FIVE YEARS OF OPERATION EXPERIENCE AT HIT

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Abstract

Since spring 2007 the HIT company, a 100% daughter of the Heidelberg University Hospital, has taken over the responsibility for the operation of the first dedicated European ion beam tumour therapy facility. In 2009 the clinical operation started and since then more than 800 patients were treated in the facility. This success is based on a well-trained and highly-motivated team of physicists, engineers and technicians responsible for the 24/7 operation scheme as well as for more than 70% of the accelerator maintenance. The paper will give an overview of the operation organization reflecting the overall beam time schedule. In addition, the accelerator statistics will prove the achieved high availability of about 98% besides planned maintenance time. Furthermore, the reliability of the HIT accelerator including the gantry section will be illustrated resulting in long intervals before necessary retuning. At last, some examples of the continuous improvement process will be presented.

THE HIT FACILITY – A SHORT OVERVIEW

The core of the Heidelberg Ion-Beam Therapy (HIT) Centre is an accelerator facility designed to optimally support the raster scanning dose delivery method by producing light ion pencil-beams having energies that allow for the treatment of deep-seated tumours. It is comprised of two ECR ion sources (p, C), a compact linac consisting of an RFQ and an IH-DTL and a synchrotron to accelerate protons, helium, carbon and oxygen to predefined end energies e.g. for carbon ions from 88 to 430 MeV/u in 255 steps [1].

To operate the centre the HIT company as a 100% daughter of the university hospital was founded in July 2004. The mission of the company is to deliver a quality assured dose distribution for patient treatment with ion beams. About half of the personnel work in the accelerator section, the other half takes care about treatment planning, quality assurance and medical physics.

FROM COMMISSIONING BY GSI TO OPERATION BY HIT

In the HIT project GSI was responsible to manage all supplier companies, the installation as well as the commissioning of the accelerator. The ion sources and the linac were put into operation in 2006 and beginning of 2007, afterwards the synchrotron as well as high energy beam transport lines were commissioned [2] including a technical start-up of the gantry. From the beginning it was intended that the HIT company should take over the responsibility for the permanent operation. The first step was done in spring 2007, when the linac operation was completely passed over to the HIT team. The operation of all other systems was transferred in summer 2008 with initial settings for most of the parameters.

After the handover GSI still backed up the operation, a support contract was signed guaranteeing on-call duty and help in special repairs, if necessary.

FIVE YEARS OF HIT OPERATION AT A GLANCE

The HIT accelerator core team hired in 2004 and 2005 only comprises of six employees, thus this team was mainly enlarged in the period from mid of 2006 to mid 2008 (see Fig. 1) to be able to operate the facility, at first in two shifts from Monday to Friday, stepwise expanding to a 24/7 mode. Continuous training by the GSI commissioning team on one side as well as intense briefing on the supplied devices by the contracted companies was organized besides "training on the job". This was necessary because only 1/3 of the employed persons worked in the accelerator field before or had to be retrained as most of the HIT equipment was newly designed or has undergone substantial changes in contrast to the original GSI designs.

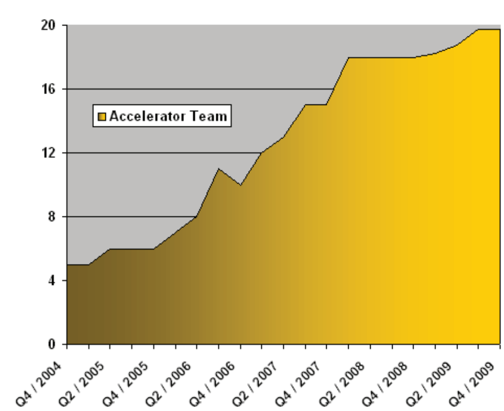

Figure 1: Development of the HIT accelerator team

Within one year it was possible to operate the whole accelerator chain from the ion sources to the high energy beam transport including linac and synchrotron by the newly formed HIT team. Three teams were formed, responsible for

- Power supplies, RF amplifiers and cavities
- Control, personal safety and interlock systems
- Ion sources, vacuum devices, beam diagnostics and mechanics.

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Each team provides an on-call duty in case of severe trouble-shooting using mainly a secure remote control access, but also an on-site support is guaranteed within 60 minutes. The team members are physicists, engineers and technicians. In addition to the internal maintenance organization for the most subsections, contracts with only a few supplying companies were signed which have very special knowledge (control system, gantry) or are needed due to the huge amount of work within the short shutdown periods (power supplies). In total, more than 70% of the accelerator maintenance is done by HIT personnel and slowly increasing over the years. The infrastructure maintenance is completely outsourced to a private company with technically specialised subcontract-tors, but the organization is done in close collaboration with HIT as the sequential arrangement of exclusionary works is a delicate task.

The accelerator shifts consist of two operators coming from the three teams. The physicists among the HIT accelerator crew are also responsible for retuning the optic parameters in case the performance leaves the pre-defined limits for intensity, beam position and foci at the treatment places. These conditions are checked every early morning. Whereas the intensity adjustment is done regularly in time intervals of some days, retuning of sections of the linac, synchrotron or the beam lines is only necessary every three to four months. The stability is mainly influenced by stable temperatures of ambient air and cooling water, but also other conditions like e.g. ageing of electronic parts play an important role.

In the second half of 2008 and in 2009 was dominated by establishing a high-level routine operation of the accelerator, especially the work on consolidation of the control system was very important. This resulted in an availability of about 98% in average. The whole time beam was used for the commissioning of the treatment equipment to achieve the medical compliance labelling by Siemens PT sustained by HIT medical physics personnel. As this was reached the first patients were treated on 15th November 2009 – since then more than 800 until May 2012 – at first in one horizontal room, since the beginning of 2011 in two treatment rooms.

In parallel, the beam optical commissioning of the gantry restarted in 2011 after solving some severe problems of the drag chain. After two main iterative steps the whole variety of ion beam properties, i.e. 37,000 combinations (carbon ions and protons), the beam foci, and the centre position (all energy steps, and gantry angles) are now within the given tolerances (with only a few exceptions). Only a small number of interpolation points (approx. 1 %) and the following calculation of set values by an interpolation are necessary, all based on a sophisticated setting of the gantry optics and a well aligned beam injection into the gantry [3]. First long-term checks show that retuning period are in the same order as of the horizontal treatment rooms. The scanning field covers 180 x 180 mm^2 with uniform dose distribution.

Until end of 2011 two longer shutdowns of 2 – 4 weeks per year were used for maintenance and new installations besides single device service shifts every 2 – 3 weeks. During these relatively long maintenance intervals the patients have to be phased out. This results in "ramping down" the patient numbers before the shutdown and "ramping up" afterwards. To improve the patient through-put a new maintenance strategy is under test now with "mini-shutdowns" of only 4 consecutive days: 2.5 days for service and 1.5 days for restarting the accelerator and carrying out all necessary quality assurance tasks. These very condensed maintenance blocks demand a sophisticated pre-organization. Up to now the new concept was successful, the "ramping" effects could be minimized and a continuous patient flow could be achieved.

CONTINUOUS IMPROVEMENT PROCESS – EXAMPLES

Besides the routine accelerator operation of the facility a continuous improvement process was installed with two major aims:

- Enhancement of the ion source beam intensities and introduction of further ion species for research and treatment, especially $^4He^{2+}$,
- Stepwise increase of the duty cycle by consequent elimination of dead times within the acceleration process and the control system.

Some selected examples of activities in these fields will be described.

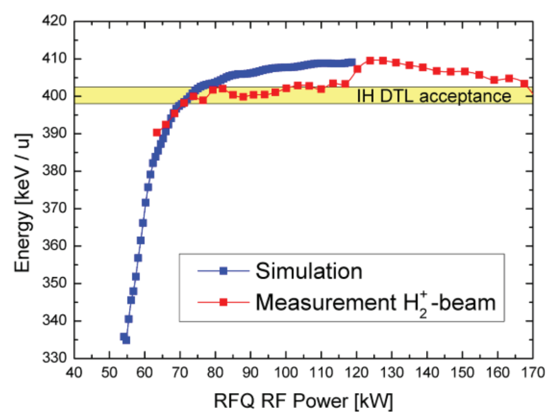

Figure 2: Measurement of the RFQ output energy in comparison to the simulation for a H_2^+ beam

Ion Source and RFQ Test Bench

At first, a test bench at HIT was used to create new solutions for the ion source [4]; i) To produce a better proton beam a modified extraction system (consisting of four electrodes) was successfully tested and thus a shortened version of the LEBT resulted with the ion source placed in the focus of the analyzing dipole – this LEBT configuration was installed in the production facility at the beginning of 2012 and works well generating a lower emittance beam as before; ii) A working scheme to produce $^4He^{2+}$ was developed including all safety measures to guarantee that possible contaminations with nitrogen or oxygen are below 10^{-4}. In 2012 the focus of the test bench activities changed and now the enhanced version of the RFQ (new input radial matcher, better alignment, etc.) is under investigation. Figure 2 shows one of the first results. To reach the input energy of the IH-DTL of 400 keV/u a working point should be chosen around a feasible RF power of 90 kW corresponding to values of about 210 kW for H_3^+ and C^{4+} (250 kW of RF power are available from the amplifier). The measurements are ongoing.

Magnetic Field Control in the Synchrotron

At the end of 2011 a magnetic field feedback control system for the synchrotron dipoles was put into clinical operation. Therewith the magnetic field deviation of the ramped dipoles depending on eddy currents and hysteresis are no longer in effect. Waiting times on the flattop before extraction are no longer necessary. The efficiency of the accelerator is increased by shortening the cycle time by around 600 ms. The core of the magnetic feedback system is a real time control unit consisting of a Hall sensor combined with a measuring coil and sophisticated downstream electronics with extremely high precision; see [5] for more details.

A similar system is under investigation for the quadrupole groups in the synchrotron to avoid the washing procedure after beam extraction to get rid of hysteresis effects. The commissioning is foreseen in 2012.

ACS Optimization

The HIT control system was specially developed for the needs of a therapy facility including a high safety level.

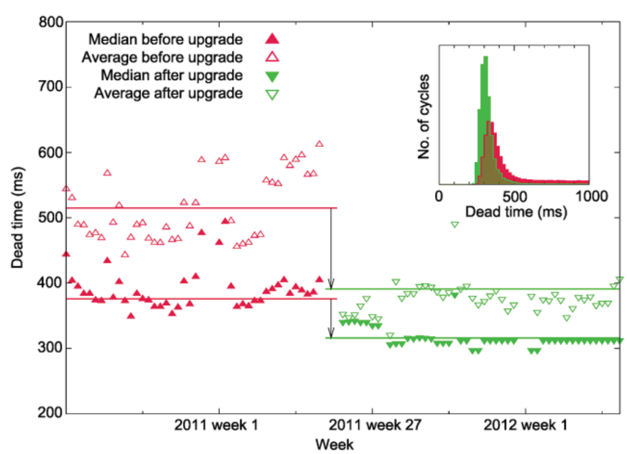

Figure 3: Dead time between cycles in therapy mode (weekly analysis)

After running the accelerator for patient treatment some time an initiative was started to optimize the control system (delivered by Eckelmann [6]) with regard to the timing performance. As an example one optimization step is presented in Fig. 3 – the shortening of the dead time between the machine cycles. In this period a huge amount of database operations take place and the detailed analysis lead to optimized table structures and access strategies. In addition, the server hardware and their configuration were significantly updated to the special requirements of a real-time database. Thus more than 100ms could be saved in every cycle and the spread could be significantly reduced.

Dynamic Intensity Control

The slow extraction process is driven by a transverse RF-knockout exciter. So far, this device has an adjustable but predefined amplitude curve to produce more or less rectangular shaped spills. As the phase space distribution of particles is not homogeneous and varies slightly from pulse to pulse, intensity-fluctuations of the extracted beam appear. Moreover, adjustment of the exciter for the whole energy range is time consuming. To keep the intensity on a predefined level, a feedback loop has been implemented [7]. The actual-value of the intensity is provided by an ionisation chamber in front of the patient, which is part of the medical product IONTRIS [8]. The approved implementation inside the treatment system will follow in some months. This will reduce the beam-on time by 10-20% depending on the individual beam plan.

Besides a beam with a rectangular intensity characteristic, a dynamic intensity adaptation during one spill with respect to the particular treatment plan is under investigation as a second optimization step. First tests for variable intensity control show promising results.

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