ACCELERATOR SYSTEMS FOR PARTICLE THERAPY

S.P. Møller, F.S. Albrechtsen, T. Andersen, A. Elkjaer, N. Hauge, T. Holst, M. Jensen, S. Madsen, DANFYSIK A/S, Jyllinge, Denmark
K. Blasche, BTE, Heidelberg, Germany
B. Franczak, GSI, Darmstadt, Germany
S. Emhofer, H. Kerscher, V. Lazarev, H. Rohdjess, Siemens AG, Erlangen, Germany

Abstract

Danfysik and Siemens have entered a cooperation to market and build Particle Therapy* systems for cancer therapy. The systems are based on the experience from GSI together with a novel design of a synchrotron, the High-Energy Beamlines and Siemens experience in oncology. The accelerator systems will include an injector system (7 MeV/u proton and light ions), a synchrotron and a choice of fixed-angle horizontal and semi-vertical beamlines together with gantry systems. The slowly extracted beam will cover the energy ranges of 50-250 MeV for protons and 85-430 MeV/u for carbon ions. The extraction time will be up to 10s with intensities well beyond the needs of scanning beam applications. We will describe the layout of such a system and present details on some of the subsystems.

INTRODUCTION

Cancer therapy with protons and light ions has developed considerably during the last years, and the technique holds great promise in the fight against cancer. Several facilities have already been built or are under construction world-wide. The field has also matured to the extent that such facilities cannot only be built by large research accelerator laboratories but are now also offered by industries.

In the present contribution, we will describe the results of the efforts to design such a particle-therapy accelerator, where consideration has been given to industrial and modular production. In addition to a description of the performance specifications, some details of hardware components will be given. The synchrotron will be described in more detail in a separate contribution [1]

The present design was based on the design of the HICAT accelerator being built at the Universitätsklinikum in Heidelberg by GSI [2] and the experience obtained with the therapy facility at GSI [3].

GENERAL LAYOUT AND SPECIFICATIONS OF THE ACCELERATOR

The accelerator to be described will be based on a synchrotron with its associated injector and high-energy beam transport and delivery systems. The supported PT facility is designed to treat deep-seated tumours using active raster scanning of proton and light ion beams. The choice of a synchrotron as the main accelerator stems from the requirement of using also the heavier light ions , primarily carbon ions. In addition, the use of a synchrotron, as opposed to a cyclotron, also means that the energy can be varied continuously from cycle to cycle without the need for any energy degradation and the resulting contaminations and beam losses. This continuously variable energy is a key element in the raster scan technique developed at GSI. The system is optimized to do active scanning and prepared for moving target applications.

The accelerator will operate in pulsed mode with a repetition time varying from a minimum of less than 1 second for short pulses of low-energy protons to a maximum of more than 12 seconds for long extracted spills (10s) of high-energy carbon ions. The main parameters of the Particle Therapy accelerator are given in Table 1.

Table 1: Main design parameters of the PT accelerator

Proton energy range	50-250 MeV/u
Carbon energy range	85-430 MeV/u
Ramping time	< 1s
Extraction time	< 10s
Max. number of protons extracted	$2{\cdot}10^{10}$
Max. number of C ions extracted	$1{\cdot}10^{9}$
Intensity variation after source	0.001-1
Ion species	H, He, C, O
Ion source energy	8 keV/u
Injection beam energy into synchrotron	7 MeV/u
95% emittance of beam after stripper foil injected into synchrotron	8 π mm mrad
95% momentum spread injected into synchrotron	<±0.1%
Beam focus (FWMH) at treatment position	<5 to 12 mm
Transverse field for scanning	200×200 mm^2

*Particle Therapy is a work in progress and requires country-specific regulatory approval prior to clinical use.

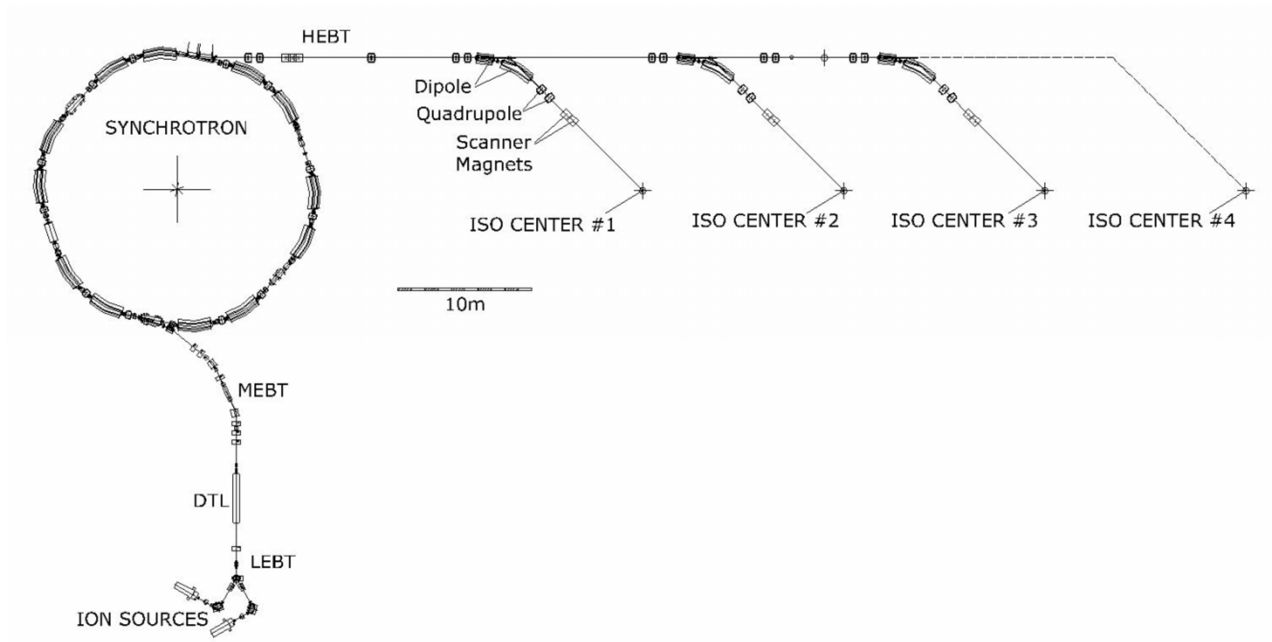

Figure 1: Layout of PT Accelerator with 3 beamlines.

The layout of the accelerator appears from Fig. 1. The beam will originate in either of two ECR ion sources with their own Low-Energy Beamline Transport (LEBT) system with spectrometer magnets for isotope separation. Either of these two beams can be switched into a common LEBT matching the beams to the input of a Radio Frequency Quadrupole. The RFQ accelerates the beams from an energy of 8 keV/u to an energy of 400 keV/u. Subsequent acceleration is performed with a drift-tube LINAC to a beam energy of 7 MeV/u. A Medium Energy Beam Transport (MEBT) system chops, de-bunches and charge-state separates and transports this beam to the injection point of the synchrotron.

A multi-turn injection is performed in the SYNCHROTRON with an electrostatic septum and a three-bumper system, to provide a sufficiently high intensity. The synchrotron accelerates the beam to the required beam energy and stores the beam for subsequent slow extraction. A third-order resonance makes the particles jump the electrostatic septum followed by two magnetic septa. A High Energy Beam Transport (HEBT) system transports the beam through either of a number of beamlines, which matches the beams to the properties required at the isocenter, i.e. at the position of the patient.

High-Energy Beam Transport

The beamlines in the High Energy Beam Transport system is designed to transport the beam from the synchrotron to the end of the beamlines with minimal losses and with an optics system which can give an adjustable spot size of less than 5 mm up to 12 mm FWHM at the isocenter. The adjustment of the beam size is designed to be done by varying the currents in the last quadrupole doublet only. The dispersion and the dispersion gradient at the end of the last dipole in a given beamline is designed to vanish. The HEBT system will consist of a common beamline followed by a number of beamlines starting with a 45º deflection. These individual beamlines will end either in different fixed beam angles (single or combined) or a proton gantry. An example of the beam envelopes for the first treatment room (ISO CENTER #1 in Fig. 1) is shown in Fig. 2.

For ease of installation and to allow the beam to pass the 45º deflection to the proceeding treatment rooms, this deflection is separated into a 15º deflection followed by a 30º deflection. The 30º magnet will then be similar to that of the synchrotron, and the same profile will also be used for the 15º magnet. Similarly, the quadrupoles designed for the HEBT will also be used in the MEBT.

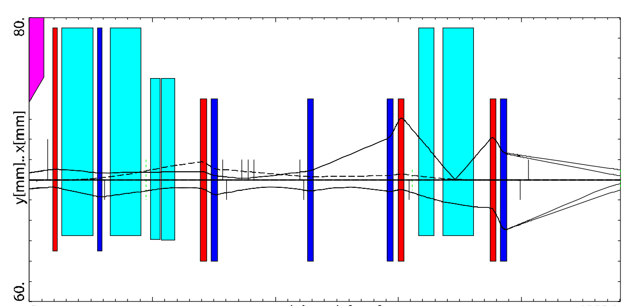

Figure 2 : Beam envelopes for the first treatment room drawn for emittance ellipses of 0.7 (hor.) and 5 (vert.) π mm·mrad and beam diameters of 4 and 10 mm at the isocenter. The dotted curve shows the dispersion for $\Delta p/p$=0.1%.

The common part of the beamlines will have an abort system, which shall prevent any beam-particles entering the beamline within 250 µs after an interlock signal. In addition, the extraction process is also stopped. Finally, as a third and slower precaution, the beam is also not sent to the treatment room by switching off the last dipole magnet normally deflecting the beam into the treatment room.

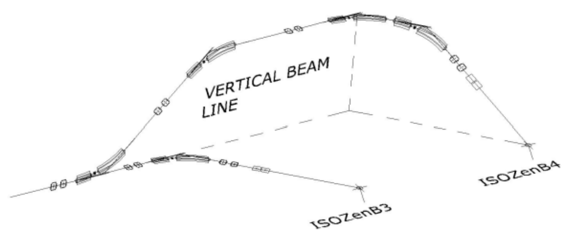

Figure 3: Layout of a semi-vertical beamline.

Besides the proton gantries SIEMENS/DANFYSIK offers for their PT accelerator a larger number of treatment angles which can also be achieved with a combination of fixed beam outlets. A layout drawing of an example of a semi-vertical 45º beamline is given in Fig. 3.

In order to switch between different beamlines, a system to nullify the magnetic field in the switching magnets will be installed.

The accelerator is mainly designed for raster scanning irradiating the tumour in spots, or rather in 3-dimensional voxels. The transverse position of each voxel is determined by the setting of the magnetic field in the scanning magnets, whereas the longitudinal position, the depth in the body, is determined by the energy of the beam particles. In a given iso-energy slice, corresponding to a given beam-energy of the synchrotron, the raster scanning is performed during one or more synchrotron cycles. For the next iso-energy slice, a new cycle, corresponding to a new maximum magnetic field in the synchrotron, is required.

Beam Diagnostics is one of the costly parts of a particle therapy accelerator, and some attention has been paid to this issue in the present project. In particular it is proposed to control beam alignment on the beam line axis in front of the isocenter of each treatment room by means of the precise position of the last quadrupole doublet and by the center position of the large area MWPC in front of the patient. In this way one can save most of the beam position profile monitors in the HEBT system and still has equal or better supervision of the beam.

CONCLUSIONS

The present contribution has described an accelerator for a Particle Therapy facility optimised for modular design and industrial production.

ACKNOWLEDGEMENTS

Numerous persons at GSI are acknowledged for their support and interest in the present project.

REFERENCES

[1] H. Eickhoff et al., Proceedings of EPAC ‘04, Lucerne, Switzerland, p. 290.
[2] H. Eickhoff et al., Proceedings of EPAC ’96, Sitges, Spain, THP052G.
[3] S.P. Møller et al., present proceedings of EPAC ‘06, Edinburgh, Scotland, WEPCH160.