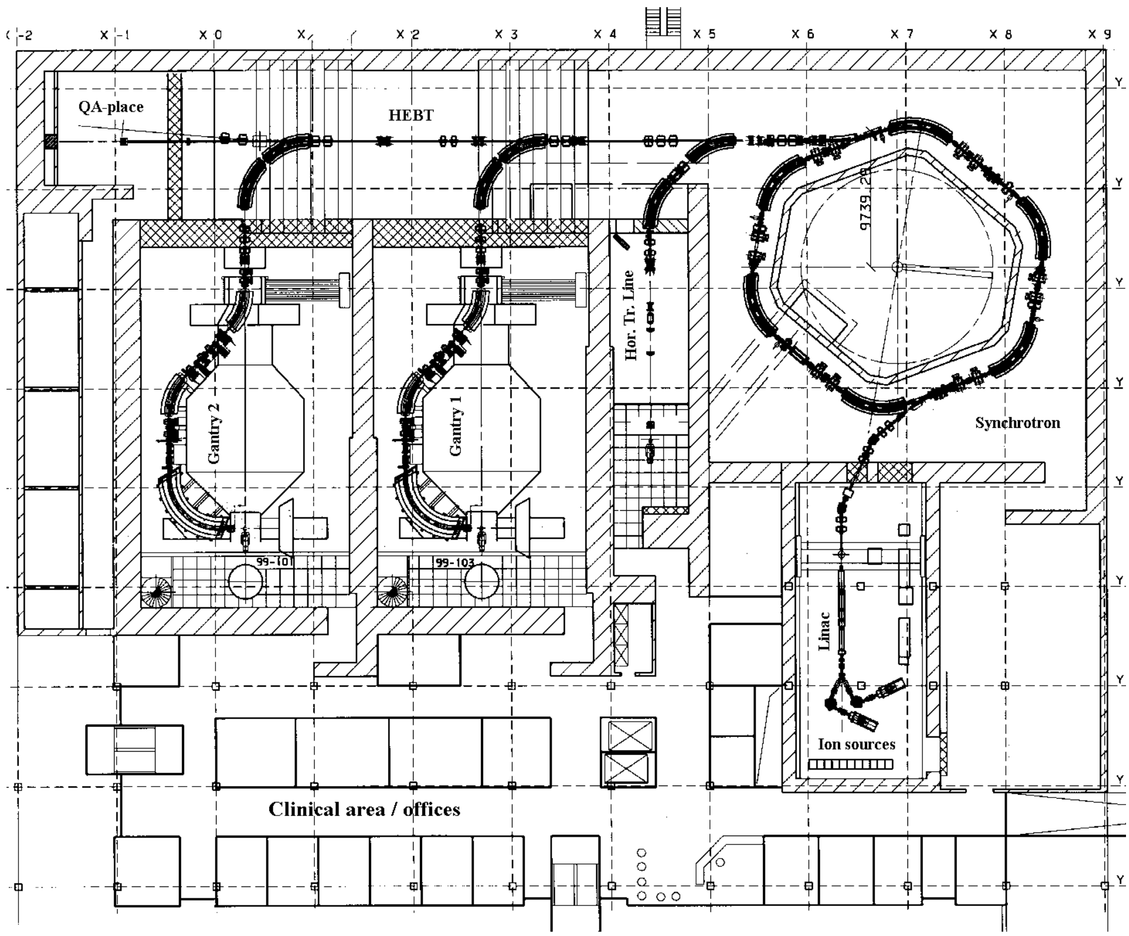

Figure 2: Layout of the accelerator sections

The required particle currents between 80 µA (for $16O^{6+}$ and 1.2 mA (for p) are rather conservative; beam tests of this commercially available source indicate, that both the current and the requested beam emittance can easily be achieved. The extraction energy of the ECR-source is 8 keV/u.

Within the low energy beam line the requested intensity reduction down to 0.1% of the maximal ion intensity will be performed by means of appropriate beam defocusing.

b) Linac, Medium energy beam transport

A combination of RFQ and IH-linac structure with a total length of about 6 m is proposed to accelerate the ions up to 7 MeV/u. The RF-frequency of these structures is 216 MHz. The designed pulse length is 200 µs, the maximal repetition frequency is 5 Hz. The normalized beam emittance is about 0.8 πmm mrad, the momentum spread ± 0.15%.

The medium energy beam transport consists of a stripping and a matching section to the synchrotron. In addition, for multiturn injection a chopper system is provided to match the pulse from the linac. A rf debuncher cavity is foreseen to reduce the momentum spread for the synchrotron injection in order to maximize the multiturn injection efficiency.

c) Synchrotron [3]

For the synchrotron with a circumference of about 64 meters 6 bending magnets with a maximum flux density of 1.53 T. Four long and two short drift spaces are available for the installation of injection and extraction elements and the RF-cavity. After a 15 to 20 turn injection, corresponding to an injection time of about 30 µs, the acceleration to the maximal extraction energy takes place within 1.0 s.

The synchrotron has a doublet focusing structure with a slightly different ion optical setting for beam injection and extraction.

For slow extraction the 'transverse knock out' method is proposed with variable extraction time between 1 and 10 s and multiple beam extraction at the same flat top.

d) High energy beam transport (HEBT)

The high energy beam transport system transports the slowly extracted beam either to a beam dump or distributes it to three treatment places. Just after the synchrotron extraction section a fast deflecting magnet will prohibit the beam delivery in case of interlocks.
At the end of the high energy transport line a 'Quality-Assurance' (QA)-place is foreseen for beam diagnosis purposes, further developments of the treatment technique and biophysical research activities.

e) Treatment areas

In order to meet the demand for a patient flow of 1000 patients/year three treatment areas are foreseen. For the first area the beam will be delivered from a horizontal beam line, similar to that used at the GSI pilot project. The beam for the second and third treatment places will be delivered by a rotating beam transport system ('isocentric gantry'). All beam lines are equipped with horizontal and vertical scanning magnets and beam dignostic devices for the intensity controlled rasterscan.

The integration of PET monitoring systems both in the horizontal and the gantry beam lines is proposed as well.

f) The Gantry [4]

As up to now no heavy ion gantry system has been built a design study of the mechanical structure was performed in collaboration with the firms ACCEL and SEAG. A frame of box girders between two wheels is proposed, similar to that realized at the PSI proton gantry, that had been constructed by SEAG (see Fig. 3).

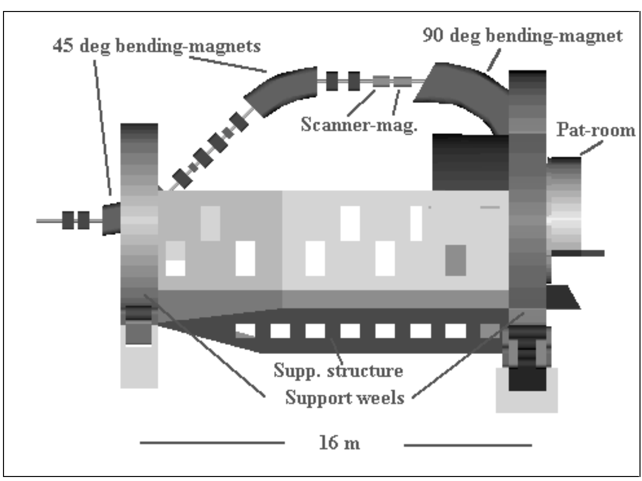

Figure 3: View of the gantry assembly (the upper structure elements are excluded to show the magnet elements)

The total weight including all magnets and supports is estimated to be near 600 tons. FEM calculations for this structure result in a maximum angle dependent deformation of about 0.3 mm , which leads to a beam position variation at the isocenter of about 1.5 mm, mainly due to a steering of the last focusing quadrupole. Similar values have been determined for a slightly lighter gantry structure, proposed by GSI. 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.

In addition to construction aspects of the gantry structure beam tests of the last gantry section, including the scanner magnets and the 90 degrees bending magnet in a horizontal setup are foreseen in the first half of 2002 as a part of the approved HGF-strategy funds for investigations on ‚Multifield irradiation techniques‘ [5].

3 PLANNING STATUS AND OUTLOOK

In 1999 the need for the proposed therapy facility was formulated by the board of the clinics at Heidelberg and the 'planning-group medicine' was estabished to start the project preparations. In a preplanning phase financing models were investgated and the building layout was intensively discussed. Within a project study detailed cost estimates for all sections and project phases have to be performed as well as estimates concerning medical, economical and technical riscs; the project decision is expected after completion of the project study within the next year.

Besides activities for the HGF-funds further technical design work had been performed in order to specify the components to be constructed by industrial partners; a technical report will be available this summer. In addition, prototyping work for the linac section will take place. Further theoretical and experimental investigations of the proposed ‚transverse knock-out‘ method for slow beam extraction have been performed.

Further optimization steps of the gantry structure are foreseen including all essential aspects of the treatment area, that are presently investigated.

As it is planned to build the facility under the project leadership of the radiological clinic in Heidelberg with substantial support from industries intensive work has been undertaken concerning the project organization scheme both for the project construction and operation phase.

First patient treatments are scheduled around 2005/6 after an extensive commissioning phase of about 1 year.

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