BEAM DIAGNOSTICS FOR COMMISSIONING THE HEBT AND GANTRY SECTIONS OF THE HIT MEDICAL ACCELERATOR

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Abstract

The HIT medical accelerator at Heidelberg, Germany, is the first dedicated heavy-ion cancer therapy facility in Europe, consisting of a two-stage injector Linac followed by a compact synchrotron for ions energies up to 430 MeV/u. It features three treatment places: two horizontal beam lines, where treatment will be carried out from 2008 using mainly proton and carbon beams, and the first 360° rotating heavy-ion Gantry structure. The accelerator sections of this facility were designed and constructed by GSI. By now, the required medical beam quality has been achieved in both horizontal beam lines, and commissioning of the Gantry structure has started.

In this contribution we describe the technical layout of beam diagnostic devices and present measurement data taken in high-energy beam transport lines and patient treatment places.

HIT ACCELERATOR FACILITY

The HIT (Heidelberg Ion Therapy) medical accelerator located in close vicinity to the Heidelberg university clinics is presently in the final stage of commissioning. Fig. 1 shows a 3D model of the accelerator that was designed, installed and commissioned by GSI. It consists of a two-stage RFQ/IH-DTL linac (7 MeV/u), a compact synchrotron (magnetic rigidity 0.38-6.6 Tm), 2 horizontal treatment places and 1 heavy ion Gantry for 360 degree patient treatment. Additionally a quality assurance (QA) place is available for medical experiments and detector tests. The HIT facility is dedicated to the treatment of tumour patients with hadrons, mainly protons and carbon, using the raster-scan method developed by GSI with proton and carbon ions of 48-430 MeV/u [1]. The typical spill length is 5 seconds.

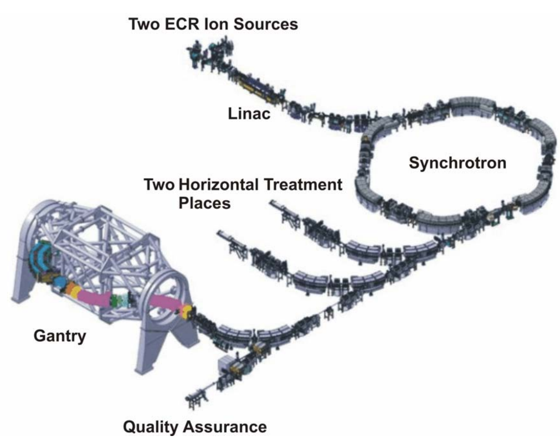

Figure 1: Layout of the HIT accelerator facility.

Civil construction of the building was finished by the end of 2005 and from 2006 to present the commissioning by GSI is performed. Whereas all accelerator parts were manufactured by commercial partners, all diagnostic equipment was produced and installed by GSI beam diagnostic group. Details about the general concept of the diagnostic layout and the according technical parameters are given in [2, 3].

BEAM DIAGNOSTICS: HEBT AND GANTRY SECTIONS

The High Energy Beam Transport (HEBT) section includes 13 detector combinations of multi-wire proportional chambers (MWPC) and ionization chambers (IC) for determination of beam profile and intensity.

These combined detectors are mounted inside a cylinder with 50 μm stainless steel foil windows at the beam entrance and exit. Detectors and housing are moved together by a pneumatic drive. In this way the detector may be dismounted without breaking the beam line vacuum. During operation the cylinder is filled with a 80% Ar/20% CO_2 gas mixture.

Each of the two (hor./vert.) MWPC planes is covered by 64 wires with 1.1 mm spacing. For standard measurements two adjacent wire signals are summed at the input of a high-resolution integrator circuit with 16 integrations times (100 μs and 6 s), multiplexed by a control unit and sequentially digitized by a differential ADC board. Both, MWPC and IC have an active area of 70x70 mm^2. A fast current-to-frequency converter [4] monitors the IC current and provides the input signal to a gated PXI-6602 scaler from National Instruments.

For measurements of very low beam intensities (< 2 MHz) and for verification of the IC calibration a total of 5 plastic scintillators are installed. The BC400 material is 3 mm thick with an active area of 70x70 mm^2. The detector can be inserted into the same pneumatic drive as the MWPC/IC combination. The analogue signal is fed to a NIM discriminator which provides the logic signals to the same type of scaler as for the ICs [5].

At 10 critical positions beam position and profile can be recorded by compact 8-bit CCD cameras (AVT Marlin) detecting the scintillation emitted by a P43 screen. The circular screens are mounted at an angle of 45 degree wrt. the incident beam and the optical signal is observed vertically from above by the CCD camera through a glass window in the top flange of the pneumatic drive. Adjusting gain, shutter time and iris setting, measurements are possible even at the lowest of the ten standard beam intensity settings.

At the isocenter of the gantry room and the two horizontal treatment places, i.e. the position where the ion beam is applied to the patient, a special detector construction is employed, the so-called isocenter diagnostics. This device consists of a large (300x226 mm^2) P43 scintillator screen installed together with a CCD camera in a blackened container to protect against stray light, since the detector is positioned about 1 m behind the beam nozzle. A 12-bit, high-resolution Hamamatsu camera acquires beam profiles with a resolution of 0.27 mm/pixel. Separation of the Peltier-cooled camera head and control unit results in a very low noise level which is important to minimize image distortions.

SPILL PROFILES BY MWPC/IC

As a primary tool to monitor the homogeneity of the spill intensity in the extraction beam line ICs are used. Data taken at four intensity settings I4, I6, I8 and I10 with carbon ions are presented in Fig 2 (top) at a rate of 200 Hz. For high-resolution measurements the rate can be increased up to 10 kHz. The blue curves show repeated measurements for settings I4, I6 and I8, while the data set for I10 illustrates the good quality of the spill structure. Compared to the quality achieved in the pilot project at GSI the spill presented here is much more uniform, but studies to optimise the spill will continue in the future.

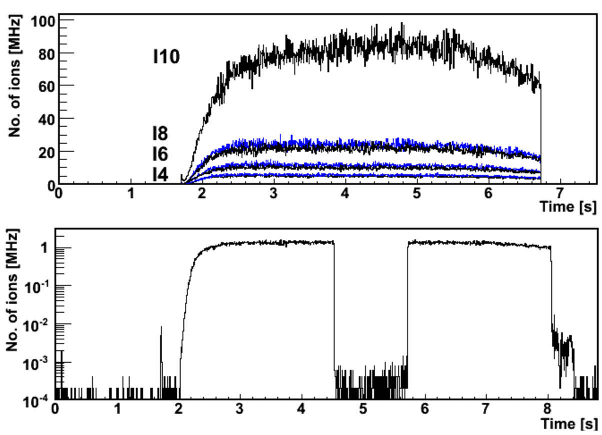

Figure 2: Spill structure for intensities I4, I6, I8, I10 (top) and example of a 1 second spill break (bottom).

Fig. 2 (bottom) shows a unique feature of the HIT accelerator: the spill-pause function, recorded by the 1st scintillator in the HEBT. By a fast de-tuning of the rf-knockout system the extraction is stopped for 1 s at a pre-selected time 2.5 s after the start. The spurious counts in the pre- and post-spill are cut off by the fast spill abort magnet further down the beam line. This functionality optimises the patient treatment process, as the split spill can be applied to discontinuous treatment areas.

For studies of the transverse beam profile MWPCs are used. Apart from single measurements, the electronics allows to operate the MWPCs in a fast mode, recording successive profiles within a single spill at a maximum repetition rate of 750 Hz. In Fig. 3 the horizontal beam distribution shows the good homogeneity of the spill, but reveals a small drift at the start of the extraction. Position and FWHM of each profile are calculated by the data acquisition system and displayed in the control room.

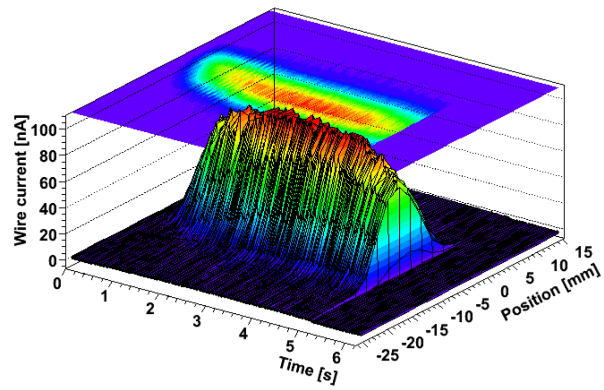

Figure 3: Horizontal distribution of a 5 s spill.

Stability checks of the transverse beam profile were an important issue during machine commissioning and the fast-mode was extensively used for this purpose. Fig. 4 shows an example for an erroneous machine parameter detected by a MWPC. At the end of the spill a 20 ms fraction of the beam was dumped in the HEBT scraper due to an incorrect timing of the spill abort magnet.

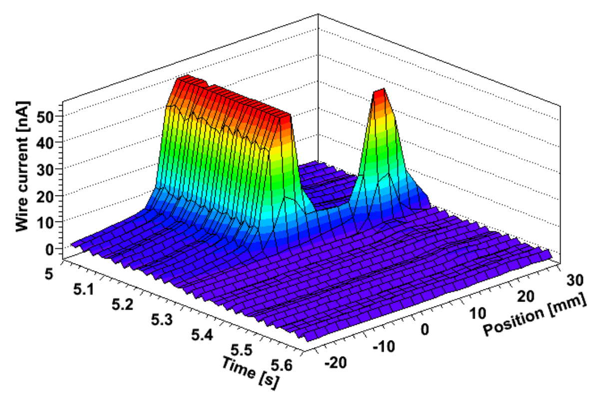

Figure 4: Spill shift at end of extraction.

SPILL PROFILES BY SCINTILLATION SCREENS

As mentioned before a central tool for the commissioning of the beam lines to the treatment places is the isocenter diagnostics. These special kind of visual screens are mounted on the robots that precisely position the patient during treatment. Therefore, the first important task of the isocenter diagnostics is the matching of accelerator and treatment coordinate system. The isocenter diagnostics is tightly bound to the medical coordinates, defined by the robot position, via the tool changer with a small mechanical tolerance. Fig 5 shows the device readily mounted on the robot arm. The ions exit the beam nozzle (on the right), enter the detector housing and hit the viewing screen at the back.

Figure 5: Isocenter diagnostics mounted on patient robot.

A second important task is the determination of the beam spot size for the four focus settings that are employed during therapy mode, especially in the context of verification of the beam quality. From the raw data beam position and width are calculated from horizontal and vertical projections after subtraction of the background. As an example the 1st beam at the gantry isocenter is presented in Fig. 6. Generally, any data like beam position or width can be displayed online, stored in the database or exported for offline analysis.

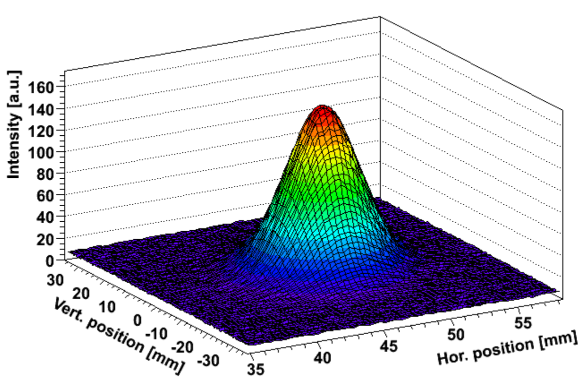

Figure 6: Profile of 1st beam in gantry (220 MeV protons).

AUTOMATED THERAPY PROTOCOLS

All beam diagnostic devices are an integral part of the overall accelerator control system (ACS) of HIT. The basic principle of the ACS is to store all relevant beam parameters and device settings, such as set values for magnet power supplies or the rf system, in so-called virtual accelerators (VACCs). This concept is then further enhanced for the needs of a medical accelerator by MEFI-settings, encapsulating whole sequences of VACCs with various Energy, Focus or Intensity settings as needed for patient treatment.

Clearly, procedures have to be foreseen to test and verify the large amount of beam parameters during the MEFI controlled operation of the accelerator. These so-called therapy protocols automatically step through user-defined sequences of MEFI beams and can acquire data from any selected diagnostic device. The data are stored in the data base, analysed, and the results displayed in a standard way for comparison with previous data. Raw data obtained from such a protocol is presented in Fig. 7 for the carbon beam at the quality assurance place.

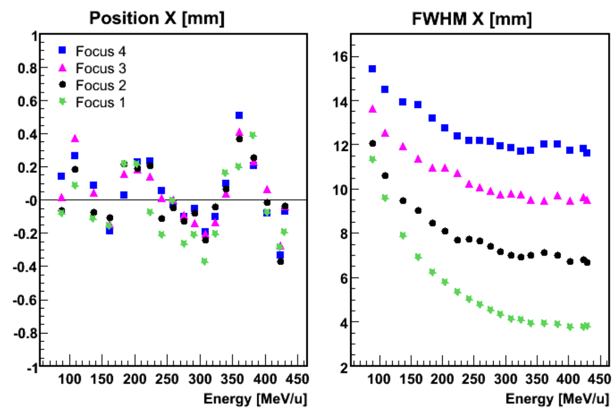

Figure 7: Beam position and width as function of energy.

The plots show the energy dependence of the center-of-mass and width of the horizontal beam profile for all 4 focus settings. The position is independent of the focus setting, but jitters systematically within a range of 1 mm. The width of the beam strongly depends on the energy mainly due to scattering effects in the beam nozzle where the treatment monitoring (3 ICs and 3 MWPCs) system is located. Scattering is most evident for the smallest focus and at low energies.

CONCLUSIONS AND OUTLOOK

The presented data show that the beam diagnostics of the HIT facility provide all necessary tools for commissioning and machine operation, especially for the verification of the beam quality for medical treatment. The HEBT devices deliver highly resolved data and allow fine-tuning of synchrotron extraction and HEBT lines. Any device, most importantly the isocenter diagnostics, can be integrated into therapy protocols which have proven to be a reliable tool to monitor the beam quality in the final stages of the HIT commissioning.

REFERENCES

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