IMPROVING THE SYNCHROTRON PERFORMANCE OF THE HEIDELBERG ION BEAM THERAPY CENTRE

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Abstract

The linac-synchrotron-system of the Heidelberg Ion Beam Therapy Centre (HIT) [1] routinely delivers pencil beams to the dose delivering raster scanning devices at 3 treatment rooms, including the worldwide first scanning ion gantry and 1 experimental cave. At HIT the quality-assured library of pencil beam parameters covers roughly 100.000 combinations of the ion, energy, intensity and beam size. Each patient-specific treatment plan defines a subset of these pencil beams being subsequently requested during the dose delivery. Aiming at shortened irradiation times an upgrade program making heavy use of feed-back mechanisms is under way. Driven by patient-specific data out of the scanning beam dose delivery process central synchrotron components are coupled to the therapy control system in order to tailor the beam characteristics in real-time to the clinical requirements. The paper will discuss the functional upgrades and report about the impact on the medical application at HIT.

INTRODUCTION

The Heidelberg Ion Beam Therapy Centre is the first European particle therapy facility using protons as well as heavier ions to treat deep-seated tumours. It is a hospital-based facility being designed to treat more than 1.000 patients per year and to conduct a broad research and development programme in parallel. HIT fully relies on active beam scanning dose delivery, i.e. active energy variation in the synchrotron as well as variable beam intensity and focussing on a cycle-by-cycle basis. The synchrotron and the high-energy beam transport system are used to produce a library of highly focussed pencil-beams. This library covers about 100.000 beam parameter combinations (4 ions species, 250 energies per ion, 15 intensity steps and 6 spot sizes). It is shared between the accelerator control system and the treatment planning platform. 3D dose delivery is performed using the raster scanning technology [2]. This method is based on the virtual dissection of the target volume into iso-energy slices. In the frame of the treatment planning process each slice is subdivided into voxels that generate a beam path being scanned using a subset of the pencil beam library. At each raster point a pre-calculated amount of stopping ions is deposited. The variation in dose per raster point can be as large 1:100. In order to scan the iso-energy slices as fast as possible and to meet the dose quality requirement of 2.5% the extracted intensity distribution from the synchrotron (spill structure) is an essential parameter. Stepping in depth through the stacked iso-energy slices is a time consuming process as the synchrotron has to be filled, ramped up and down besides the extraction phase which is used to scan the tumour. The HIT synchrotron operation can be optimized prior to and during beam extraction for the patient treatment. Magnetic field feed-back (B-train) and dynamic spill shaping have the potential to significantly reduce the irradiation duration.

PERFORMANCE CONSIDERATIONS

Particle therapy centres like HIT represent a major investment and typically have to meet the requirements of a business plan. One crucial design parameter is the number of treatment rooms being served by the accelerator system. Three to five rooms are considered to be reasonable in this context. For clinical use HIT comprises two horizontally-fixed treatment rooms and the worldwide first scanning ion gantry. The latter will go clinical in 2012. Obviously the ratio of the preparation time to the irradiation time of an average patient needs to be larger than 2 in order to avoid that fully prepared patients have to wait for a beamtime slot and the total patient throughput would be limited. Shorter irradiation times allow for higher patient numbers and the stress for the individual patient due to the uncomfortable immobilization during the treatment could be reduced.

As the scanning ion gantry at HIT will be labelled as a medical device in summer 2012 the three-room operation mode will require shorter irradiation times, i.e. less and shorter synchrotron cycles per treatment field, to realize a smooth clinical workflow and a sufficient patient throughput. To meet the requirements of the upcoming clinical all-out operation an upgrade programme was launched that focussed on issues:

- Accelerator controls performance
- Magnetic field feed-back for the synchrotron dipoles and quads
- Dynamic spill structure shaping

ACCELERATOR CONTROL SYSTEM

Facing the challenging phase space of HIT's pencil-beam library the real-time management of the process data for the numerous devices of the HIT accelerator system requires efficient strategies to request and

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distribute these informations just in time. After the initial commissioning of the accelerator control system in 2007/8 during the last months the oracle-based real-time database operations could be optimized yielding a time saving of about 100ms per synchrotron cycle.

MAGNETIC FIELD FEEDBACK

In normal, i.e. current-controlled, mode stable extraction conditions are reached once the eddy currents in the dipoles have faded. Typically this accounts for a prep phase of 700 ms. Additionally the normalization of the hysteresis in the quadrupoles is done by ramping up to the maximum field. Via introducing a magnetic field feed-back (Fig. 1) for the dipoles and quads [3] in the synchrotron these time-consuming mitigations are no longer needed: the time saving can be up to 30%.

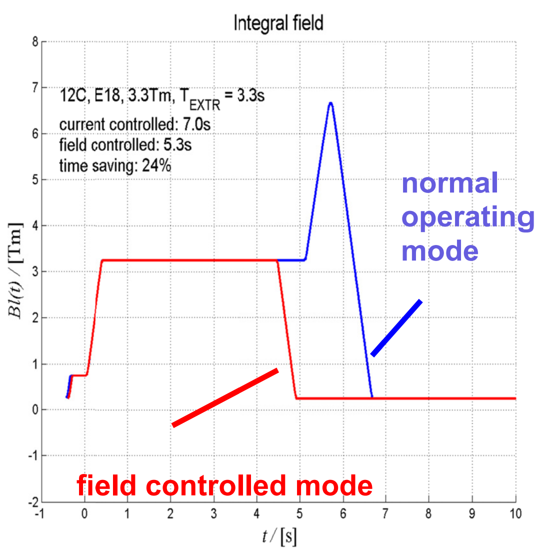

Figure 1: Magnetic field feedback relevantly reduces the cycling time of the HIT synchrotron as the extraction can be started earlier and the ramping to the maximum field level is no longer needed.

DYNAMIC SPILL SHAPING

The raster scanning dose delivery process deposits a pre-calculated amount of stopping particles at a pattern of raster points. These fluence maps are stacked in depth ordered by the energy, respectively the Bragg-peak position, of the pencil-beams to cover the target volume in 3D. Presently the extracted intensity (spill structure) from the synchrotron is shaped via a static feed-forward concept in the process data generation aiming at an almost rectangular shape. As the intensity of the pencil-beam is sampled at a rate of 100kHz using parallel-plate ionization chambers directly in-front of the patient a feed-back to the RF-knock-out exciter driving the extraction process could be developed. In phase I this feed-back mechanism will be used to dynamically optimize the rectangular shape of the spill structure. The time-saving will be about 25%!

In phase II the extracted intensity will be tailored in real-time to the structure of the patient-specific fluence maps potentially saving up to 45% beam-on time!

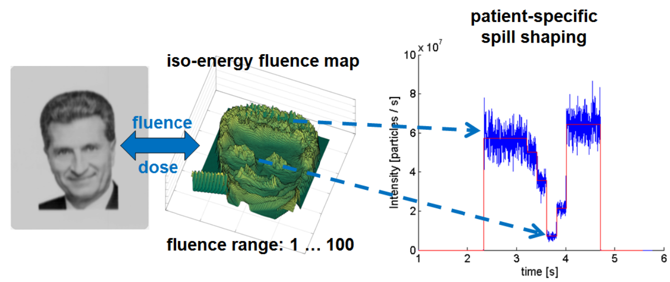

Figure 2: Patient-specific dynamic spill shaping will be driven by the particle fluence definition which is the result of the treatment planning process. This teaching example shows dose distribution (raster scanned portrait, left) and the corresponding fluence map (center). The high-dose parts (upper arrow) will be irradiated using the high-intensity part of the spill structure (right). Whereas the low-dose parts require the extraction of low intensities (lower arrow).

CONCLUSION AND OUTLOOK

The HIT synchrotron operation can be optimized prior to and during beam extraction for the patient treatment. Magnetic field feed-back reduces the cycling time up to 1.7s or 30%. Patient-specific shaping of the extracted intensity distribution has the potential to reduce the beam-on time up to 45%. The combination of these upgrades will go clinical within the next months and allow for a relevant increase in patient throughput at HIT.

REFERENCES

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