BEAM QUALITY MEASUREMENTS AT THE SYNCHROTRON AND HEBT OF THE HEIDELBERG ION THERAPY CENTER

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Abstract

The Heidelberg Ion Therapy Center (HIT) for tumor treatment is presently being commissioned using the beam diagnostic devices designed and produced by the GSI beam diagnostic department. To fulfil the requirements for hadron therapy a high-resolution analysis of the particle distribution within the slowly extracted beam is necessary. We present spill-structure measurements for carbon ion beams at energies from 88 MeV up to 430 MeV, also with respect to the spill-pause and abort functionality of the rf-knock-out extraction method. The spill-structure, as measured by internal intercepting ionization chambers (IC) is compared to data recorded with external beam loss monitors (BLM). The high-resolution data acquisition system with sampling rates up to 10 kSa/s and the connected detectors are described and the achievements during the commissioning phase are discussed.

INTRODUCTION

The Heidelberg Ion Therapy center (HIT) is a new dedicated hadron accelerator facility for medical treatment of tumor patients. The advantage of using hadrons in cancer therapy is their characteristic energy loss profile in irradiated materials. When applied to tumor tissue this leads to a DNA destructive maximum at the Bragg peak immediately before the particles come to rest. To reach penetration depths of 20-300 mm in water, which is almost comparable with human tissue, ion energies of 50-430 MeV for carbon ions are required. The tumor is irradiated in sliced fractions (iso-energy-layers) by means of cycle-to-cycle energy variation. Within such a layer the intensity controlled raster-scan method applies a pencil beam which is moved from voxel to voxel (3D-pixel) by two fast scanner-magnets. Due to this technique some accelerator characteristics have to be taken into account to assure the fulfilment of the manifold requirements of medical radiotherapy.

In this contribution the spill-pause and abort functionality are analyzed. During raster-scan operation within a synchrotron cycle the spill-pause functionality spares healthy tissue in cases where irradiation areas are spatially separated. Secondly the spill-pause is an important tool to optimize treatment planning, and machine efficiency. The qualities of the rising and falling edges and the intensity of the residual particles within the pause, and after the spill-abort have to be investigated. To gain a homogeneous irradiation per fraction the spill-structure has to be optimized as spike effects and small interrupts increase the failure rate. The spill-structure is influenced by many factors such as the rf-knock-out extraction (KO) method, the power supplies, and the beam bunching parameters.

HIT ACCELERATOR COMPLEX

Presently HIT is in the final phase of its commissioning. All treatment areas can be served with carbon ion beam in the designed energies range from 88 MeV up to 440 MeV. As shown in Fig.1, the complex consists of two ECR ion sources, a 7 MeV RFQ/IH Linac (A), a Synchrotron (B) with magnetic rigidity of Bρ=0.38-6.5 Tm, two horizontal treatment places (C), a 360º patient irradiation gantry (D), and a quality assurance section (E). A more detailed description of the facility and its diagnostics is given in [1] and [2].

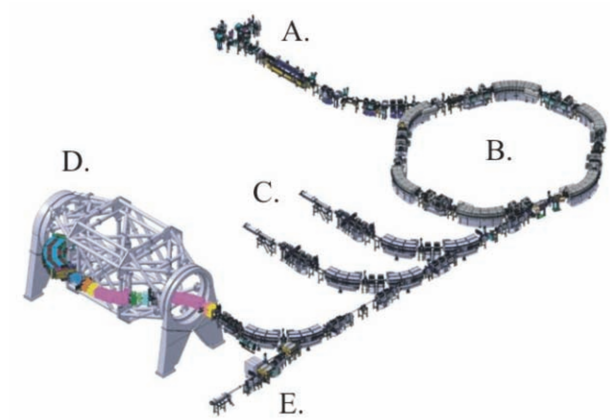

Figure 1: Isometric drawing of the HIT accelerator complex.

BEAM DIAGNOSTICS AND DATA ACQUISITION

The complete beam instrumentation, from layout and production to the final installation including the final proof of operability with beam, was managed by the GSI beam diagnostics group. All beam diagnostic devices were categorized into separate device classes on the base of the detected beam parameter such as current, energy, beam profile, position, phase and others. One of these device classes is the "event counting" class, which is from its functional point of view a down-sized reproduction of the GSI ABLASS system [3]. It combines all particle counting devices such as plastic scintillators, ionization chambers with I/f converters [4], and beam loss monitors (BC400 plastic scintillator, 20x20x75 mm^3), which all can be used to investigate the spill-structure beneath the standard usage for intensity, transmission and beam loss measurements. The analogue signals of the scintillators are shaped and digitized by standard NIM modules (Fan In/Out, Discriminator, Level adaptor). All signals are finally fed into the data acquisition system (DAQ).

The general concept of the LabViewRT based DAQ at HIT is to use “commercial off the shelf” products (COTS) as the facility is operated by a university hospital and therefore needs the most practicable standard for operation and maintenance. In addition, standardized DAQ modules reduce the spares inventory and improve the facility-wide exchangeability of components. The DAQ consists of PXI front-end systems using many types of PXI modules. Four eight-channel PXI-6602 Scalers from National Instruments were installed for the “event counting” class. In default mode the scalers sample and deliver data of all 32 channels with 1 kSa/s. In addition, data of three selected channels may be acquired with a sample rate of 10 kSa/s using the DMA mode. The spill-structure measurements presented in this paper were observed by using this fast mode.

SPILL-STRUCTURE

The detectors and the DAQ system of the “event counting” device class allow a detailed analysis of the synchrotron spill-structure that fulfills the demands of the ongoing commissioning as well as the requirements of

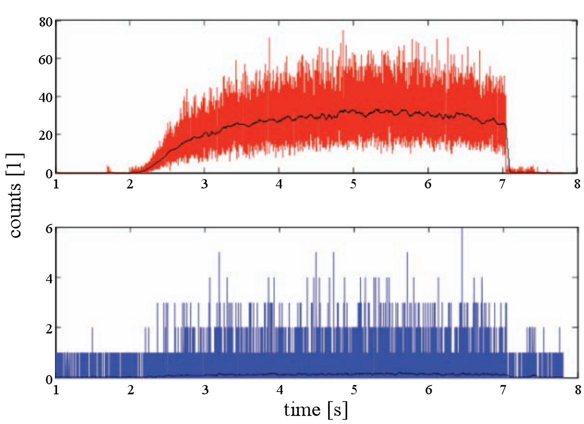

Figure 2: Spill-structure measurements with $^{12}C^{6+}$ at 430.10 MeV and $8 \cdot 10^7$ p/spill. Top: IC. Bottom: BLM.

routine operation. The spill shape is usually observed by ionization chambers (Fig. 2, top), here in front of the first treatment area in the high energy transfer line (HEBT). In addition, one of the movable non-intercepting BLMs (Fig. 2, bottom) placed at the electrostatic septum of the synchrotron is used to examine the spill. The count-rate of the BLM in this measurement is low as the machine is well tuned and only negligible beam loss is created at the extraction section of the synchrotron.

The spill data measured with the IC can be used for spill-structure optimization purposes by calculating the count-rate ratios of minimum to average and maximum to average values [5]. The interspace between the two

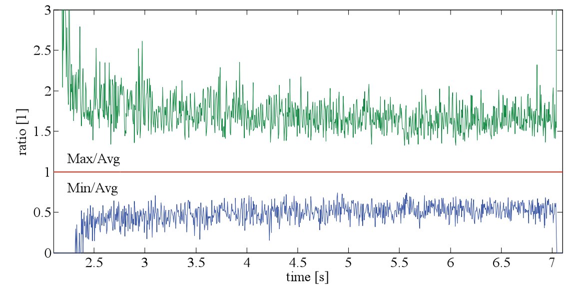

Figure 3: Ratios of Min and Max values divided by the average (5 ms integration window). Minimization of the interspace of both functions smoothes the spill-structure.

graphs shown in Fig. 3 has to be minimized for best results. The shown value below 2 for the Max/Avg ratio is already satisfactory. The influences of machine settings such as the KO-extraction parameters, which are significantly affecting the spill-structure, are currently studied as part of the machine commissioning.

SPILL PAUSE AND SPILL ABORT

At present the implementation of the spill-pause and spill-abort functionality is still in progress. The pause is

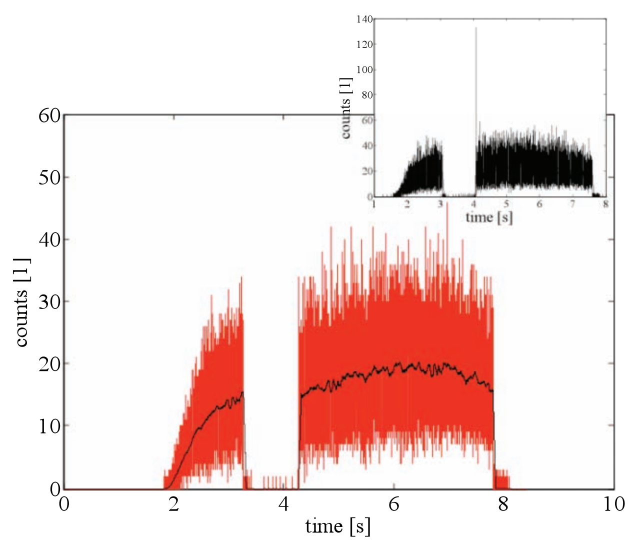

Figure 4: Slowly extracted $^{12}C^{6+}$ beam at 270 MeV with 1s spill-pause, 10 kSa/s. The black line is the result of a rolling average filter of 500 points window-size. Top right: spill with re-entry spike.

created by shifting the synchrotron rf out of the KO-extraction noise band. In order to completely dump accidentally extracted particles within a spill-pause, a spill abort magnet (SPAM) is installed in the 1st section of the HEBT behind the extraction septum as a second safety arrangement. These mechanisms together ultimately prevent unwanted beam transport, e.g. inside a spill-pause to the treatment places. Fig. 4 shows a spill with 1s pause and the final beam abort.

Examinations of these pauses are essential since unwanted spikes at the pause edges may occur as shown in the top right corner of Fig. 4. The rise- and fall-times of the pause should be constant for all possible energies. Otherwise, energy-dependent corrections have to be added to the extraction parameters.

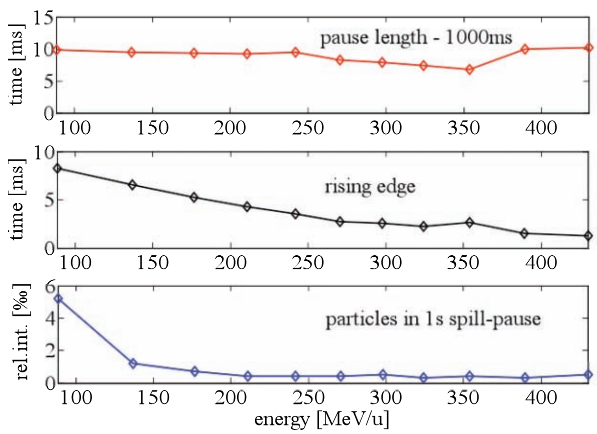

Figure 5: Energy-dependent effects: Top: variation in time of the real spill-pause minus 1s (pause set-value). Middle: rise time at the pause end. Bottom: intensity of residual particles in spill-pause.

With measurements from 88.83 up to 430.10 MeV the time behavior of the edges as a function of energy were analyzed. In the top graph of Fig. 5 almost no influence on the pause length can be seen. The length was calculated by linear regression on both edges, and subtracted by the set pause length of 1 s. The middle graph represents the pause-end flank, which shows a significant decrease of the rise-time with increasing energies. The residual particle amount within a spill-pause of 1s is estimated by finding the minimum of a 1s-integration window shifted across the recorded spill data. The results are shown in the bottom graph of Fig. 5. Only at lower energies (88-130 MeV) max. 0.52% of the average spill intensity is leaking through the spill pause mechanism. This preliminary measurement indicates very good particle suppression. Even without using the spill abort magnet for spill pauses, the intensity is already very low. The final value of accepted residual particles in the pause is yet to be defined in the ongoing risk assessment.

FFT ANALYSIS

The spill-structure data is passed to a Fast Fourier Transformation (FFT) algorithm to discover objectionable ripples of machine parts such as the mains, power supplies or vacuum pumps. Fig. 6 shows 10 averaged FFTs for synchrotron cycles at 88.83 MeV (top) and 430.10 MeV (bottom). At both energies the harmonics of the 50 Hz mains are visible, but, for unknown reasons, only at the lower energy the 50 Hz itself is present. The influence of the synchrotron frequency of 2 kHz at 88.83 MeV and of 456 Hz at 430.10 MeV is clearly visible. The noticeable peaks at 165 and 262 Hz give a hint to minor ripple influence of the synchrotron equipment and are subject of further investigations.

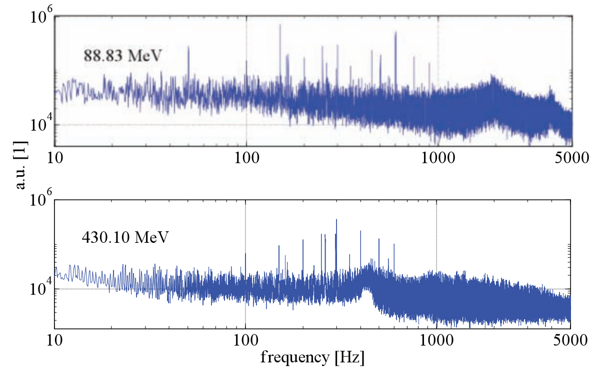

Figure 6: Averaged FFTs at 88.83 MeV (top) and 430.10 MeV (bottom) are showing significant ripples of the mains (50Hz, Germany) and of unknown sources.

CONCLUSION

By means presented here the spill-structure, spill-pause, and spill-abort functions are studied in the course of HIT commissioning. The applied FFT routines give good information about unspecific machine effects, which yield to separate investigations. The usage of a non-intercepting BLM for online spill-structure measurements is possible, but at the relatively low beam intensities at HIT scintillators with a greater active volume are required to achieve useful count rates in DMA mode.

With a view to the requirements of a hospital based accelerator facility the described beam diagnostic devices and DAQ are meeting all demands for commissioning, maintenance and daily operation. The authors would like to thank Dmitry Liakin for helping on the data evaluation and many fruitful discussions.

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