GETTING STARTED - FIRST OPERATIONAL EXPERIENCE AT THE HEIDELBERG ION BEAM THERAPY CENTRE

R. Cee*, T. Haberer, A. Peters, S. Scheloske, T. Winkelmann,
HIT Betriebsgesellschaft mbH, Im Neuenheimer Feld 450, D-69120 Heidelberg

Abstract

The Heidelberg Ion Beam Therapy Centre is a worldwide unique radiation therapy facility and the first installation of its kind in Europe. The design, assembly and commissioning of the accelerator is carried out under the responsibility of GSI Darmstadt. The routine operation for patient treatment will be assigned to an operating company. Since its foundation in May 2004 a team of experts consisting of physicists, engineers and technicians has been assembled. With the knowledge acquired during the commissioning phase the operating team could accept full responsibility for the injector linac, which has to deliver a steady ion beam for the ongoing commissioning of the synchrotron and the irradiation units. Since the first accelerated beam behind the injector linac end of 2006 the facility runs in a three shift model including call-on duty for the involved systems. One shift per week is reserved for short term maintenance. A shutdown of 5 weeks for a general inspection was placed in summer 2007. The goal is to come into a continuous 24/7 operation only interrupted by short service periods. We describe here the first experience concerning personnel organisation, radiation protection and linac operation.

INTRODUCTION

HIT (**H**eidelberg **I**on Beam **T**herapy Centre) [1] is the first combined proton / heavy ion therapy device in Europe, which is operated by a hospital and used for treating patients as well as clinical studies. The accelerator part includes a 7 MeV/u injector linac consisting of a radio frequency quadrupole (RFQ) and an IH-type drift tube linac (IH-DTL) [2]. A synchrotron with a circumference of 65 m ($B\rho$ = 0.38–6.5 Tm) accelerates protons and heavy ions up to 220 MeV/u (protons) resp. 430 MeV/u (carbon, oxygen) [3]. The medical part consists of two horizontal treatment rooms and a worldwide unique heavy ion gantry for 360° patient irradiation [4]. The beam lines and structures of the HIT-accelerator have been designed under the leadership of GSI Darmstadt with contributions from IAP Frankfurt (RFQ, IH-DTL) [5, 6]. If the commissioning of the synchrotron and irradiation places continues well advancing first patients will be treated in spring 2008. The machine will then be operated by an operating company (HIT GmbH), that has been founded specially for this purpose in May 2004. Since June 2007 the injector Linac is already running under its responsibility.

PERSONNEL ORGANISATION

At present (Sept. 2007) the HIT staff consists of 28 employees covering the complete work flow for patient treatment. Eleven employees work on the medical and biophysical field, 15 on accelerator operation and two deal with administrative and economical tasks. The accelerator team consists of five physicists, four engineers and six technicians. For accelerator operation we built three expert teams as shown in Tab. 1. Each team is responsible for several systems and parts of the infrastructure. This simplifies the organisation of the machine operation, as each member acquires a diversified knowledge of the facility.

At present, the accelerator runs 6 days per week from Monday 3:00 pm to Saturday 11:00 pm. On Sunday, the plant is shut down. The time between Monday 7:00 am and 3:00 pm is reserved for service and linac recommissioning. The shifts (three per day at 8 hours) are occupied with two operators. During the shifts used for synchrotron commissioning additional personnel from GSI is working in the control room. In the long term, we intend to control the machine by one operator.

Table 1: Expert teams of HIT with their responsibilities and manning.

Expert Team IS/BD/Vac	
Systems:	*Infrastructure:*
Ion Sources	Ion Source Gases
Beam Diagnostics	Detector Gases
Vacuum	Compressed Air
Staff: 2 Physicists, 1 Engineer, 1 Technician	

Expert Team RF/PS/Cav	
Systems:	*Infrastructure:*
Radiofrequency	Cooling System
Power Supply Units	Electric Power Supply
Cavities	
Staff: 2 Engineers, 4 Technicians	

Expert Team CS/IL/RP	
Systems:	*Infrastructure:*
Accelerator Control System	Timing System
Interlock System	Computer Network
Personnel Safety System	
Staff: 2 Physicists, 1 Engineer, 1 Technician	

---

[*] rainer.cee@med.uni-heidelberg.de

RADIATION PROTECTION

Radiation protection has been in the responsibility of HIT since the beginning of the ion source commissioning in spring 2006. According to the German radiological protection ordinance officers with sufficient professional experience and an additional education have been appointed. These radiation protection officers provide a 24/7 call-on duty.

The technical aspects of the radiation protection such as gate control and safety interlocks are part of the personnel safety system (PSS). All rooms of the accelerator including the treatment places are defined as radiation protection areas (SB1–9 in Fig. 1). The PSS is controlled via a graphical user interface of the accelerator control system. It provides an overview of the most important information of the PSS. E.g. the state of the protection areas (accessible / inaccessible / service / alarm), the gates (open / closed) and the emergency stop buttons (pressed / unpressed) are visualised in different colours. Further relevant parameters can be found at a lower level.

During accelerator operation the ion source room (SB5) is accessible for the personnel. This is guaranteed by lead screenings around the ion sources absorbing the x-rays emitted during plasma generation. The linac- and synchrotron-rooms (SB6+7) are inaccessible. The treatment-rooms (SB1–3) can be opened and closed by the medical personnel.

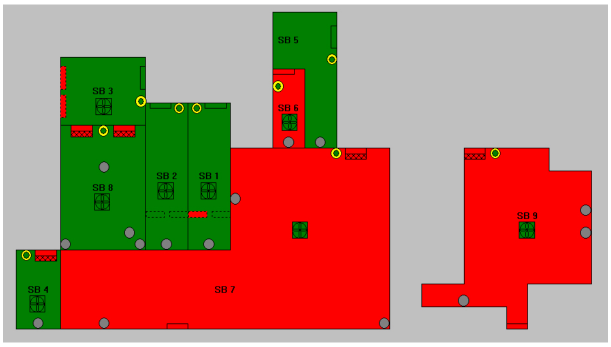

Figure 1: Control of the nine radiation protection areas at the HIT facility. Green areas are accessible, red ones are inaccessible.

LINAC OPERATION

The injector linac (see Fig. 2) comprises two identical ECR ion sources [7], a low energy (8 keV/u) beam transport (LEBT), a 400 keV/u four-rod RFQ and a 7 MeV/u IH-DTL [8], both cavities operated at 216.816 MHz.

Since June 2007 the injector linac is operated by HIT and delivers carbon and proton beams for the commissioning of the synchrotron and the irradiation units.

ION SOURCE

In the beginning of the ion source operation we encountered several breakdowns of the microwave-generators which caused us to change our spare-part strategy. Instead of a traveling wave tube we now hold complete amplifiers on stock. In the course of the first year we observed a reduction of the initial output current for carbon ($I = 200\ \mu$A) by ~35 % which could be counteracted but not completely be reversed by cleaning the plasma chamber. The specified intensities for H_2^+ ($I = 1$ mA) could be easily achieved and even exceeded. Launching the sources takes us ~1 hour for hydrogen and ~2 hours for carbon. Once the working point is adjusted the sources proof to run in a stable mode.

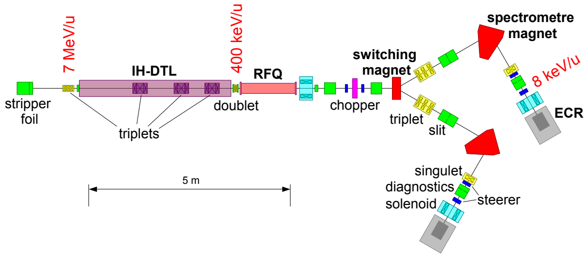

Figure 2: Injector linac of HIT. The two spectrometre branches converge into a straight accelerator line. The left source is used for the carbon beam, whereas the right source delivers hydrogen-ions.

LEBT

The LEBT consists of two separate spectrometre branches and a common straight accelerator beamline. For reproducibility of the found magnet data sets we introduced a cycle procedure for the magnet excitation current which has to be launched before starting the accelerator. The beamline is equipped with a variety of beam diagnostics elements such as illuminating screens, Faraday-Cups, profile grids and DC-transformers [9]. As an example the beam profile measured with one of the three profile grids is illustrated in Fig. 3.

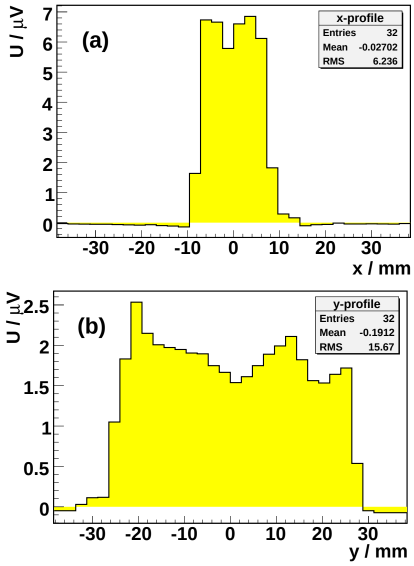

Figure 3: Horizontal (a) and vertical (b) profiles of a $^{12}C^{4+}$-beam behind the spectrometre dipole. A statistical evaluation of the beam centre (Mean) and width (RMS) is given in the box.

LINAC

Before the injection into the linac the DC-beam is chopped into 300 μs pulses with a repetition rate of 5 Hz. The RF-pulses of the RFQ and the IH-DTL are 500 μs long at a repetition rate of 10 Hz, corresponding to a duty cycle of $5{\cdot}10^{-3}$. The initial conditioning of the cavities took us two weeks for the RFQ and one week for the IH-DTL. Reconditioning after venting with nitrogen takes 3 hours and after a short shutdown (weekend) 1 hour, independent of the cavity. The correct settings of the tank parameters (amplitude and phase) are checked by transmission control, tank signal comparison and energy measurement. The energy determination is performed with a Time-of-Flight (ToF) measurement between two capacitive phase probes positioned behind the linac (see Fig. 4). A sophisticated signal evaluation (cross correlation function) implemented in the control system allows a fast and accurate calculation of the energy.

The naked nuclei required for the irradiation are generated with a charge stripper assembled with 100 $\mu g/cm^2$ carbon foils. Relating the measured electrical current increase ΔI_{meas} to the theoretical limit ΔI_{lim} (50 % of the incoming current for $^{12}C^{4+}$ and 100 % H_2^+)

$$\eta_{fs} = \frac{\Delta I_{meas}}{\Delta I_{lim}}$$

we have achieved stripping efficiencies η_{fs} of ∼80 % for $^{12}C^{4+}$- and ∼95 % for H_2^+-ions.

Despite the fact that the output beam current is sufficient for patient irradiation, the specified intensities have not yet been achieved. We have therefore initiated a transmission optimisation programme including a redesign of the RFQ-electrodes on the basis of recently acquired emittance data of the LEBT.

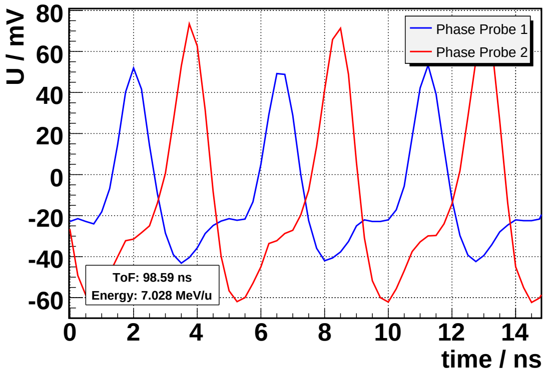

Figure 4: Phase probe signals of a $^{12}C^{4+}$-beam behind the linac. The probes are mounted in a distance of 3.61 m corresponding to a bunch number of 21. The signal resolution is limited by the acquisition electronics (1 GHz analog bandwidth, 4 GS/s digitisation, 8 bit).

FAILURE STATISTICS

Since July 2007 all failures interrupting or disturbing the operation are logged in a failure protocol. The result is shown in Fig. 5. The largest fraction of failures was caused by the radiofrequency (28.3 %) followed by the power supply units (25.2 %) and the control system (20.4 %). The residual 26.1 % are distributed between the systems ion sources, machine cooling, radiation protection (PSS) and beam diagnostics. The statistics is rather low and the assignment to one of the systems is not always unique but the general trend corresponds to the daily experience.

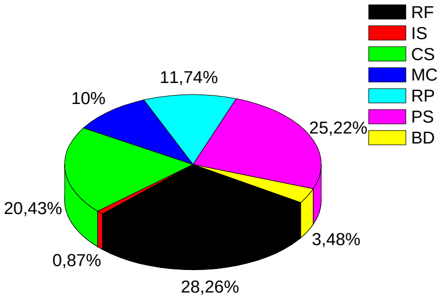

Figure 5: Failure statistics since July 2007 broken down into systems. RF: radio frequency, IS: ion sources, CS: control system, MC: machine cooling, RP: radiation protection, PS: power supplies, BD: beam diagnostics.

REFERENCES

[1] J. Debus et al., “Proposal for a dedicated ion beam facility for cancer therapy”, University Heidelberg, http://www.hit-centrum.de.

[2] B. Schlitt et al., “Status of the 7 MeV/u Injector Linac for the Heidelberg Cancer Therapy Facility”, LINAC’04, Lübeck, August 2004, p. 51.

[3] A. Dolinski et al., “The Synchrotron of the Dedicated Ion Beam Facility for Cancer Therapy, Proposed for the Clinic in Heidelberg”, EPAC’00, Vienna, June 2000, p. 2509.

[4] U. Weinrich, “Gantry Design for Proton and Carbon Hadrontherapy Facilities”, EPAC’06, Edinburgh, June 2006, p. 964.

[5] A. Bechtold et al., “Beam Test Stand of the RFQ-Drifttube-Combination for the Therapy Center in Heidelberg”, EPAC’04, Lucerne, July 2004, p. 2571.

[6] Y.R. Lu et al., “The Compact 20 MV IH-DTL for the Heidelberg Therapy Facility”, LINAC’04, Lübeck, August 2004, p. 57.

[7] T. Winkelmann et al., “ECR Ion Source Experience at the Heidelberg Ion Beam Therapy Center (HIT)”, ICIS’07, Jeju, August 2007.

[8] M. Maier et al., “Status of the Linac-Commissioning for the Heavy Ion Cancer Therapy Facility HIT”, EPAC’06, Edinburgh, June 2007, p. 1571.

[9] M. Schwickert, A. Peters, “Computer Controlled Beam Diagnostics for the HICAT Facility”, EPAC’04, Lucerne, July 2004, p. 2547.